

Impact of Stacked Sheds on EHV Polymer Insulators

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Abstract

Grading protection for polymer insulators is widely accepted as essential for improving electrical performance and extending service life, yet there is little consensus on when and how it should be applied. MacLean Power Systems (MPS) implemented “stacked sheds” as a built-in grading feature that combats the effects of electric field stress and corona discharge. This design was first evaluated at a coastal test facility in South Africa and later validated through domestic field testing of 345kV insulators that operated for over 10 years without corona rings. Even without external grading devices, the insulators passed all key performance tests, including hydrophobicity, sheath bonding, dye penetration, and tensile strength. These results demonstrate that stacked sheds offer additional corona protection and prevent polymer degradation in high-stress areas, supporting their use as a standard feature in Extra High Voltage (EHV) and Ultra High Voltage (UHV) applications.

Insulator Design and Grading History

Mechanically, an insulator gets its capability from the fiberglass core rod and the metal fittings crimped onto each end. To achieve the required electrical performance, the core rod is fully enclosed in a protective rubber sheath. Additionally, rubber sheds are incorporated into the protective housing to control and minimize the path of electrical tracking. Without the protection of the sheath or sheds, conductive contaminants would otherwise seep into and sit on the surface of the fiberglass, turning the assembly into a poor conductor instead of a great insulator.

Polymer insulators utilize grading devices in applications as low as 138kV to protect the housing that prevents moisture from reaching the core rod. Without grading devices, the electric field can concentrate in specific areas and begin to break down the silicone sheath. When the sheath is compromised, moisture will seep in and travel between the interface of the rod and the sheath. Proper silicone to fiberglass bonding will help prevent this, but electrical and environmental stresses will prevail over time, and the insulator will fail. The highest concentration of e-field stress is located where the insulator body meets the line (live) side end fitting. In applications 500kV and above, significant stresses are present at both the line and tower end fitting connections. It is at these critical locations that MPS has implemented the stacked shed design for improved protection.

The history of polymer insulators has led to inconsistent best practices for grading protection amongst utilities. This stems from the fact that not all polymer insulators are made equal, and certain designs may need grading protection even at low stress levels/voltages to prevent premature aging. Studies have been completed in an attempt to standardize corona ring requirements regardless of insulator design and manufacturer. The results are an ultra-conservative rule of thumb for the industry, but do not educate people on how to choose properly sized grading devices based on equipment, configuration, and environment. This proved generally unhelpful, evidenced by the fact that many utilities still rely on manufacturer recommendation for corona ring selection. While the specifics of corona ring requirements can be debated, it is undeniable that grading is necessary for EHV and UHV polymer insulators and that an insulator will last longer when e-field stresses and surface discharges are minimized.

Application Specific Grading Selection

The amount of grading needed depends most heavily on the environment, voltage class, and geometry of the assembly. When a utility evaluates a “standard” application, or something very similar to a previously used configuration, this is often determined from historical lab testing data and real-world performance history. When designs and configurations are brand new, E-field modeling analysis is also used to predict which size corona ring will provide the necessary performance. This helps provide design confidence prior to investing in lab testing.

Stacked Shed Design Intent

EPRI has shown that water droplets on the surface of polymer insulators can elongate under the influence of an electric field. As the droplet elongates and loses its spherical shape, a “tip” forms at either one or both ends of the oblong shape, depending on its location on the insulator. This results in an enhancement of the electric field at the tip of the droplet, and subsequently corona discharges can occur.

Droplets elongate in the direction of the electric field, so a droplet on an insulator shed will elongate perpendicular to the surface. In this case, the tip of the droplet where corona would occur is not in contact with the silicone. Conversely, a droplet sitting on the sheath will stretch linearly along the shank of the insulator. In this situation, the harmful corona occurring at the tips of the droplet is in direct contact with the protective sheath, which could lead to material degradation. A pictorial representation of this elongation and corona discharge can be seen in *Figure 1* below.

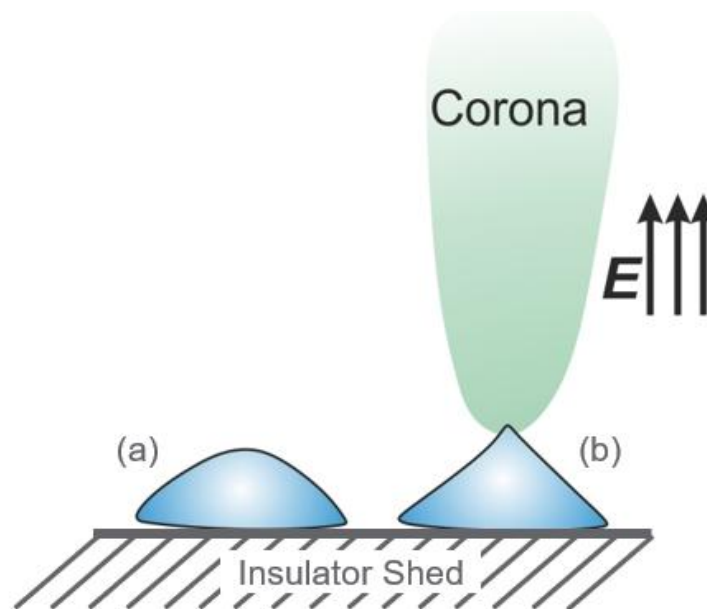


Figure 1: Schematic of a water droplet (a) without an electric field present and (b) being deformed and generating corona due to an electric field

Stacked Sheds are a design feature that combat the effects of e-field stresses and prevent water droplet corona from damaging the protective sheath. This added protection is achieved by tightly stacking silicone sheds together and completely covering the protective sheath underneath, as seen in *Figure 2* below. This significantly changes the insulator profile in the high stress region, resulting in a greater surface area and a lower current density when leakage currents flow via contamination and surface wetting. The stacked shed profile also replaces any straight sheathed rod in the high stress area where water droplet corona would occur.



Figure 2: Non-stacked shed (left) vs stacked shed (right) insulator design

In most cases, the hydrophobicity of silicone helps disrupt the continuous path of leakage current, however, this can eventually be compromised in extreme conditions. High leakage currents can lead to dry band arcing, which ultimately results in material erosion. If this erosion progresses enough to allow moisture ingress to the fiberglass core rod, electrical flash under may occur. Extreme conditions and eventual erosion may be unavoidable, but adding more silicone material in high stress areas will extend the amount of time it takes for the erosion to expose the core rod. Where there are stacked sheds, there is double the thickness of silicone standing between moisture and the core rod. Stacked sheds therefore increase an insulators' lifespan by offering improved protection from moisture penetration caused by electrical activity and extreme environmental conditions.

The following analysis features two real world examples that have proven the effectiveness of stacked sheds.

Stacked Shed Testing – Cape Town, South Africa

The first testing example is a 2-year trial that was completed at the Koeberg insulator test station in Cape Town, South Africa. One unit with stacked sheds and one without, referred to as “standard design” for this experiment, were tested side by side in one of the harshest environments on earth. In addition to the standard electric field stresses, the insulators were subject to daily salt fogs and heavy oceanic winds as the testing location was only 50 yards from the ocean. Both insulators were designed to a specific creepage distance of 19mm/kV whereas a normal creepage distance for this location would be 31mm/kV. The severe conditions in conjunction with under designed insulators helped intensify the stresses and speed up the aging experiment.

The results were similar between the two designs for the first year of testing. During the second year of testing, it was found that the leakage currents across the “standard design” were 10x higher than the unit with stacked sheds. The measured test results are shown in *Table 1*. Visual examination of the units showed significant material erosion on the standard design, and minor traces on the stacked shed design. See *Figure 2* and *Figure 3* below.

Koeberg Test Summary

	March 1996-February 1997		July 1998-July 1999	
	Std Design	Stacked Sheds	Std Design	Stacked Sheds
Cum. Charge, coulomb	242	211	2284	223
Coulomb -Ampere	7.13	6.05	32.38	6.55
Current >75 mA	59,776	60,535	50,637	39,452
ESDD, mg/cm ²	0.03-0.95		0.06-0.90	
NSDD, mg/cm ²	0.01-2.1		0.1-1.4	
Pollution Index, μS/cm	500-3000		400-3000	

Table 1: Koeberg insulator testing measured results

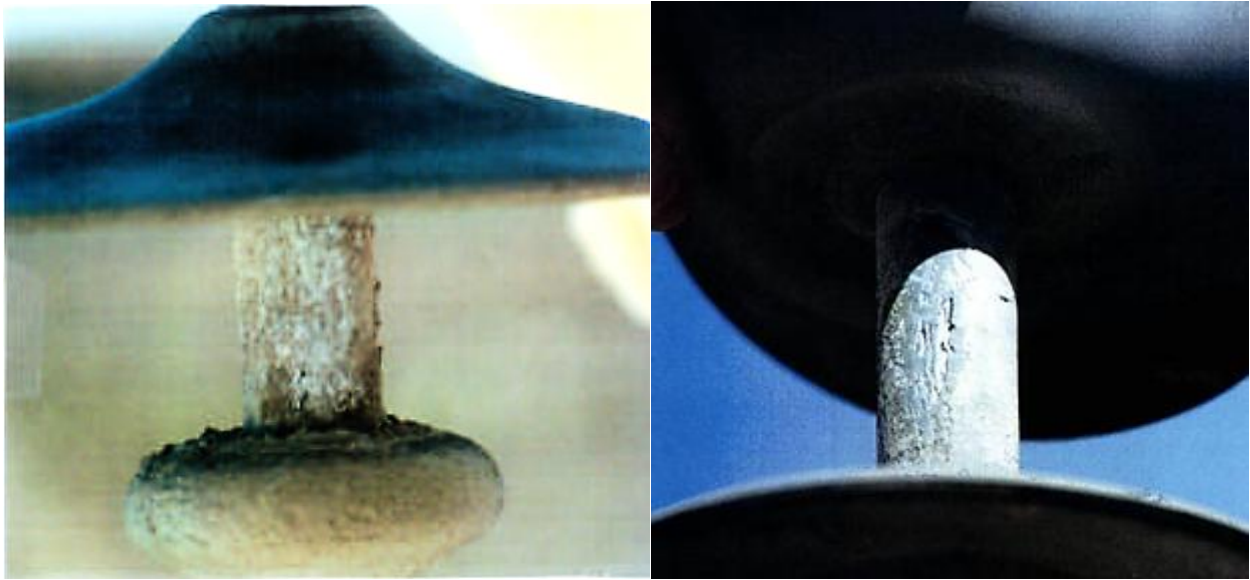


Figure 2: Non-stacked shed sheath contamination and degradation – 2 years

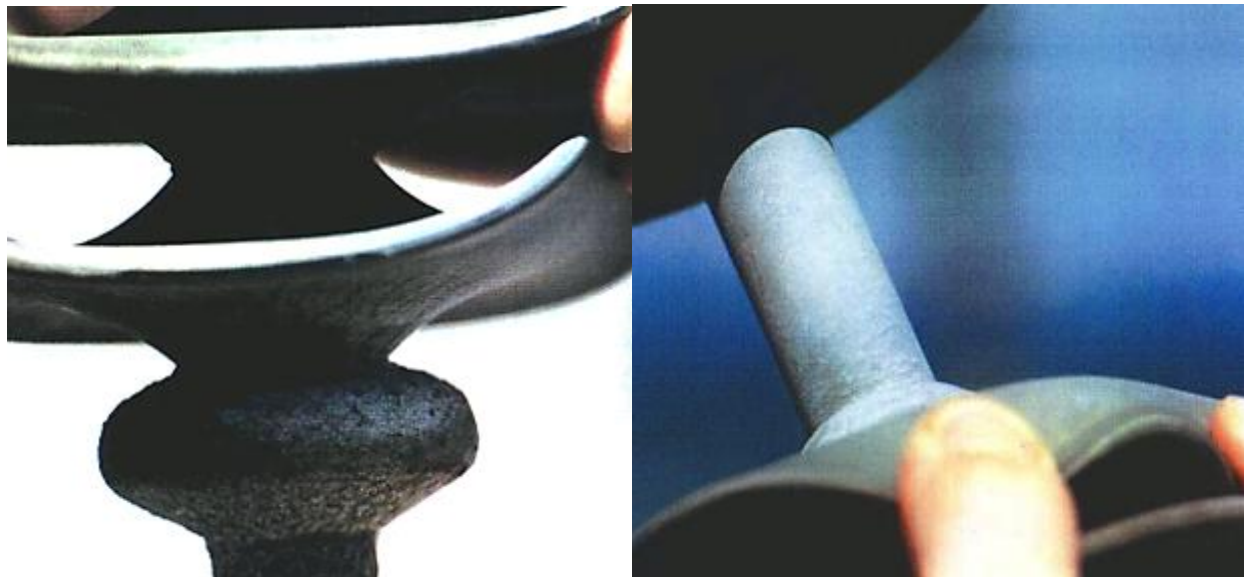


Figure 3: Stacked shed sheath contamination and degradation – 2 years

Stacked Shed Testing – Indiana, USA

A longer-term case study was unintentionally performed when a customer's contractor forgot to install the corona rings on their 345kV transmission line. The line had been energized for over 10 years before routine inspections led to the discovery of this improper installation. Six suspension insulators were sent back to MPS for evaluation to advise if insulator replacements were needed.

The following tests were performed:

- Visual Inspection
- Silicone Hydrophobicity (as received)
- Silicone Hydrophobicity (after cleaning)
- Silicone Shed Bend Test
- Silicone Sheath and Fiberglass Rod Bonding
- Silicone Sheath and Silicone Sheds Bonding
- End Fitting Seal Integrity via Dye Penetration
- Fiberglass Rod Integrity via Dye Penetration
- Tensile Strength

The purpose of each test and the pass / fail criteria are listed below:

- Visual Inspection
 - **Purpose:** Identify any visual areas of concern that aren't identified via testing and may contribute to final recommendation (chalking silicone, negative corona witness marks, misc. damage, etc.)
 - **Pass Criteria:** N/A
- Silicone Hydrophobicity (as received)
 - **Purpose:** Measuring silicone health and aging by evaluating hydrophobicity; a key performance metric that relates to product performance
 - **Pass Criteria:** HC1 or HC2 from STRI Guide (*see appendix A*)
- Silicone Hydrophobicity (after cleaning)
 - **Purpose:** Measuring silicone health and aging by evaluating hydrophobicity; a key performance metric that relates to product performance
 - **Pass Criteria:** HC1 or HC2 from STRI Guide (*see appendix A*)
- Silicone Shed Bend Test
 - **Purpose:** Measuring silicone health and aging by testing for brittleness / ease of cracking as this can lead to moisture ingress to core rod
 - **Pass Criteria:** Silicone does not crack or permanently discolor from significant bending
- Silicone Sheath and Fiberglass Rod Bonding
 - **Purpose:** Ensure that bonding does not weaken over time, as that could lead to flash under failure
 - **Pass Criteria:** Bond is stronger than the tear strength of the material itself
- Silicone Sheath and Silicone Sheds Bonding
 - **Purpose:** Ensure that bonding does not weaken over time, as that could lead to electrical tracking bypassing the weather sheds and intended current path
 - **Pass Criteria:** Bond is stronger than the tear strength of the material itself

- End Fitting Seal Integrity via Dye Penetration
 - **Purpose:** Ensure the end fitting seal can withstand the electrical and environmental stresses and prevent moisture ingress for entire product lifespan
 - **Pass Criteria:** Fiberglass rod is not stained with fuchsia colored dye
- Fiberglass Rod Integrity via Dye Penetration
 - **Purpose:** Ensure there are no voids within the fiberglass rod
 - **Pass Criteria:** Fuchsia dye does not seep through the sample piece
- Tensile Strength
 - **Purpose:** Ensure the insulators' mechanical capability has not weakened over time
 - **Pass Criteria:** Insulator breaks at or above published Specified Mechanical Load (SML)

Due to the destructive nature of dye penetration testing and tensile testing, half of the test lot was subject to tensile testing, and the other half were evaluated for dye penetration. The full test results can be seen below in *Table 2*. The dashes in the table indicate that the test was not performed on that unit due to other tests being performed.

Sample	Hydrophobicity	Hydrophobicity (Cleaned)	Shed Bend Test	Shed Bonding	Sheath Bonding	Dye Pen: End Fittings	Tensile Pull	Dye Pen: Rod
1	Passed (HC1)	Passed (HC1)	Pass	Pass	Pass	Pass	-	Pass
2	Passed (HC1)	Passed (HC1)	Pass	Pass	Pass	Pass	-	Pass
3	Passed (HC1)	Passed (HC1)	Pass	Pass	Pass	-	Pass	-
4	Passed (HC1)	Passed (HC1)	Pass	Pass	Pass	-	Pass	-
5	Passed (HC1)	Passed (HC1)	Pass	Pass	Pass	-	Pass	-
6	Passed (HC1)	Passed (HC1)	Pass	Pass	Pass	Pass	-	Pass

Table 2: Testing Results for Unprotected 345kV Insulators Energized for 10+ Years

Based on the evaluations performed, there was no evidence that the insulators were nearing end of life, or that performance had degraded. Some minor material aging was seen during the visual examination, located underneath the bottom most shed, where the e-field stresses are highest. The end fitting seals on both the line and tower end of the insulator were still fully intact, preventing moisture ingress. The silicone housing and sheds maintained proper elasticity and hydrophobicity, which indicated the silicone was in good health and had maintained its dielectric properties. All mechanical tensile tests and bonding tests were also successful.

There was no concrete way to determine how many years of remaining life these insulators would have if kept in service as is. It was clear, however, that a failure was not imminent and that equipment replacement did not need to be handled as an emergency. Although the insulators appeared to be performing without issue, the MPS recommendation was to replace and re-install with corona rings as intended. This ensures a proper life span of the polymer insulator.

MPS Grading Practices

From testing and nearly 23 years of field experience, MPS has established their best practices for corona rings and stacked sheds. Those general guidelines can be seen below in *Table 3*. It is important to note that these are generic to an average application, and MPS will consider each individual application and its environment to determine the proper combination of stacked sheds and corona rings. In the case of unique and brand-new applications, E-field modeling can be used as a tool to guide the decision prior to formal lab testing.

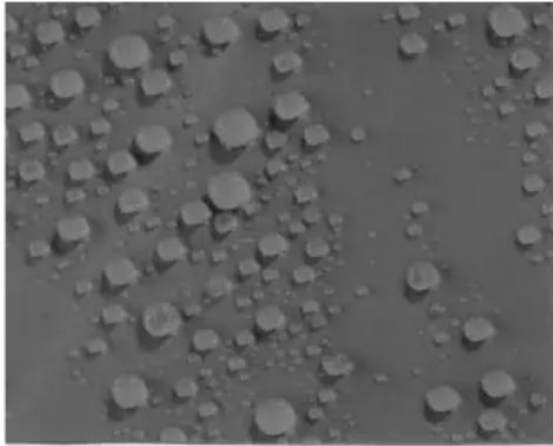
System Voltage	Corona Rings Required	# of Stacked Sheds
138-161kV	None	3 – line end
230	8” (line end)	3 – line end
345	12” (line end)	3 – line end
400	12” (line end)	6 – line end
500	17” (line end) - 8” (tower end)	6 – line end
765	17” (line end) - 12” (tower end)	12 line end / 6 tower end

Table 3: MPS Grading and Stacked Shed Best Practices

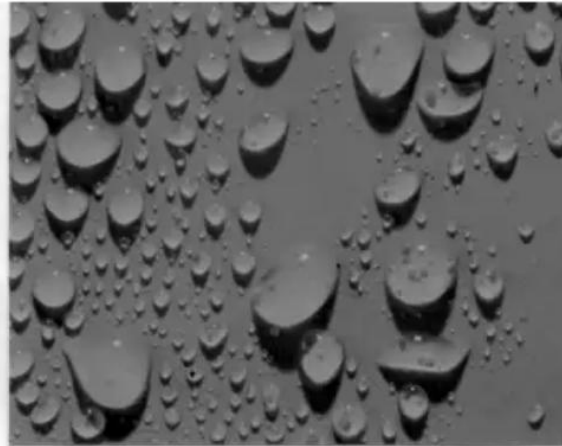
Conclusion

From both the international and domestic field testing discussed in this paper, it can be concluded that stacked sheds are a safeguarding feature that help insulators resist degradation from electrical and environmental stressors. This added protection comes from the extra silicone material that completely engulfs the sheath in the highest stress areas of the insulator. This added protection leads to improved product longevity.

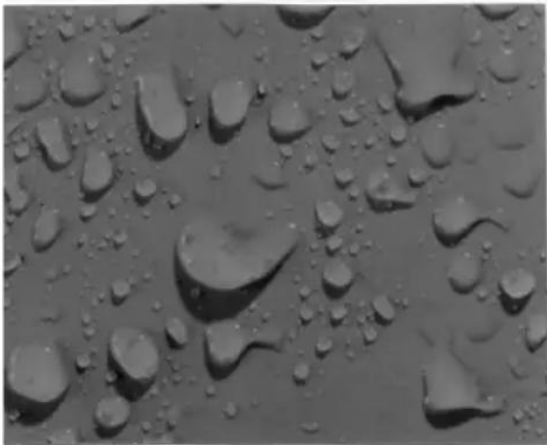
Appendix A - STRI Guide for Hydrophobicity



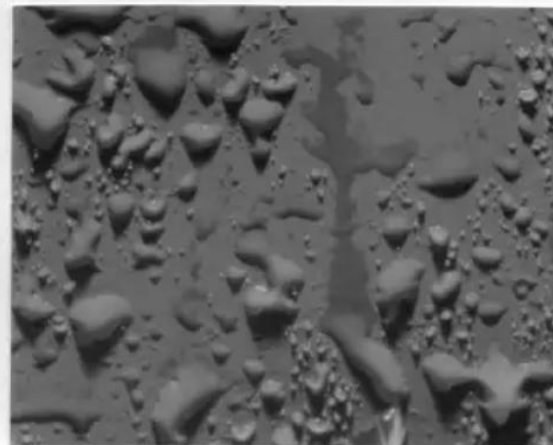
HC 1



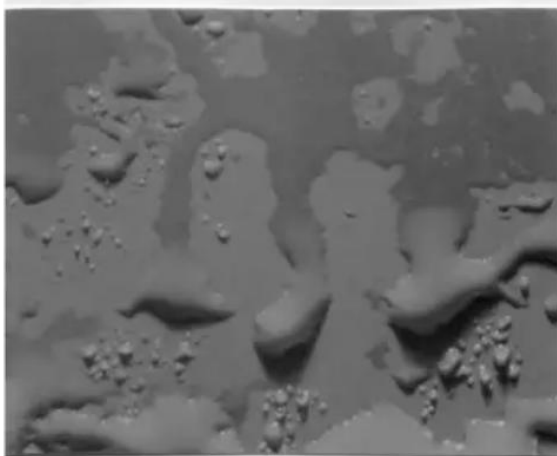
HC 2



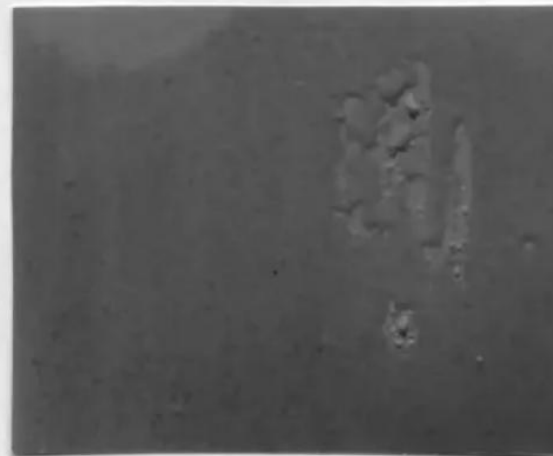
HC 3



HC 4



HC 5



HC 6

References

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 - Published in the IEEE Transactions on Power Delivery, Vol. 14, No. 3, July 1999
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