MATERIAL SELECTION REDEFINES SOLID DIELECTRIC MEDIUM VOLTAGE SWITCHGEAR

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ABSTRACT

This paper describes a material selection process and validation testing for the modular design of medium voltage solid dielectric insulated switchgear. Modular design of the switchgear is desirable to increase design flexibility, reduce production scrap, and improve product serviceability.

INTRODUCTION

Solid dielectric switchgear represents an eco-friendly solution to SF6 gas insulated switchgear. For medium voltage outdoor switchgear the standard cycloaliphatic epoxies are favoured along with silicone rubbers to encapsulate each individual interrupting module of the switch. With these materials, the single module design is typical; all the internal components of the interrupting module (vacuum interrupter, current and voltage sensors, and conductors) are moulded as one piece.

On the contrary, a modular module design consists of a number of molded parts that are later assembled together. This is possible by splitting the module into its basic components by function (Figure 1):

- Interrupting medium
- Conductor and sensor
- Module housing and housing

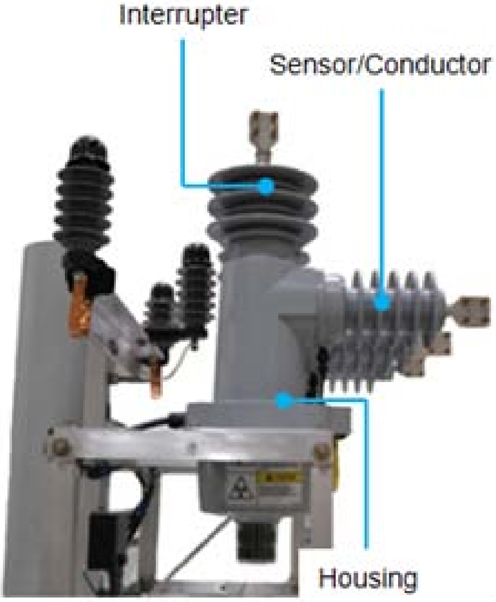

Figure 1: Modular Design by Functional Components

This paper focuses on the material selection process and validation testing for the functional components per the use and application criteria for the final product.

OVERVIEW OF THE SWITCHGEAR USE AND APPLICATION

The medium voltage solid dielectric switchgear described in this paper has three interrupting modules. Each module consists of a vacuum interrupter, current and voltage sensors, conductors and a mechanical housing. The switch can be classified as live tank design since the surface of the interrupting module is not at Earth potential. With the modular design a plastic housing can be used for a live tank design providing more external over surface distance from line to ground. This additional creepage distance gained from the housing contributes to the overall creepage necessary for severe environmental conditions for the switch. Therefore, the product can be used in the areas with the most severe environmental conditions (class E), as defined in IEC 60815-3 standard [1].

MATERIAL SELECTION PROCESS

The interrupter and conductor are molded in a standard cycloaliphatic epoxy separately, thus decoupling them from a single module design. This material was chosen based on existing industry acceptance of this material for similar products and applications.

However, other materials were considered for the housing to make the overall design more technically and economically feasible with the following criteria:

- The material had to have similar dielectric strength to cycloaliphatic epoxy.
- The material had to be UV resistant in order to hold up to harsh environmental conditions.
- The material had to have similar tracking and erosion behavior as that of epoxy.

During material selection process the following steps were executed; electrical stress finite element analysis, rapid prototype development and testing and initial material selection for arc tracking tests.

a) Electrical Stress Analysis

Electrical stress analysis was performed to determine the area of maximum localized electrical stress across the surface of the housing (Figure 2).

The electric stress to which an insulating material is subjected to is numerically equal to the voltage gradient and is equal to the electric field intensity:

$$\vec{E} = -\nabla\phi \qquad (1)$$

Where Φ is applied voltage and ∇ is the gradient:

$$\nabla = a_x \frac{d}{dx} + a_y \frac{d}{dy} + a_z \frac{d}{dz} \qquad (2)$$

And a_x, a_y, a_z are the components of the position vector

$$\vec{r} = a_x\,\hat{X} + a_y\,\hat{Y} + a_z\,\hat{Z} \qquad (3)$$

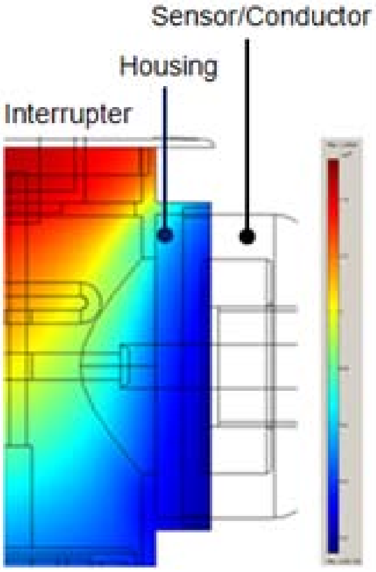

Figure 2: Electric Stress Across Housing Surface

The analysis confirmed that the highest voltage gradient occurred at the interface of the interrupter and conductor bushings. After that further analysis was performed to determine if the electrical stress in air at that juncture exceeded the allowable electrical stress limit of 4kV/mm (Figure 3). This limit was determined by performing BIL tests on single modules and correlating this data to electrical analysis of the same modules.

The FEA analyses lead to a modified housing design in order to achieve the electrical stress limit in air around the housing. This modified design was developed as a prototype and further verified through an initial salt spray test [2] and BIL tests.

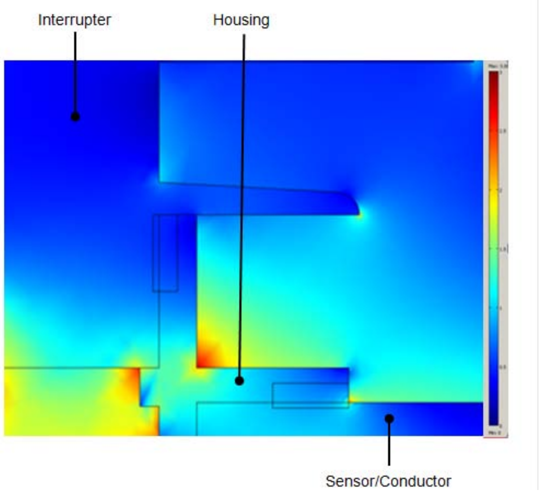

Figure 3: Electric Stress in Air < 4kV/mm

b) Rapid Prototype Development and Testing

After completion of the electrical FEA analysis the prototype was created. The housing was made using the rapid prototype process out of urethane material which has poor tracking resistance. VI and CT bushings were created using the prototype hand molds, but using cycloaliphatic epoxy. All internal conductors were assembled to realistically mimic the design. The objective was twofold; first, to quickly verify the dielectric integrity of the design before investing in the production tooling and second, to improve the design.

The first prototype was subjected to the following tests:

- 60kV 1min AC withstand test
- 125kV BIL test
- 1000 hours of salt spray test, energized to 22kV [1].

The results were very encouraging. The module passed AC Withstand and BIL tests. The housing material did track during the 1000 hours; however, it passed for that duration. The tracking occurred in the expected area of the interface of the two bushings (Figure 4).

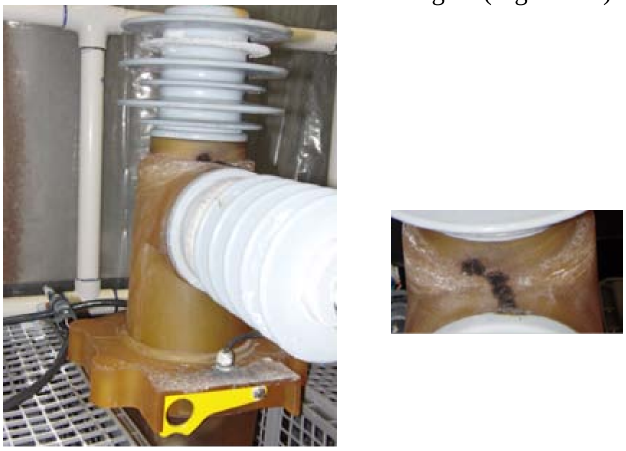

Figure 4: Salt Spray Test of Prototype Housing made out of urethane

c) Initial Material Selection for Arc Tracking Tests

After the initial testing and analyses to confirm the design of the housing was complete, the material selection process began. Materials were selected by their dielectric strength by comparison to that of cycloaliphatic epoxy (Table 1). Materials were not initially omitted due to tracking values because it may have been possible to get good results using additives with or coating [3] polycarbonates for a reduced cost. The incline plane test [4] of the materials would determine the feasibility.

Material Description	Dielectric Strength
cycloaliphatic epoxy - baseline	18kV/mm
standard polycarbonate	17kV/mm
pc with rtv coating	17kV/mm
thermoset	16kV/mm
thermoset - no UV stabilization!	18kV/mm
UV stabilized PBT with glass fiber and 20% silica	20kV/mm
UV stabilized Nylon 6 w/ glass fiber & 20% silica	20kV/mm
UV stabilized Nylon 6 w/ glass fiber & melamine-based additive	20kV/mm

Table 1: List of Possible Materials for Track Testing

MATERIAL VALIDATION PROCESS

Cycloaliphatic epoxy material was chosen as the control to either meet or exceed. For the first round of testing only two plaques of each material were created. Incline plane tests were then performed on all samples of cycloaliphatic epoxy along with other possible material candidates. The epoxy consistently met 3.5kV. Only one other type of material passed at this level or higher, the two thermoset materials. These polyester bulk molding compounds selected for this screening consistently passed at 3.75kV (Table 2).

Material Sample	Test Result		
	3.25 kV	3.50 kV	3.75 kV
Cycloaliphatic Epoxy	Passed (2)	Passed (2)	Passed(1) Failed (1) @ 3 min
Thermoset	Passed (2)	Passed (2)	Passed(1) Failed (1) @ 37 min
Thermoset w/o UV stabilization	Passed (2)	Passed (2)	Passed (2)

Table 2: Initial Incline Plane Test Results

While the analysis and testing were being carried out, samples of the second BMC material (without UV stabilization) were placed in a UV chamber for 1000 and 1500 hours [5]. The plan was to further rerun a sample incline plane test after the UV exposure. The results were less encouraging (Table 3).

Material Sample	3.25 kV	3.50 kV	3.75 kV	4.0 kV	4.25 kV
BMC#1 1000hours	Passed	Passed	Failed 6 min		
BMC#2 1000 hours	Passed	Passed	Passed	Passed	Failed 35 min
BMC#1 1500 hours	Passed	Failed 27 min			
BMC#2 1500 hours	Failed 48 min				

Table 3: UV Exposed Incline Plane Test Results

Two samples UV aged for 1000 hours showed a reduction of the pass level to 3.5 kV and two samples UV aged for 1500 hours showed a further reduction of the pass level to 3.0 kV. From this it was determined to add UV stabilization to the material, rerun the 1500 hour UV test and then rerun the incline plane tests. After a couple more iterations, three material formulations were tested for the full incline plane test with six samples per formulation. All passed at 3.5 kV or above.

After the research, analysis, and testing, the final material was selected. The tracking and erosion maintained 3.5kV or better after the 1500 hour UV test, actually holding up slightly better than the industry preferred cycloaliphatic epoxy. The housings were molded in the BMC material and assembled into the modular switchgear. The design was further validated using other environmental tests including 1000 hour energized salt spray and a 1000 hour multi-stress test [6] (Figure 5) yielding good results.

Figure 5: 1000 Hour Multi-Stress Test

Lastly one switchgear unit is currently undergoing a 1 year environmental test in a coastal environment with the materials used [7].

CONCLUSION

The design analyses and test results suggest that materials can be used for solid dielectric insulated switchgear as long as they meet the basic criteria of the product and application.

Additionally the solution has allowed for a modular design which provides more manufacturing flexibility. The utilization of the UV enhanced BMC material for the housing decreases the overall amount of epoxy in the design thus reducing product weight and cost. The material meets or exceeds the robustness of the cycloaliphatic epoxy for the same application and should be considered for the over-molded components as well in the future.

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