A Second-Generation Experimental Apparatus for Direct Observation of Anode Initiated Vacuum Surface Flashover

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Abstract

Vacuum surface flashover imposes size requirements for large-scale pulsed power machines. Our understanding of the subject imposes a hard barrier to the modernization and improvement of existing infrastructure. Modern insulator configurations suppress cathode-initiated flashover and requires anode-initiated flashover to be considered. This is achieved by mitigating the electric field at the cathode at the expense of the anode field being several times higher. The mechanism of anode-initiated flashover is of limited understanding but is believed to depend on the cascade growth of a conducting plasma along the length of the insulator from the anode. In the case of pulsed, anode-initiated flashover, experimental evidence suggests that charge is directly extracted from the insulator resulting in the insulator taking on a net positive charge advancing the anode potential. Along with accompanying gas desorption from the surface, the potential will then propagate from the anode towards the cathode until the effective length of the gap is sufficiently reduced to support flashover. A first-generation test fixture for direct localization and direct observation of vacuum surface flashover is presented along with a discussion of the insight gained by the apparatus. A review of limitations and challenges encountered is included along with a review of the second-generation platform which is being developed.

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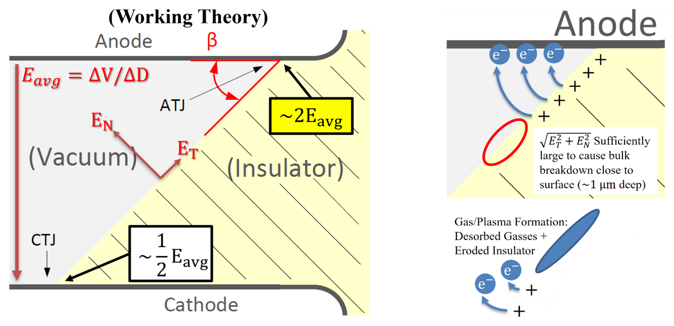
Motivation

- Large pulsed power machines are geometrically constrained.
  - Predicting flashover is rooted in empirical models, not rigorous physics.
  - Surface flashover threshold of insulators are much less than vacuum.
  - Informs the minimum size of facilities and power limits of existing ones.
- Grow the body of evidence for anode initiated flashover
  - Direct observations are limited in literature.
  - The existing the model is very qualitative.

Anode Initiated Flashover



Anderson Model

(1) Intense electric field develops near the anode triple junction (ATJ) which results in bulk breakdown of a thin (few um) surface layer. (2) Emitted electrons desorb gas and result in the formation of a local plasma which conducts the anode potential into the gap. (3) (Continues) until the anode potential is conducted across the gap and the final breakdown occurs. [1]-[3]

Design Philosophy

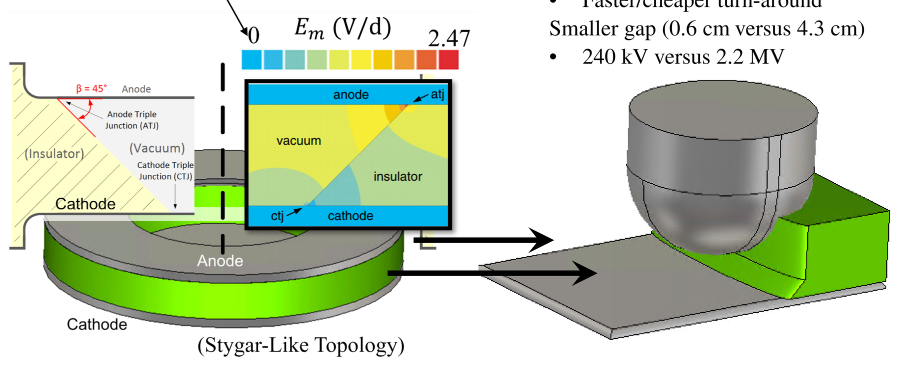
Improved design of a high-voltage vacuum-insulator interface

- W. A. Stygar et al. 2005, Physical Review Special Topics – Accelerators and Beams 8, 050401 (2005)

TTU Design with Improved Diagnostic Accessibility[6]

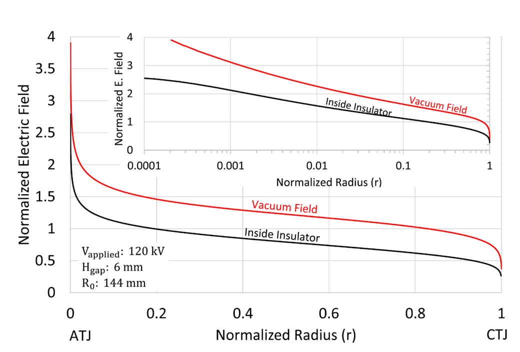
Smaller insulator
- 4 cm x ~40 cm OD versus 5 cm x 10 cm x 4 cm
- Faster/cheaper turn-around

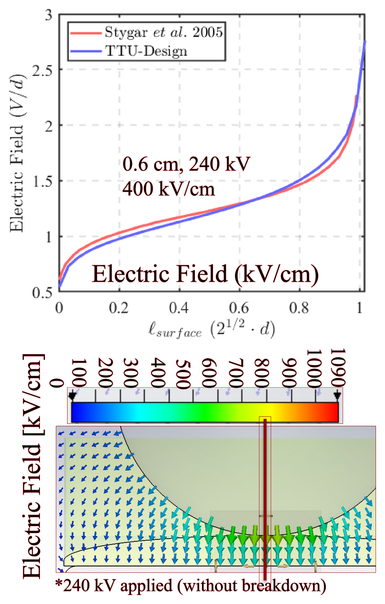
Smaller gap (0.6 cm versus 4.3 cm)
- 240 kV versus 2.2 MV



(Stygar-Like Topology)

Simulated Electric Fields





Electric field along the vacuum-insulator interface (45◦ surface). Field in Vacuum plotted in red; field in insulator plotted in black. In keeping with [1] electric field magnitude is normalized to Vapplied/Hgap; insulator Er = 2.53. Radius is normalized to the width of the insulator assuming the ATJ lies at 0. This is proportional to distance from the ATJ, the complement of distance from the CTJ [3].

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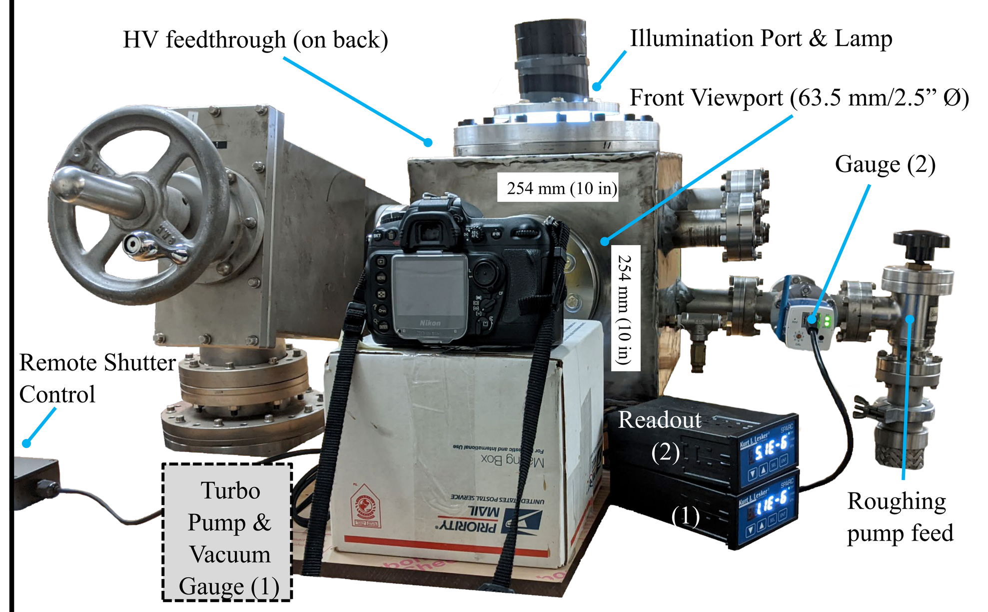
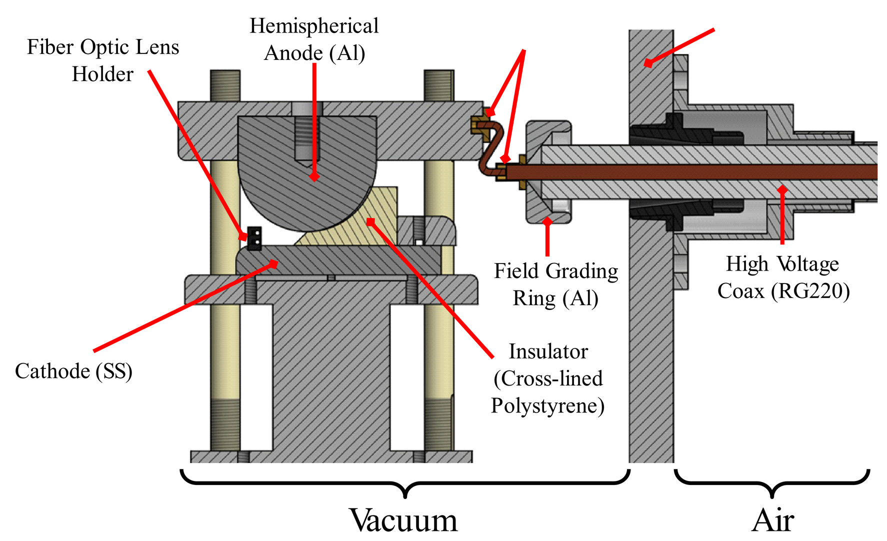
First Generation Chamber

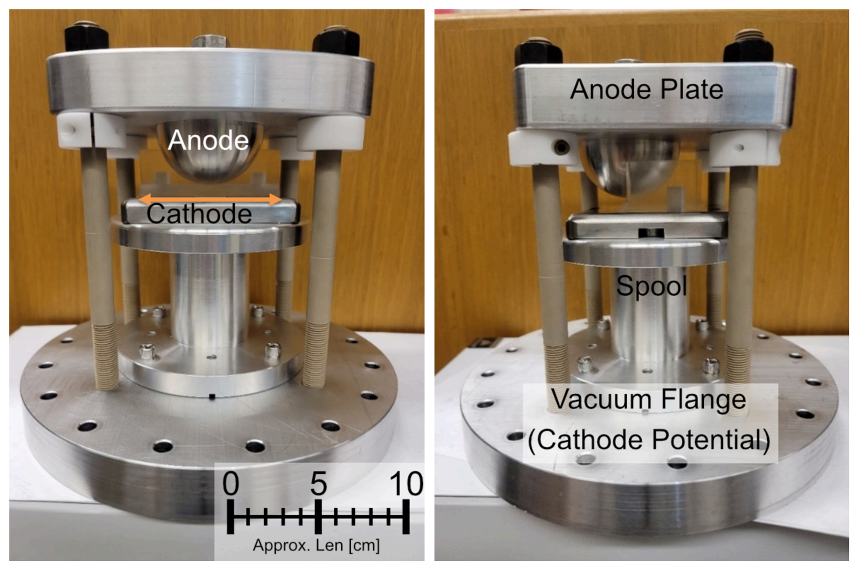


First Generation Fixture

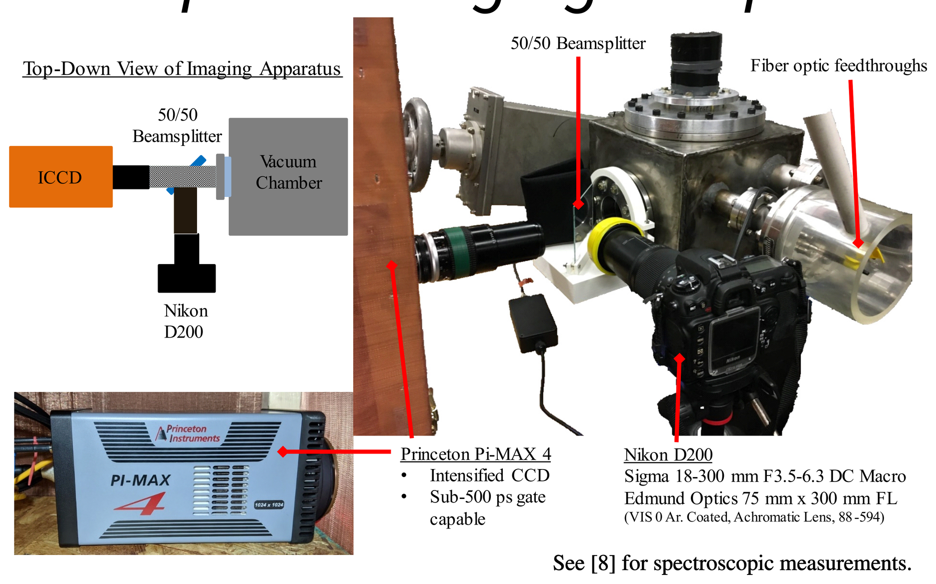


(Above) Cross-section of the first generation test fixture featuring an electrically excited anode, and grounded cathode base plate [4].

(Below) Experimental test fixture with first-generation PMMA insulator. Left: front view looking directly at the insulator wedge (slightly above the arrow). Right: profile view showing the anode protrusion extended into the insulator bulk with the tip centered near the ATJ. The arrow denotes the insulator width of 95mm (3.75 in) [3].

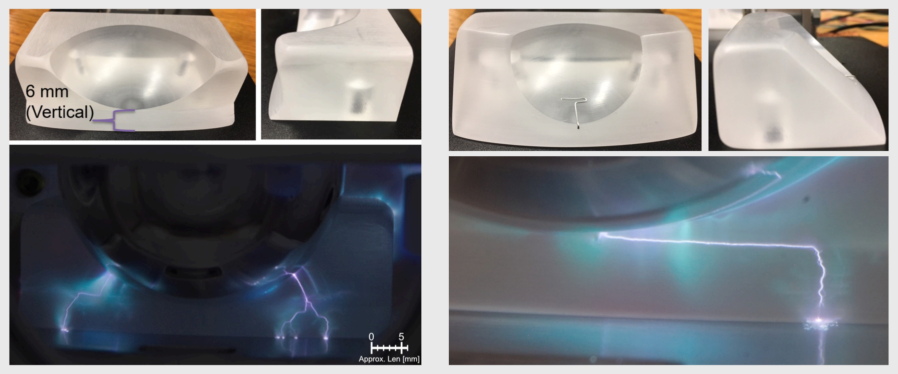


Optical Imaging Setup



See [8] for spectroscopic measurements.

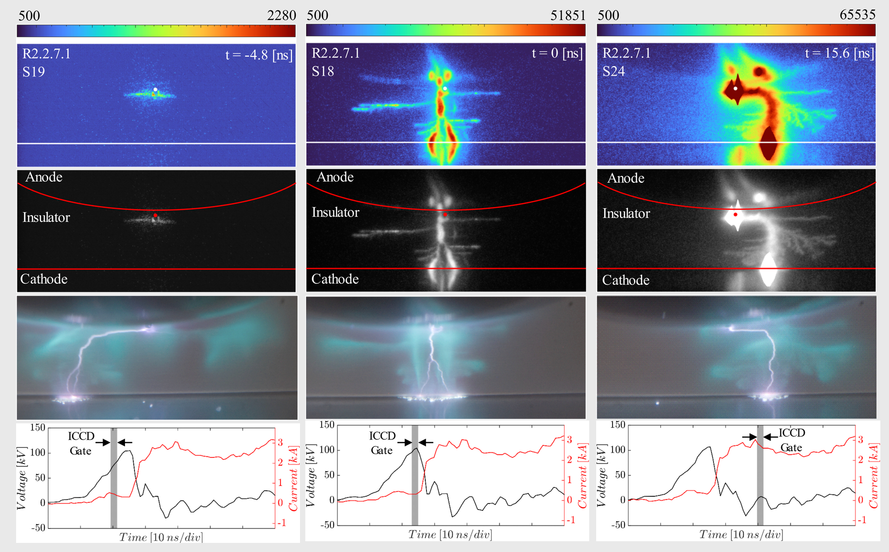
Early Insulator Geometries



First-generation insulator. Very high tangential electric fields along the vertical surfaces are believed to result in flashover along the side and back surfaces. Flashover along the 45 degree wedge was not observed. Rounding of the non-critical edges was necessary to prevent flashover along the respective boundaries [3].

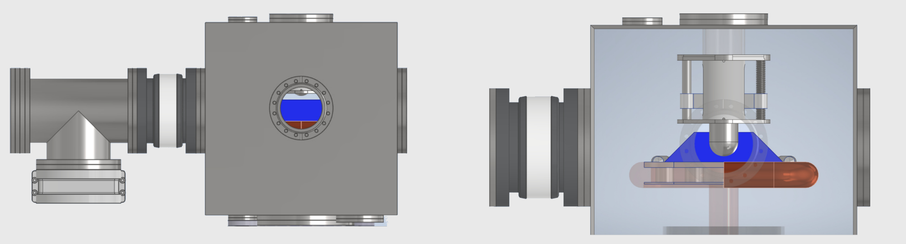
Second-generation insulator. The 45 degree wedge was extended to the entire front face. Flashover to the rear continued to be an issue, however, use of a aluminum wire simulating a defect in the insulator geometry could be used to reliably initiate flashover along the front surface. Path was prone to traverse laterally along the sanding groves [3, 4].

Time Evolution of Flashover



Series of three (non-sequential) fast-gated ICCD camera images of light emission from the evolution of anode-initiated surface flashover. Column 1 (left) early light is seen from the anode during the voltage rise. Column 2 (center) light from the impedance collapse. Column 3 (right) light from after the impedance collapse. Note the lack of cathode spots in 1,2. Bottom Row: Time integrated light [4].

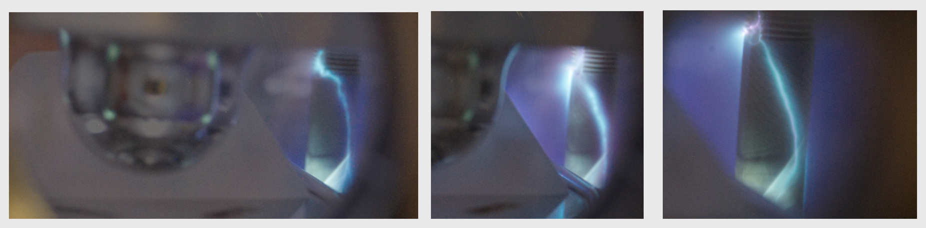
Second Generation Chamber



(Early Design Concept)

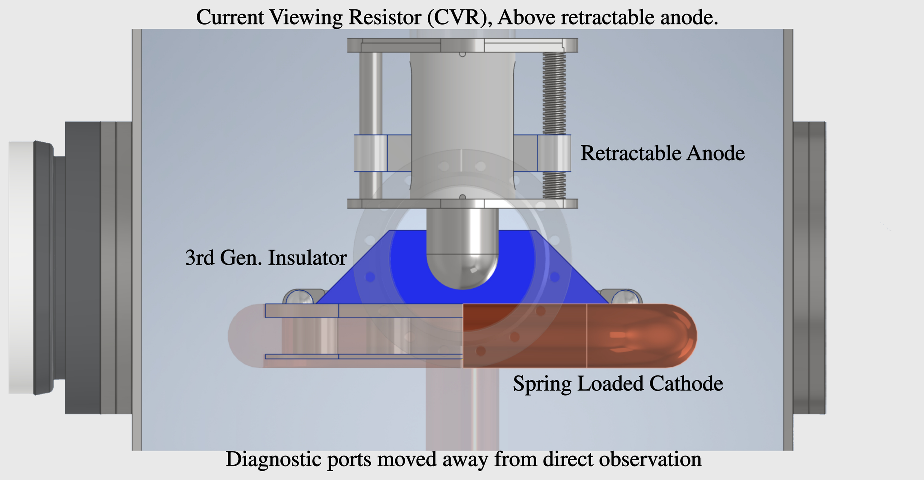
Improved Accessibility
- Approximately 2x Larger Dimensions
- (18 to 22)" Exterior dimension
- Existing diagnostic ports on top and bottom
- Ceramic Break moved to side of chamber.
- Lateral access for deflection diagnostics

Distributed Complexity
- Existing diagnostic ports on top and bottom
- CVR moved to *retractable* anode
- Spring load moved to cathode base plate
- Cathode easily replaceable/modifiable
- Supporting rods between anode and cathode have been ***completely* eliminated**.



Selected images of flashover across the insulating rods separating anode and cathode on the 1st generation test fixture. This is a consequence of the increasingly high flashover resilience exhibited by the 2nd- and 3rd (shown)- generation insulators. The issue can be mitigated, however, it is taken as indication the existing setup is near its physical limits.

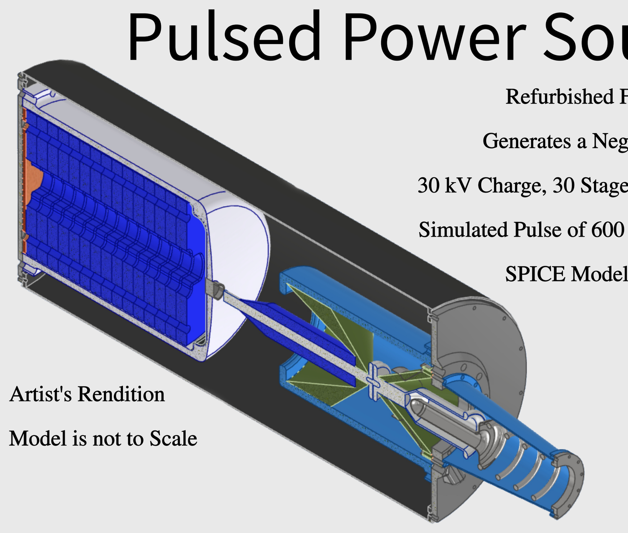
Current Viewing Resistor (CVR), Above retractable anode.



Diagnostic ports moved away from direct observation

Cathode is directly supported by HV feed through

Pulsed Power Source



Refurbished Febetron Marx Generator

Generates a Negative High Voltage Pulse

30 kV Charge, 30 Stages (2 Stages per Element)

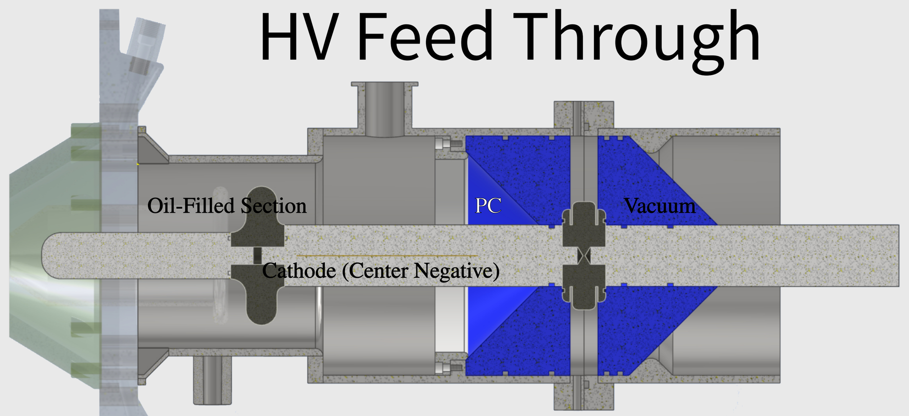
Simulated Pulse of 600 kV (2.5x to 3x Existing)

SPICE Model based on Allen et al [7].

Artist's Rendition

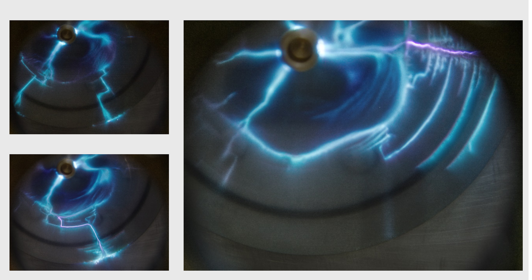
Model is not to Scale

HV Feed Through

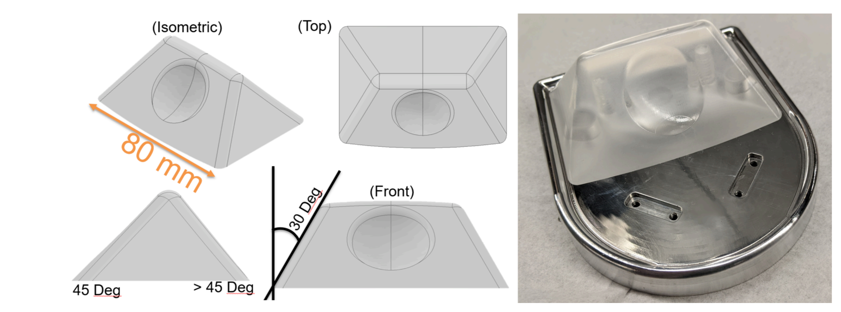


- Drop-in replacement for original Marx load.
- Left portion is oil-filled with submerged peaking gap.
- Design optimized to avoid bulk breakdown of insulator under electrostatic conditions.
- Integrated salt-water resistor for guaranteed minimum load.
- Field shaping at the anode and cathode triple junctions.

Selected images of flashover of the 1st gen. HV feed through (positive polarity center). The issue has been addressed, but special care is taken to avoid and easily diagnose the potential issue in the 2nd generation design. Likewise the presence of the issue is taken as indication of the existing system being at or near its physical limits.

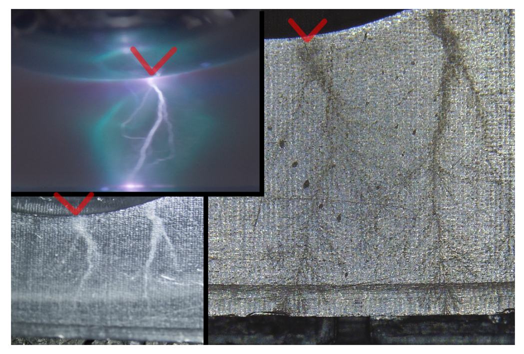


Third Gen. Insulator



(Top) The third-generation insulator geometry consists of an extend 45 degree wedge along the entire front face with a variable fillet to meet the anode, and a pyramidal construction about the remaining edges. Fields are similar to the Stygar Geometry with the rear and side faces accessing the flashover strength of a sloped insulator [3].

(Bottom) Visible light microscopy of an anode initiated flashover event on the third generation insulator. Of particular importance, no aluminum wire was necessary to initiate the breakdown near the center [3].



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