

A NOVEL WAY OF IMPLEMENTING VISIBLE BREAK IN A SOLID DIELECTRIC SWITCH

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ABSTRACT

This paper discusses a novel way of embedding a visible break (disconnect switch) into a solid dielectric switch for vault and pad-mount style applications. In vaults these switches are designed to remain operational submerged in water up to 6 m (20 feet) for up to 20 days. Emphasis is placed on the design constraints and manufacturing challenges, as well as electrical stress analysis and partial discharge mitigation. Validation testing and applicable industry standards are also discussed.



Figure 1: SafeVu switch installed in a vault.

INTRODUCTION

SF₆ has been used as insulation and interrupting medium in high voltage switchgear since the 1960s and for a few decades in medium voltage switchgear. In recent years, however, the use of SF₆ has been heavily scrutinized by environmental protection agencies around the world because of its high potency as a greenhouse gas. The U.S. EPA reports that SF₆ has a global warming potential 23,900 times greater than CO₂ and an atmospheric life of 3,200 years. Switchgear manufacturers and utilities have been leaning more toward the use of eco-friendly solid dielectric insulation used in conjunction with vacuum interrupter for medium voltage applications. In order for solid dielectric switches to replace SF₆ switches in the medium voltage applications, two key safety features provided by most SF₆ switchgear must be incorporated into solid dielectric switches.

1. Integral visible break for a visual confirmation of open state, and
2. Integral grounding (earthing) for safer isolation.

This paper focuses on item 1.

DESIGN OVERVIEW

A visible knife blade disconnect switch is connected in series with a vacuum interrupter as shown in figure 3 below. All circuit interruption occurs in the vacuum interrupter. The visible knife blade switch and vacuum interrupter are driven independently by two separate mechanisms interlocked with a graduated cam system. This internal interlock system (located inside mechanism housing) ensures that the visible break will only open when the vacuum interrupter is fully opened providing another layer of safety for line crew.



Figure 2: Details of a SafeVu switch with visible break contacts highlighted.

An external interlock system is also provided to sequence the operation (creating a Poka-yoke system), i.e., to assure that the vacuum interrupter is always first to open and last to close. The visible break contacts, which are in air at atmospheric pressure, can be seen through a ¾" thick tempered borosilicate glass window molded into the cycloaliphatic epoxy insulation, as shown figure 2 above. Since no fluid level or pressure need be monitored, the unit is maintenance free.

In addition to the safety associated with certainty of open state provided by a visible gap, this switch also allows the load-side cable to be tested with DC voltage while the line-side is at system AC voltage; a test that hitherto was

impossible to perform on solid dielectric switches that use only vacuum interrupters without disconnecting cables.

Window Material Selection:

Cycloaliphatic epoxy was used to provide insulation and structural support for the switch due its numerous years of use and wide range industrial acceptance for similar products.

For the view window 3 materials (Polycarbonate, Acrylic and Glass) were evaluated. The properties of interest include:

- Visibility
- Chemical resistance
- UV stability
- Durability
- Impact resistance > 5.4 Nm (4 ft-lbs)
- Thermal shock resistance (0°C to 60°C)
- Temperature limits > 200°C
- Bonding to cycloaliphatic epoxy

Polycarbonate had most of the required properties except temperature limits. Temperature measurements taken by sensors in the pressure gelation mold indicate temperatures as high 190°C from the exothermic reaction during curing of the cycloaliphatic epoxy.

Following extensive investigation and preliminary testing, tempered borosilicate glass was chosen for the window material.

Molding (Encapsulating the glass into the epoxy)

Molded, un-machined glass surfaces typically have tolerances as high as $\pm 1\text{mm}$ ($\pm 0.040''$). Encapsulating glass into epoxy using pressure gelation requires high pressure shut off interfaces, with tolerances of the order of $\pm 127\mu\text{m}$ ($\pm 0.005''$) or lower. To accommodate the greater tolerances of the glass surface, a high pressure bladder was designed. This bladder inflates to provide high pressure shut-off on the glass surface and deflates after gelation of the epoxy, providing scratch-free viewing window.

Differences in thermal properties

To account for the difference in thermal expansion and contraction between the glass and cycloaliphatic epoxy, while maintaining the hermetic seal integrity within the module, the glass is coated with an elastomer. The elastomer is chemically bonded to the glass and bonds well to the epoxy, providing a cushioning during contraction and stretching during expansion.

Electrical stress analysis

With the visible knife blade in air at atmospheric pressure surrounded by epoxy, electrical FEA analysis indicated stresses in excess of the allowable 3kV/mm in the air inside the module well. Subsequent BIL testing confirmed the analysis. Figure 4 below for example shows the electrical stresses at a triple point interface. (Conductor, air and epoxy)

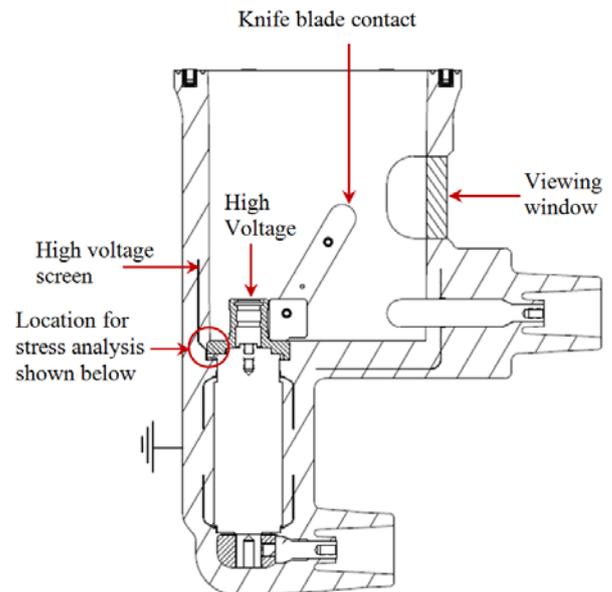


Figure 3: Cross section of SafeVu module

Stress at triple junction (conductor, air and epoxy). Refer to figure 3 above.

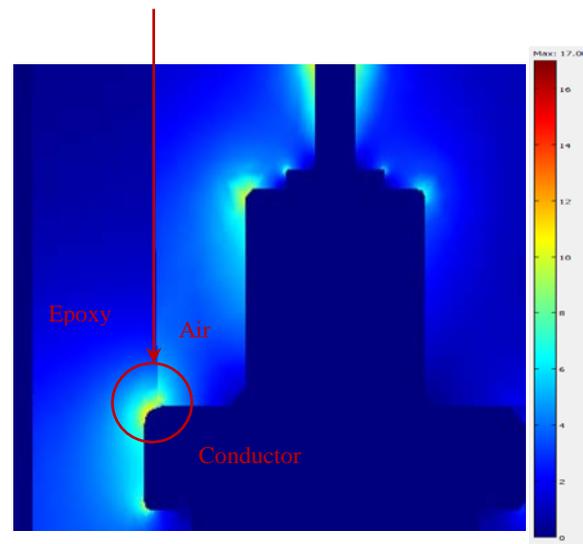


Figure 4: Electrical stress inside module well before application of the high voltage screen. The color scale for field goes from 0 (dark blue) to 17 kV/mm (deep red).

To reduce the stress, a voltage screen was applied to create a Faraday cage-like effect by pulling the stress into the epoxy which can handle fields up to 18kV/mm. The analysis indicated the voltage screen will be effective and was verified with dielectric testing. Refer to figure Figures 5 below.

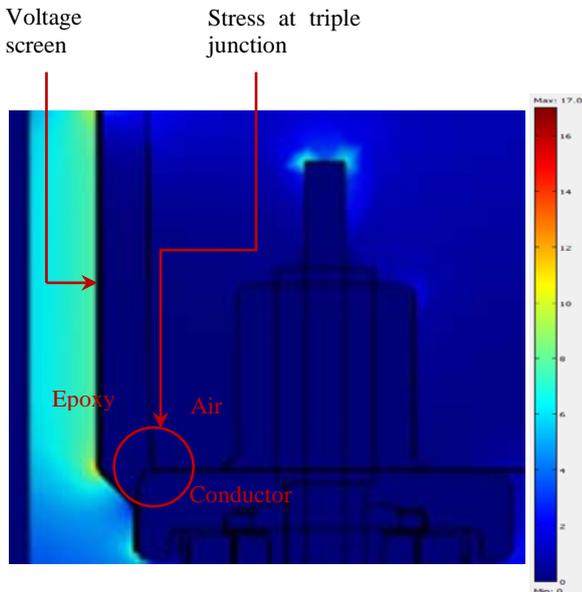


Figure 5: Electrical stress at 3 point interface after application of voltage screen. The color scale for field goes from 0 (dark blue) to 17 kV/mm (deep red).

Partial Discharge Mitigation

The equipotential lines are parallel to the exterior surface of the vacuum interrupter near the high voltage end with the operating mechanism shown in Figure 3 to 5. The equipotential lines wrap around the top corner of the interrupter which causes a high field at this point, at the location identified in Figures 3 and 4. The fact that this location is coincident with the epoxy-air interface enhances the field at that interface as a result of the dielectric contrast between the two materials, which results in a high field along the surface of the epoxy at the triple junction which results in PD under test conditions.

As noted above, this issue was addressed by adding a shield in the epoxy which is tied to the potential of the high voltage end of the vacuum interrupter. This shield puts the problematic triple junction region identified in Figures 3 and 4 in a “well” surrounded on one side by the shield and on the other side by the operating rod of the vacuum interrupter, both of which are at the same potential. As a result, the problematic triple junction region at the bottom of this “well” is at very low field, the field at the edge of the operating rod bushing is reduced very substantially, and the high field region is moved to the top of the shield, in epoxy, which can sustain the field.

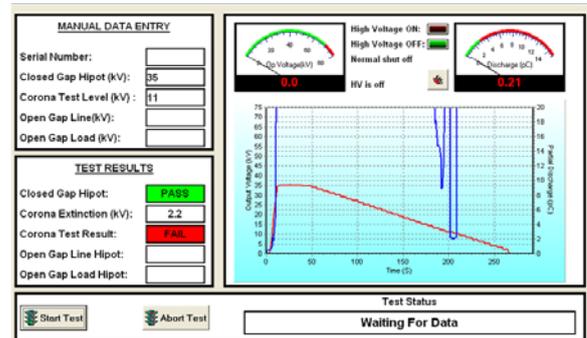


Figure 6: Results of the PD testing of module without voltage screen

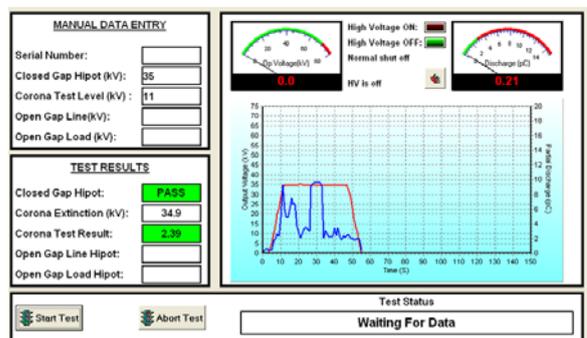


Figure 7: Results of the PD testing of module with voltage screen

TESTING AND VALIDATION

Design Testing

The SafeVu switch is designed for both load-break and fault interrupter applications. IEEE 37.74 [3] and IEEE 37.60 [4] standards were therefore used as the basis for creating validation test plan. In evaluating these standards however, gaps were discovered since this is the very first time a product of this nature has been introduced. To assure long term reliability, internal standards were created to supplement the IEEE standards.. Table 1 below shows some of the design testing performed to verify the reliability of the switch.

Table 1: Partial list of the design tests performed on the switch

Test	Standard
Peak Current Withstand	ANSI 3774-2003 SEC. 6.7.4.3
Short Time Current	ANSI 3774-2003 SEC. 6.7.4.5
Fault Interruption	ANSI 3760-2003 SEC. 6.7.4.3
Mechanical Operations	ANSI 37.74-2003 Sec. 6.7.10
BIL	ANSI 3774-2003 SEC. 6.7.2.5
AC hipot	ANSI 3760-2003 SEC. 6.7.2.4
DC Withstand	ANSI 3774-2003 SEC. 6.7.8
Mechanical interlocks	IEC62271-200 Section 6.102.2
Temperature Rise	ANSI 3774-2003 SEC. 6.7.3

Vibration (shipping)	IEC 68-2-6, MIL-STD-810F, ASTM 4169
Submersibility	IEC 60529 (IP 68) 6 m (20days)
Window Impact	G&W internal standard
Window Thermal Shock [2]	STP 2131 & G&W internal standard
Closing and Opening	G&W internal standard
Mechanical Life	G&W internal standard
Electrical and Thermal	G&W internal standard
Extreme Temperature	G&W internal standard



Figure 8: Switch during power testing



Figure 9: Speed measurements at extreme temperature (-40°C)



Figure 10: Vibration testing



Figure 11: Long term submersion test. SafeVu switch operating submerged under water for over a year

Routine Testing

To ensure long term reliability, every switch goes through rigorous routine testing before leaving the factory. Since these switches when used in vault are designed to function submerged under 6 m (20 feet), of water, every switch is helium leak test as part of the routine testing. All switch modules undergo power frequency withstand testing in two stages and partial discharge testing. The table below shows a partial list of the routine tests performed during production of SafeVu switches.

Table 2: Partial list of the routing tests performed during production

Test	Standard
X- Ray	G&W internal standard
Partial Discharge	IEEE 386 section 7.4
CT Output	G&W internal standard
CT Polarity	G&W internal standard
Contact Resistance	G&W internal standard
Shield Resistance	G&W internal standard
Leak Test	G&W internal standard
External Interlock system	G&W internal standard
AC Hipot	ANSI 3760-2003 SEC. 6.7.2.4

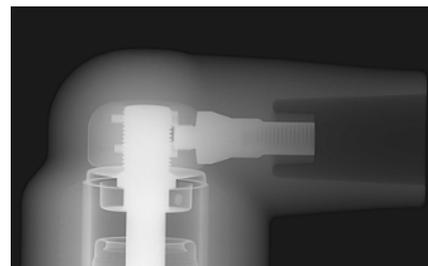


Figure 12: Detailed x-ray inspection performed during production

CONCLUSION

The continuous stringent regulation of SF₆ switches by Environmental Protection Agencies all around the world is pushing more and more companies towards the use of solid dielectric insulated switches. For such switches, having a visual indication of switch isolation is imperative to line crews that work on these switches as they migrate from SF₆ switches which possess these features. This paper demonstrates a novel way of achieving such a visual confirmation a solid dielectric insulated switch.

The production of this submersible (6 m for 20 days) dielectric switch with visible break provision has created the first step in ensuring a transition from SF₆ to the more environmentally friendly solid dielectric insulated switches. In evaluating the IEEE standards however, gaps were discovered regarding test protocols for such a switch since this is the first of its kind to be produced. To ensure the long term reliability of the switch, internal standards were created to supplement the IEEE and IEC standards.

REFERENCES

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- [4] IEEE 37.60-2003 Standard Requirements for Overhead, Pad-Mounted, Dry Vault, and Submersible Automatic Circuit Reclosers and Fault Interrupters for Alternating Current Systems Up to 38 kV
- [5] Steven Boggs, 2000, "Fundamentals of partial discharge", *IDES feature article*. vol. 16, No. 5.