IMPROVING SYSTEM SAFETY AND RELIABILITY WITH SOLID DIELECTRIC SWITCHGEAR

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ABSTRACT

This paper discusses improvements to system safety and reliability using solid dielectric insulated vacuum switchgear as a replacement to SF6 and air insulated switchgear. Challenges to integrating a visible break in solid dielectric switchgear are addressed along with validation and reliability testing. The paper also informs on embedded sensors in solid dielectric switchgear for submersible applications to enable real time diagnosis and system configuration.

INTRODUCTION

Solid dielectric insulated vacuum switches (solid dielectric switches) continue to gain market share from both air and SF6 insulated switches. Environmental concerns about SF6 persist and the environmentally friendlier alternative gases are yet to gain industry wide acceptance. Even though the initial investment is slightly higher for solid dielectric switches, studies conducted by various utilities in the United States have pointed to the long-term cost effectiveness of solid dielectric switches over the two aforementioned switch categories at least in the medium voltage applications.

In the last six years various manufacturers have introduced visible break systems in solid dielectric switches, a safety feature for line crew that was previously an advantage of air and SF6 switches. To achieve the desired insulation coordination, visible break systems currently available in the marketplace utilize various insulating media, ranging from atmospheric air, to pressurized gas, or oil.

The advent of the smart grid has also significantly increased the need for various kinds of sensors for real time diagnosis and system configuration. A solid dielectric switch with a visible break and embedded sensors is therefore desired by most utilities.

This paper highlights one way G&W Electric has developed a solid dielectric switch with visible break (insulated by atmospheric air) at 27kV level in a compact form. The report focuses on the design challenges for maintaining dielectric integrity in the visible break and the validation and reliability testing completed.

This report also covers the encapsulation of voltage sensors in the dielectric material for both the line and load side connections to ensure submersibility for underground applications, where the switches can be submerged indefinitely. This report focuses on the design challenges, validation testing and some lessons learned.

DESIGN OVERVIEW

Visible Break

The electrical industry has long utilized knife blade disconnects or earthing switches to allow for a visible break, when connected in series with an interrupter or load-break device. The challenge is achieving this in a compact size while maintaining dielectric integrity and the insulation coordination needed for a safe and reliable application. An additional challenge is to provide this switch with the ability to be operated in submerged conditions. See figure 1 below.

Figure 1: Underground application – showing a Solid dielectric switch installed in a vault.

To achieve this compact size in a 27kV rated device, various techniques were applied to reduce electrical stress and / or move the stress into a high dielectric strength medium that can handle the stress. See figures 2 and 3 for some of the details.

The design highlighted below utilizes an air insulated knife blade disconnect switch at atmospheric pressure, connected in series with an encapsulated vacuum interrupter. Since it's impossible to see the open contacts of the vacuum interrupter, the knife blade, which is interlocked with the vacuum interrupter to only open when the interrupter is opened, provides an added layer of safety to line crew.

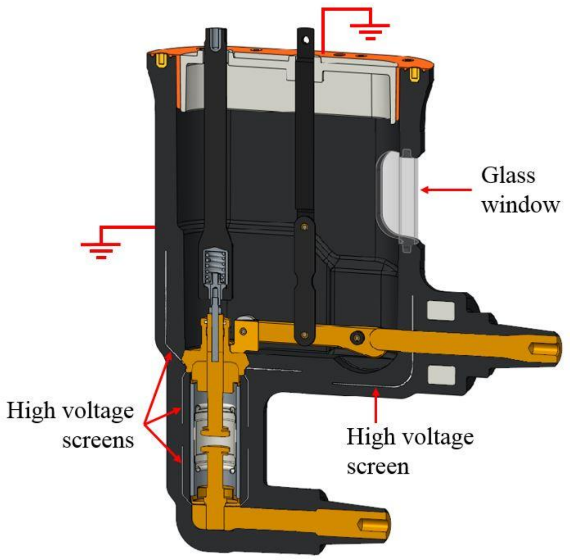

Figure 2: Solid dielectric module showing a vacuum interrupter in series with a knife blade disconnect switch

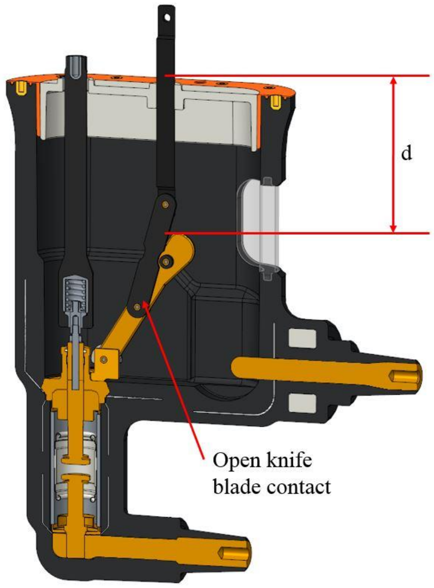

Figure 3:Solid dielectric module showing a vacuum interrupter in series with a knife blade disconnect switch (both interrupter and disconnect switches in open state)

Design challenges

See figures 2 and 3 above for the internal detail of this design. One significant challenge is dealing with the dielectrics of the air insulated knife blade disconnect at atmospheric pressure. At 27kV with a 125kV BIL rating, knife blade switches typically require approximately 9 inches [227 mm] of air clearance to ground and a creepage of approximately 14 inches [356 mm]. By utilizing a creepage extension technique (not shown) and a plug and diaphragm seal, the height of the solid dielectric module has been reduced by 7.5 inches [190.5 mm] while maintaining dielectric integrity. All air insulated conductors were designed to keep the electrical stress below 2.5kV/mm. The voltage screens create a Faraday cage-like effect around the high stress points and help pull the electrical stress from the air into the epoxy, which has a higher 18kV/mm limit. See figure 4 below.

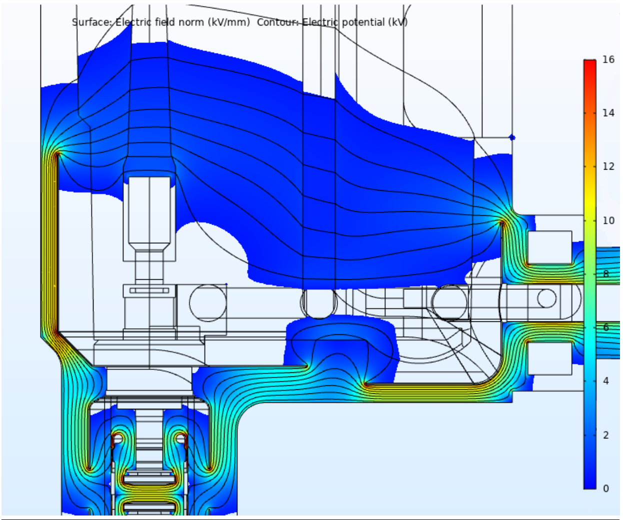

Figure 4: FEA analysis showing electrical stress in the module at 125kV

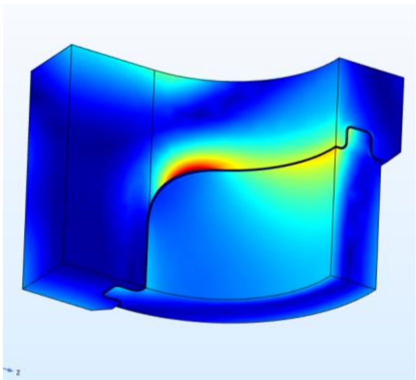

Figure 5: Symmetric sectioned view of FEA analysis showing thermal stress on glass-epoxy interface.

Manufacturing challenges

Glass was chosen for the view window because of its excellent properties for this application.

- 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

However, one significant manufacturing challenge is molding the glass window into the epoxy. A high pressure bladder system was designed to shut-off and protect the glass during the molding process. See figure 6 below.

Figure 6: Module in press just after molding, showing the bladder shut-off

Voltage Sensing

In the era of the smart grid with associated micro-grids, utilities need a way to verify the presence of voltage for both line and load sides of the switch. To achieve this, voltage screens are encapsulated into the epoxy, forming a capacitive divider.
See figure 7 below for schematic.

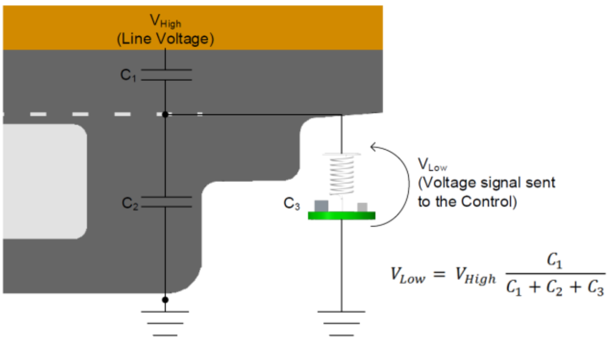

Figure 7: Schematic of capacitive voltage sensing technique used

To increase operator safety in underground applications, it is desirable to reduce the output voltages of the sensors. Figure 8 below shows a miniaturized capacitive divider board that is encapsulated into the epoxy. By encapsulating this board into the module, not only is the magnitude of the output voltage sensing signal reduced from 1500V to 5V on a 27kV system, but functionality in submerged conditions up to 6 meters is guaranteed.

Figure 8: Miniaturized capacitive divider board to be potted into the switch module.

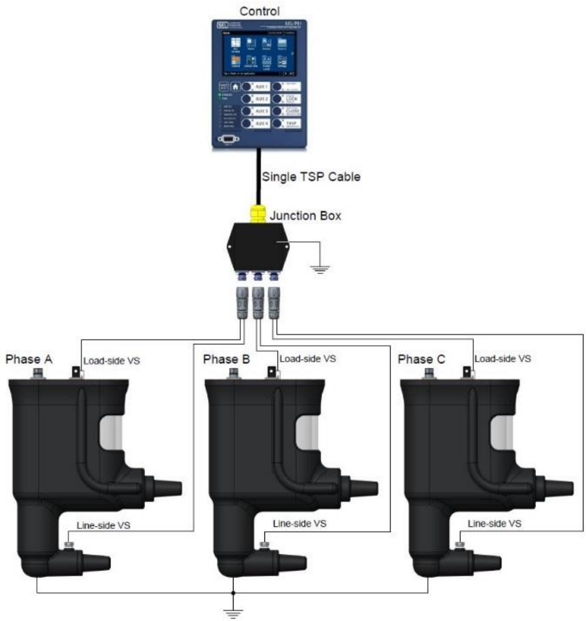

Figure 9:6VS system schematic

Design Tests (Design validation and reliability testing)

The interruption and load-break testing were completed per IEC 62271-111_IEEE 37.60-2012 and IEEE 37.74 - 2014. There are currently no available standards for integrated visible break switches as shown. IEEE has a task force looking into this issue.

Table 1 below shows a partial list of the validation testing completed on this switch.

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

Test	Standard
Peak Current Short Time Current Withstand	ANSI 37.74-2014 SEC. 6.7.4.3
Short Time Current	ANSI 3774-2014 SEC. 6.7.4.5
Fault Interruption	IEC 62271-111_IEEE 37.60-2012 6.7.4.3
Mechanical Operations (after power testing)	ANSI 37.74-2014 Sec. 6.7.10
BIL[1]	ANSI 37.74-2014 SEC. 6.7.2.5
AC Hi-pot	ANSI 3760-2014 SEC. 6.7.2.4
DC Withstand	ANSI 37.74-2014 SEC. 6.7.8
Mechanical interlocks	IEC62271-200 Section 6.102.2
Temperature Rise	ANSI 37.74-2014 SEC. 6.7.3
Vibration (shipping)	IEC 68-2-6, MIL-STD-810F, ASTM 4169
Submersibility	IEC 60529 (IP 68) 6 m (20 days)
Window Impact	G&W internal standard
Window Thermal Shock [2]	STP 2131 & G&W internal standard
Closing and Opening Speeds	G&W internal standard
Mechanical Life	G&W internal standard
Electrical and Thermal Aging	G&W internal standard
Extreme Temperature	G&W internal standard

[1] To ensure reliability of the creepage and sealing technique used for the module, a switch having passed BIL testing was subjected to extreme temperature cycles (-70°C to +50°C) for 10 days and successful tested again for BIL.

To ensure quality and long term reliability, the switch modules are subjected to detailed partial discharge testing during the design phase.

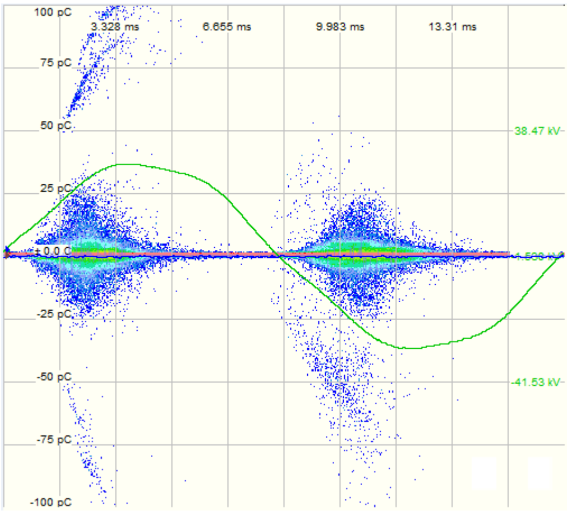

Figure 10: Sample partial discharge plot of module from design validation.

Figure 11: Modules set up in thermal chamber for extreme thermal aging (-70°C to +50°C)

Routine Tests

Every switch is subject to rigorous routine testing before leaving the factory. Table 2 below shows a partial list of routine tests performed during production.

Table 2: Partial list of routine testing completed on each switch 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[2]	G&W internal standard
External Interlock system	G&W internal standard
AC Hi-pot	IEC 62271-111_IEEE 37.60-2012 SEC. 6.7.2.4
Voltage sensing accuracy	G&W internal standard
Current injection	G&W internal standard

[2] This validates the hermetic seal at the glass-epoxy interface and the entire switch for submerged applications.

CONCLUSION

Solid dielectric switches are generally considered maintenance free; no gas pressures to monitor or oil to replace. With the well documented concerns of SF6 and studies showing long term cost effectiveness of Solid dielectric switchgear over air insulated switches, Solid dielectric switchgear will continue to gain market share in underground applications until the acceptance of an alternative gas or until some other disruptive technology emerges. Most solid dielectric switches comprise vacuum interrupters encapsulated in some epoxy or elastomer. Since the vacuum interrupter contacts are not visible, to ensure operator safety, solid dielectric switchgear needs to be able to provide the following:

1. Visual indication of open state (visible break)
2. Grounding (Earthing)

Various solutions to item 1 have been made available in the last four plus years.

This paper presents one way item 1 has been solved by G&W Electric along with challenges addressed. This paper also sheds light on the addition of a safer submersible voltage sensing system to aid in the managing of underground network systems.

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[3] IEEE 37.74-2014 Standard Requirements for Subsurface, Vault, and Pad-Mounted Load-Interrupter Switchgear and Fused Load-Interrupter Switchgear for Alternating Current Systems Up to 38 kV

[4] IEC 62271-111_IEEE 37.60-2012 Standard High voltage switchgear and controlgear – Part 111: Automatic circuit reclosers and fault interrupters for alternating current systems up to 38kV.

[5] IEC 62271-102 Standard High voltage switchgear and controlgear – Part 102: Automatic circuit disconnectors and earthing switches.

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