

Selecting Proper Corona Protection Using E-Field Modeling

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E-Field Modeling of insulator & hardware applications is becoming a great tool to determine proper corona protection for a transmission assembly before submitting for testing in a lab, or for installation & energization in the field. One of the many benefits of completing the E-Field models is that we can try multiple combinations of corona rings, shields, hardware, and insulators to get the desired customer requirements, quickly and efficiently. This can be completed for new projects at the developmental stage, or it can be a valuable tool for trouble shooting existing applications that may have been applied with insufficient corona protection. This paper will define a case study completed on a 138kV Braced Post application that was originally designed and applied without corona rings, which have performed well, but did not meet the required corona performance criteria of today.

The subject 138kV braced post model was designed and supplied without corona rings, as was the standard practice at that time (Typically corona rings were added for 230kV applications and above). Over approximately 16 years in service, some of these applications have raised concern about corona related aging of the sheath, specifically on the line post insulator of the braced post assembly. To determine the ideal corona protection for this braced post design, e-field modeling was employed to try various and compare different corona ring combinations.

E-Field Model Assumptions:

- Test Lab Simulation
- Voltage applied to line end and hardware: 80 kV
- Voltage applied to tower and hardware: 0 kV (Ground)
- Single Phase at 22ft Ground Clearance
- 138kV Braced Post (BP) – [See Appendix A for details]
 - a) BP Model with no Corona Ring
 - b) BP Model with 8" Corona Ring (CR) on Brace Insulator
 - c) BP Model with 8" CR on Brace and 6" CR on the line post insulator
- The brace and line post insulators are connected using a hot line fitting, which is unique to this design. (for this case study, this hotline fitting was not changed, as the focus was on addition of corona rings, for easier upgrades of existing applications).

Objective:

Model the ideal braced post arrangement to satisfy the recommended Industry performance criteria for E-Field Stress limits.

Performance Criteria:

- 1) Limit of E-Field stress on end fittings and grading rings: 2.0 kV/mm
- 2) Limit of average E-Field stress along sheath surface: 0.42 kV/mm

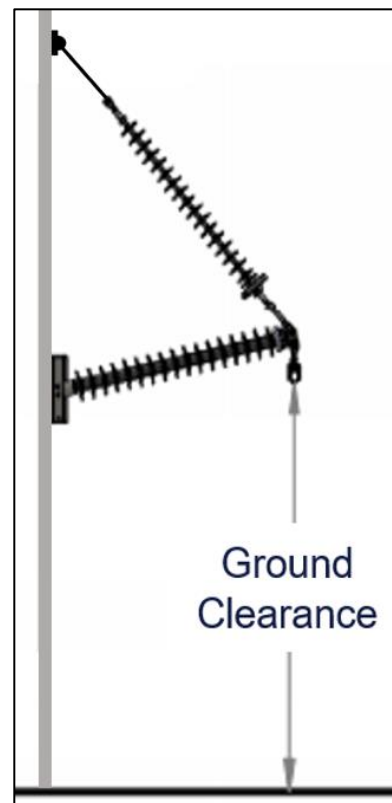


Fig. 1 – E-Field Model Set-Up

Note: results and conclusions for the proposed 138kV braced post models are specific to the defined phase to ground clearance as defined by the customer. The tighter the phase spacing, the higher the E-Field Stresses may become.

General Case Study Background

The stresses on the line post insulator are different than those on the brace insulator. The brace, or suspension, insulator has stacked sheds, so even without a corona ring, the sheath is protected from higher electrical stresses at the line end of the application. In addition, the larger corona ball feature present on the brace end fitting helps reduce the amount of stress on the sheath. This case study will identify the E-field stresses for the 3 different braced post configurations and determine the ideal corona ring applications for 138kV braced post designs.

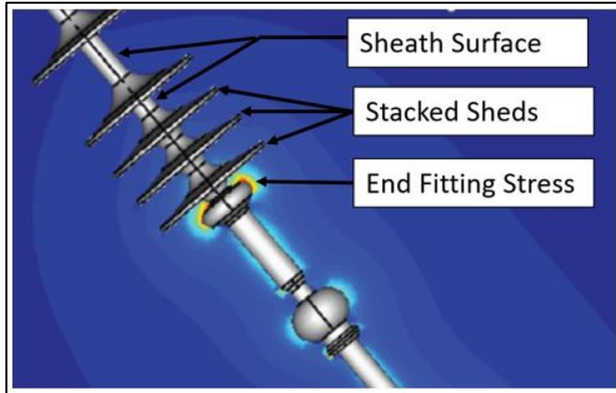


Fig. 2 - Brace Insulator Stress Plot

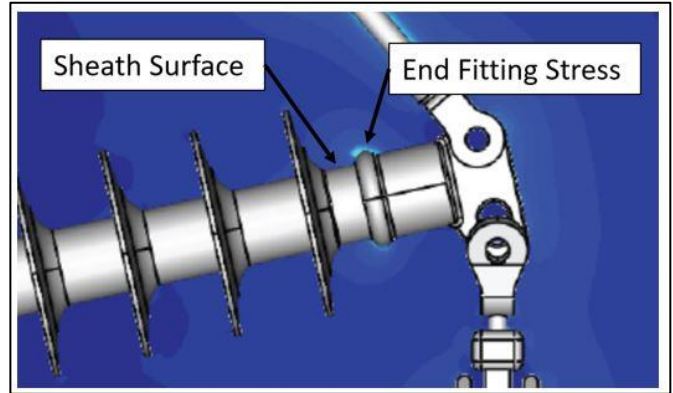


Fig. 3 - Line Post Stress Plot

For well-defined comparable results, each configuration had measurements taken at the same positions along the insulator to observe the levels of stress. Data points were captured along the end fitting, sheath, sheds, and corona rings.

Configuration #1: 138kV Braced Post – No Corona Rings

Brace Insulator: The average stress on the end fitting is high, with a max stress above the industry performance limit 2.0 kV/mm. Though this initially appears to be a concern, the stress is on the corona ball away from the silicone rubber; the presence of the stacked sheds minimize the impact this stress could have on the sheath. Therefore, there is no concern for premature aging of the sheath on this brace insulator.

- Average Stress on the End fitting = **1.95 kV/mm** [Max Stress = **2.11 kV/mm**]
- Average Stress on the Sheath Surface = **< 0.17 kV/mm** (measured beyond shed #3)
- No exposed sheath between shed #3 and end fitting.

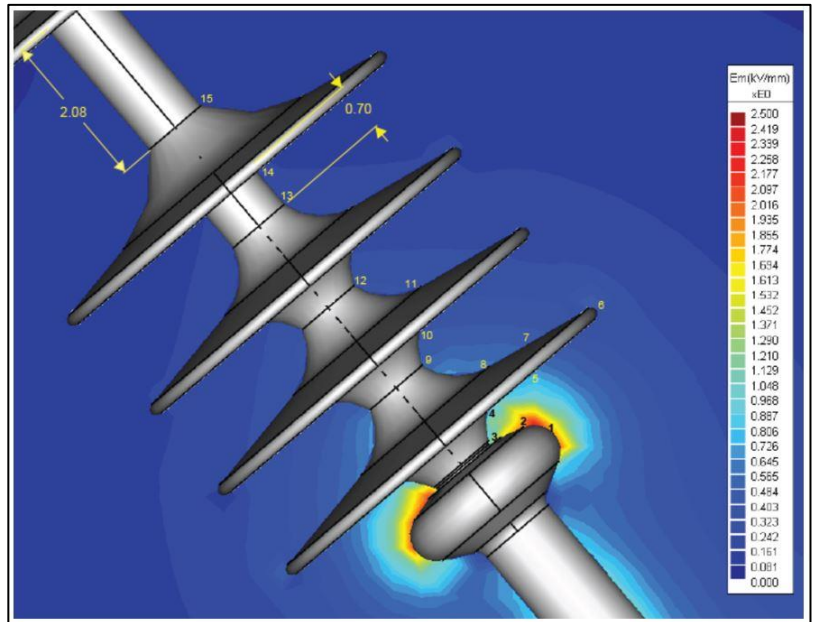


Fig. 4 – Brace Insulator without corona ring

Brace Insulator Stress Data Points																							
Corona Rings		End Fitting			Stacked Shed										Sheath			Corona Ring					
Brace	LP	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	CT1	CT2	CT3	CT4			
None	None	1.94	2.11	1.81	0.99	0.56	0.37	0.50	0.65	0.65	0.39	0.29	0.36	0.19	0.17	0.14	-	-	-	-			
Case #1		Ave:	1.95													Ave:	0.17						

Table 1A – Case 1

Line Post Insulator: In general, the stresses are lower on the post than on the brace insulator above. The average stress on the end fitting is not an immediate issue. The stresses on the sheath are at the threshold value, so there is concern of premature aging of the sheath between shed #1 and the end fitting.

- Average Stress on the End fitting = **0.77 kV/mm** [Max Stress = **0.94 kV/mm**]
- Average Stress on the Sheath Surface (EF & Shed #1) = **0.46kV/mm** [Max Stress = **0.49 kV/mm**]
- The Stress on the Sheath Surface (Sheds #1 & #2) = **< 0.16 kV/mm**

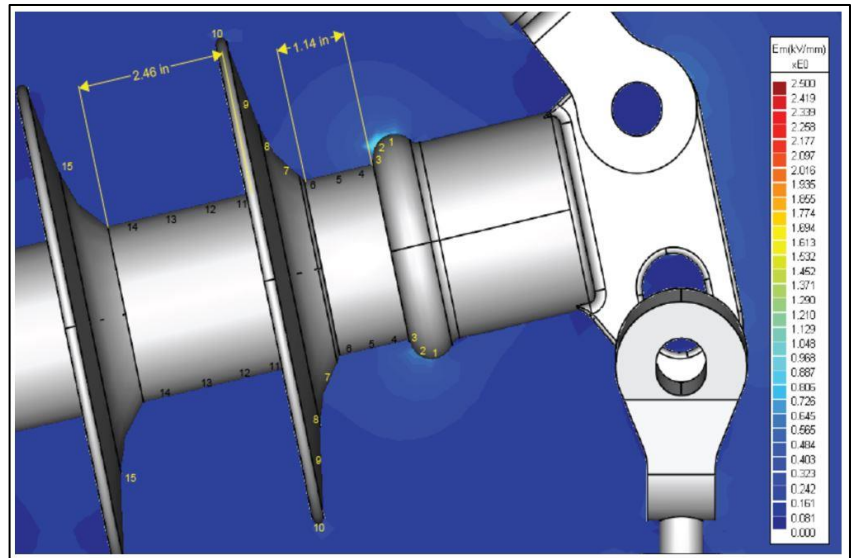


Fig. 5 – Line Post Insulator without corona ring

Line Post Insulator Stress Data Points																				
Corona Rings		End Fitting			Sheath			Shed				Sheath				Shed	Corona Ring			
Brace	LP	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	CT1	CT2	CT3	CT4
None	None	0.73	0.94	0.64	0.49	0.45	0.43	0.20	0.17	0.15	0.24	0.19	0.17	0.15	0.12	0.10	-	-	-	-
Case #1		Ave:	0.77		Ave:	0.46						Ave:	0.16							

Table 1B – Case 1

Configuration #1 – Final Observations of E-Field Analysis

Observations for Brace:

- E-Field stress focused on the EF corona ball feature, around entire EF, and some stress on the barrel.
- 1.95 kV/mm average stress on EF (above 1.8 kV/mm limit)
- No stress exposure on the sheath due to the stacked shed feature.
- Stress on first exposed segment of sheath at points 13-15 are below the 0.42 kV/mm threshold.

Observations for Post:

- E-Field stress focused on the top side of the end fitting.
- Bottom of the EF appears to be getting protection from the clamp.
- Stress on EF is below the 1.8 kV/mm threshold.

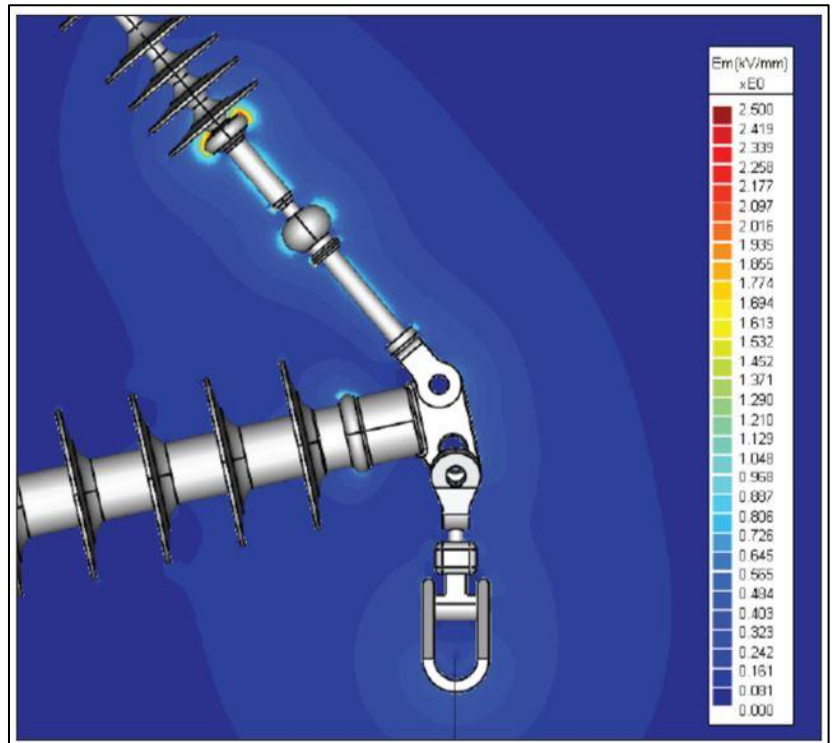


Fig. 6 – Braced Post Stress Plot without Corona Rings

- Stress on the sheath at points 4-5 are above the 0.42 kV/mm threshold, potentially leading to premature aging of the sheath.

Configuration #2: 138kV Braced Post – 8” corona ring on the brace insulators only

Brace Insulator: The addition of the 8” Corona Ring on this insulator corrects the high stresses on the end fitting, resulting in a brace insulator that is fully compliant to the industry limits.

- Average Stress on the End fitting = **0.47 kV/mm** [down from **1.95 kV/mm**]
- Average Stress on the Corona Ring Surface = **0.99 kV/mm**
- Average Stress on the Sheath Surface = **< 0.17 kV/mm**

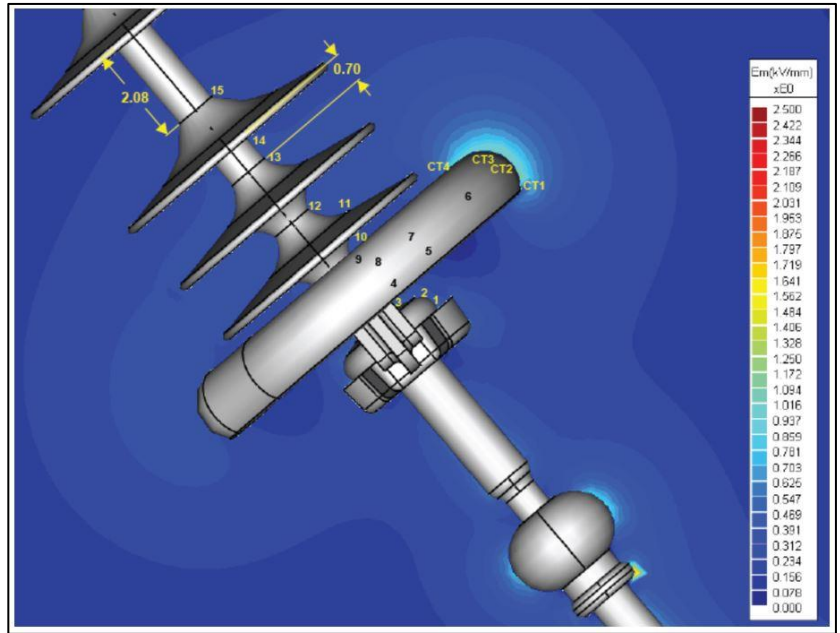


Fig. 7 – Brace Insulator with 8” corona ring

Brace Insulator Stress Data Points																						
Corona Rings		End Fitting			Stacked Shed										Sheath			Corona Ring				
Brace	LP	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	CT1	CT2	CT3	CT4		
8"	None	0.53	0.36	0.52	0.28	0.16	0.09	0.15	0.20	0.32	0.26	0.25	0.35	0.27	0.24	0.23	1.12	0.99	1.02	0.84		
Case #2		Ave:	0.47											Ave:	0.25			Ave:	0.99			

Table 2A – Case 2

Line Post Insulator: There is some improvement to this insulator from the addition of the 8” corona ring to the brace insulator. However, there is still some stress above the 0.42 kV/mm threshold, potentially being a source for premature aging of the sheath near the end fitting.

- Average Stress on the End fitting = **0.66 kV/mm** [down from = **0.77 kV/mm**]
- Average Stress on the Sheath Surface (EF & Shed #1) = **0.33kV/mm** [Max Stress = **0.45 kV/mm**]

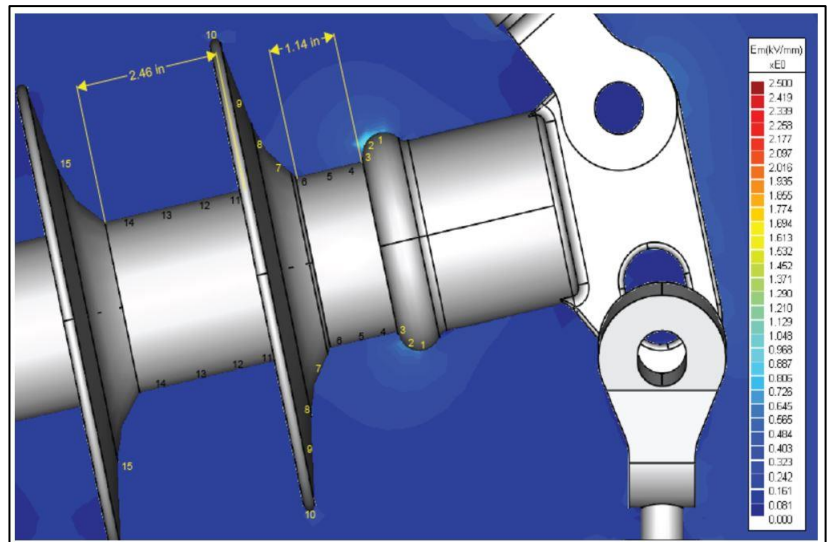


Fig. 8 – Braced Post Stress Plot without Corona Rings

Line Post Insulator Stress Data Points																					
Corona Rings		End Fitting			Sheath			Shed				Sheath				Shed	Corona Ring				
Brace	LP	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	CT1	CT2	CT3	CT4	
8"	None	0.59	0.80	0.58	0.45	0.28	0.26	0.19	0.14	0.12	0.18	0.16	0.15	0.12	0.10	0.08	-	-	-	-	
Case #2		Ave:	0.66			Ave:	0.33							Ave:	0.13						

Table 2B – Case 2

Configuration #2 – Final Observations of E-Field Analysis

Observations for Brace:

- E-Field seems to be focused on the top side of the corona ring, facing the outside of the BP.
- Some stress on the connection hardware, but still below the 1.8 kV/mm threshold.
- E-Field stress moves from EF to Corona Ring.
- 75% improvement from the EF to the Corona Ring.

Observations for Post:

- E-Field stress focused on the top side of the end fitting.
- Bottom of the EF appears to be getting protection from the clamp.
- 15% improvement on the EF.
- 28% improvement on the sheath.
- Still some concern of stress at point 4 on the sheath

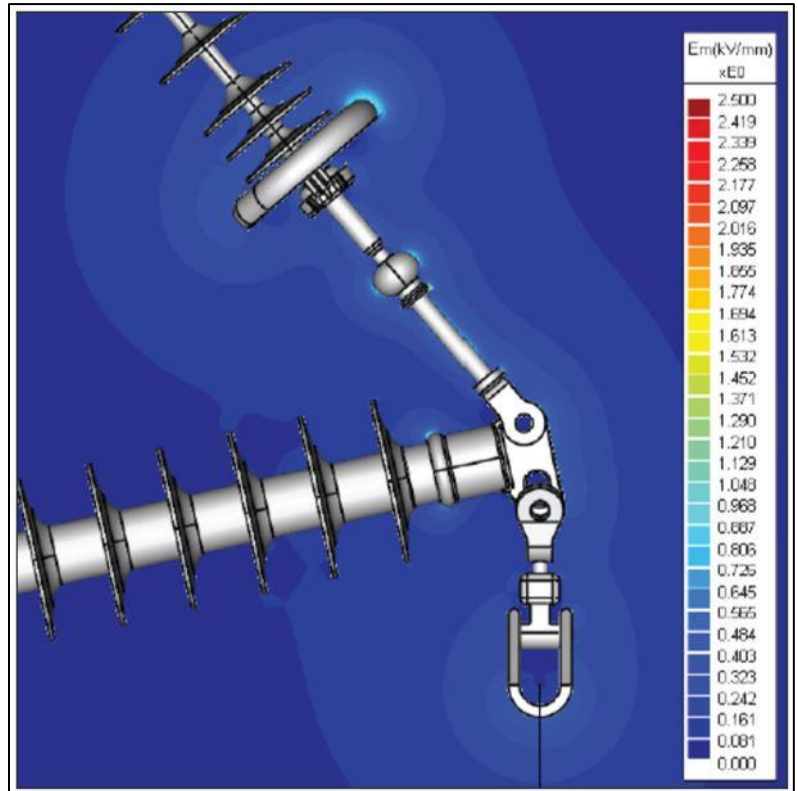


Fig. 9 – Braced Post Stress Plot w/ 8" CR on Brace

Configuration #3: 138kV Braced Post – 8" corona ring on the brace and 6" corona ring on the line post

Brace Insulator: The addition of the 8" Corona Ring on this insulator corrects the high stresses on the end fitting, resulting in a brace insulator that is fully compliant to the industry limits.

- Average Stress on the End fitting = **0.37 kV/mm** [down from **0.47 kV/mm** in model #2]
- Average Stress on the Sheath Surface = **< 0.2 kV/mm**

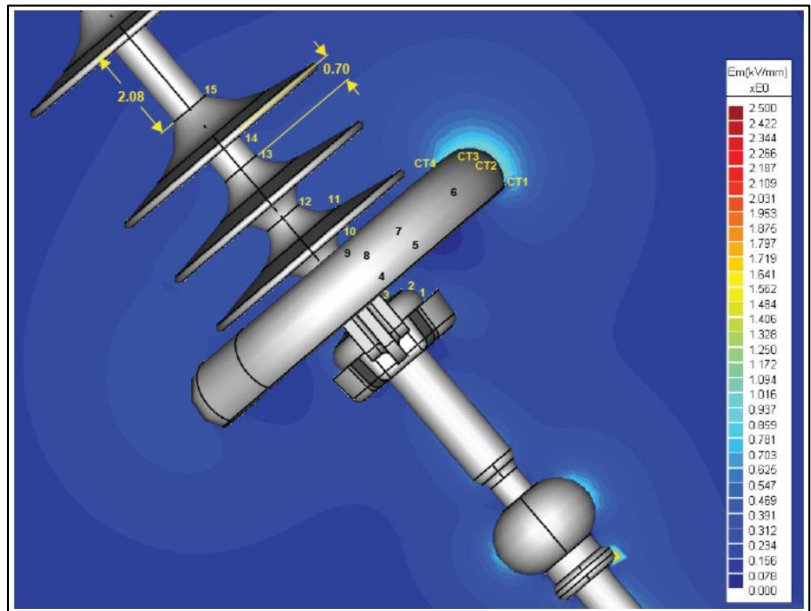


Fig. 10 – Brace Insulator with 8" corona ring

Brace Insulator Stress Data Points																						
Corona Rings		End Fitting			Stacked Shed									Sheath			Corona Ring					
Brace	LP	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	CT1	CT2	CT3	CT4		
8"	6"	0.42	0.29	0.40	0.27	0.14	0.09	0.16	0.24	0.32	0.26	0.26	0.36	0.27	0.24	0.23	1.02	0.96	0.98	0.84		
Case #3		Ave:	0.37												Ave:	0.25			Ave:	0.95		

Table 3A – Case 3

Line Post Insulator: The addition of the 6" Corona Ring onto this insulator, along with the 8" Corona Ring on the brace, provide the ideal corona protection for this braced post assembly. This configuration has the best performance, with no stresses above industry limits on either the end fitting or sheath of the line post.

- Average Stress on the End fitting = **0.14 kV/mm** [down from **0.66 kV/mm** in model #2]
- Average Stress on the Corona Ring Surface = **0.38 kV/mm**
- Average Stress on the Sheath Surface (EF & Shed #1) = **0.22kV/mm** [down from **0.34kV/mm**]

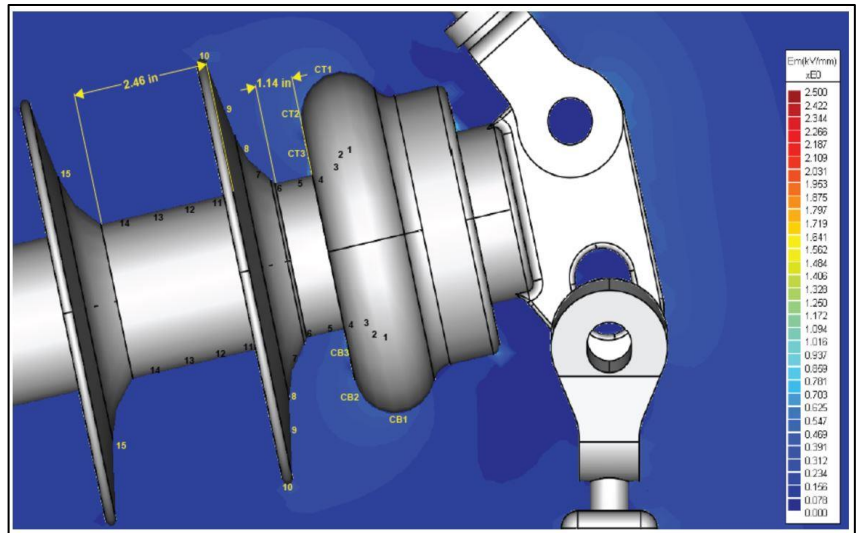


Fig. 11 – Braced Post Stress Plot with 6" Corona Ring

Line Post Insulator Stress Data Points																				
Corona Rings		End Fitting			Sheath			Shed				Sheath				Shed	Corona Ring			
Brace	LP	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	CT1	CT2	CT3	CT4
8"	6"	0.10	0.08	0.24	0.25	0.24	0.17	0.18	0.18	0.17	0.27	0.15	0.14	0.11	0.09	0.09	0.34	0.35	0.46	0.36
Case #3		Ave:	0.14		Ave:	0.22						Ave:	0.12				Ave:	0.38		

Table 3B – Case 3

Configuration #3 – Final Observations of E-Field Analysis

Observations for Brace:

- E-Field stress focused on the top side of the corona ring, facing the outside of the BP.
- Some stress on the connection hardware, but still below the 1.8 kV/mm threshold.
- E-Field stress moves from EF to corona ring.
- 80% improvement from the EF to the corona ring.

Observations for Post:

- E-Field stress is practically eliminated.
- 80% improvement on the EF to the corona ring.
- 50% improvement on the sheath.
- LP compliant to all limits.
- Ideal Corona Protection for the braced post assembly

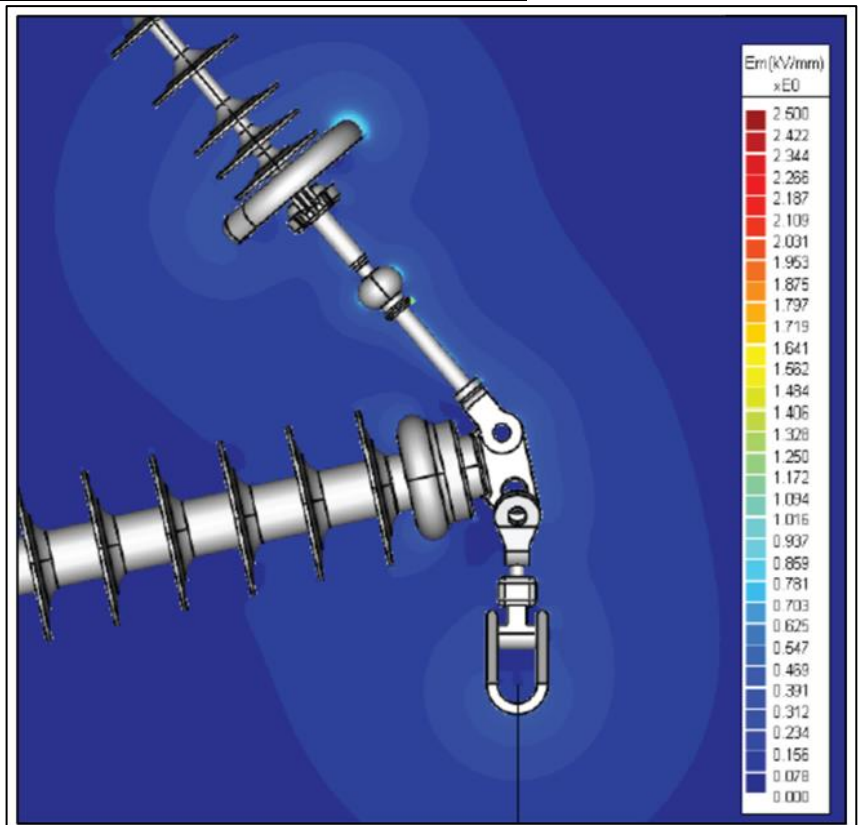


Fig. 12– Braced Post Stress Plot w/ CR on both Brace & Line Post

Conclusion

Historically, the corrective action for this 138kV Braced Post case may have been to just add the 8" corona ring onto the brace insulator, which does improve the performance of the braced post assembly. However, upon reviewing the E-Field results in the tables below, we find that even with the corona ring on the brace, the line post is still potentially vulnerable to stresses at point 4, on the sheath at the end fitting connection point.

Brace Insulator Stress Data Points																							
Corona Rings		End Fitting			Stacked Shed										Sheath			Corona Ring					
Brace	LP	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	CT1	CT2	CT3	CT4			
None	None	1.94	2.11	1.81	0.99	0.56	0.37	0.50	0.65	0.65	0.39	0.29	0.36	0.19	0.17	0.14	-	-	-	-			
Case #1		Ave:	1.95													Ave:	0.17						
8"	None	0.53	0.36	0.52	0.28	0.16	0.09	0.15	0.20	0.32	0.26	0.25	0.35	0.27	0.24	0.23	1.12	0.99	1.02	0.84			
Case #2		Ave:	0.47													Ave:	0.25			Ave:	0.99		
8"	6"	0.42	0.29	0.40	0.27	0.14	0.09	0.16	0.24	0.32	0.26	0.26	0.36	0.27	0.24	0.23	1.02	0.96	0.98	0.84			
Case #3		Ave:	0.37													Ave:	0.25			Ave:	0.95		

Limit of E-Field stress on corona ring and end fitting: < 1.8 kV/mm

Limit of average E-Field stress along the sheath surface: < 0.42 kV/mm (along a 10mm length segment)

Line Post Insulator Stress Data Points																						
Corona Rings		End Fitting			Sheath			Shed				Sheath				Shed	Corona Ring					
Brace	LP	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	CT1	CT2	CT3	CT4		
None	None	0.73	0.94	0.64	0.49	0.45	0.43	0.20	0.17	0.15	0.24	0.19	0.17	0.15	0.12	0.10	-	-	-	-		
Case #1		Ave:	0.77			Ave:	0.46							Ave:	0.16							
8"	None	0.59	0.80	0.58	0.45	0.28	0.26	0.19	0.14	0.12	0.18	0.16	0.15	0.12	0.10	0.08	-	-	-	-		
Case #2		Ave:	0.66			Ave:	0.33							Ave:	0.13							
8"	6"	0.10	0.08	0.24	0.25	0.24	0.17	0.18	0.18	0.17	0.27	0.15	0.14	0.11	0.09	0.09	0.34	0.35	0.46	0.36		
Case #3		Ave:	0.14			Ave:	0.22							Ave:	0.12				Ave:	0.38		

Table 4 – Comparison of 3 Cases

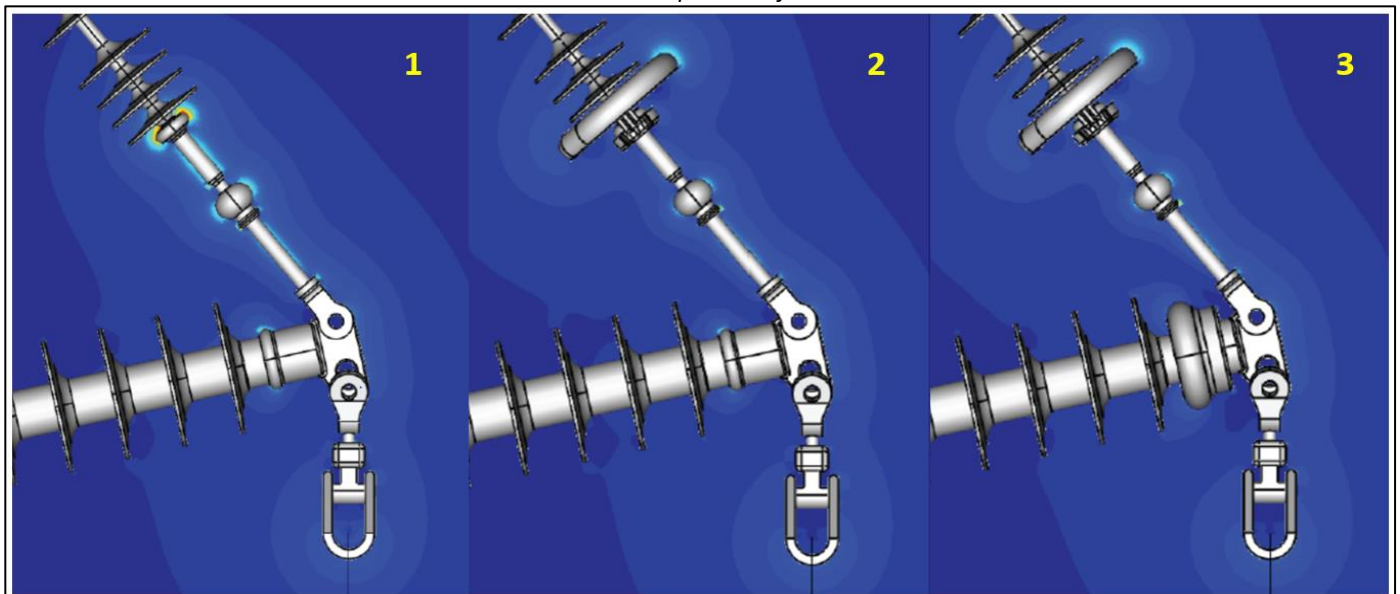


Fig. 13– Braced Post Stress Plot Comparison of Cases 1, 2, & 3

Major Take Away:

- The E-Field Model could be used to quantify with measurable data the differences (variations) from case to case of various corona ring combinations, putting forward solutions that are proven to work and meet customer expectations.
- The hot line fitting displaces the brace corona ring further away from the line post, moving the shielding the brace corona ring may normally have for the line post. Hence the need for the line post corona ring.

Appendix A:



Braced Post Insulator Assembly

138kV Braced Post - Service Design

- No Corona Rings
- As supplied for the field application
- *Braced Post components withheld for INMR Paper*

ASSEMBLY DIMENSIONAL VALUES

Post Section Length (S1)	65.0 in	1651 mm
Insulator Section Length (S2)	66.0 in	1676 mm
Height of Assembly (H)		2286 mm
Length of Brace (B)	98.4 in	2500 mm
Upper Pole Connection Offset (A)*	1.5 in	38 mm
Angle Between Insulators (C)		62 Degrees
Dry Arc Distance	53.6 in	1361mm
Leakage Distance	131.8 in	3348mm

*This connector bracket to be supplied by customer

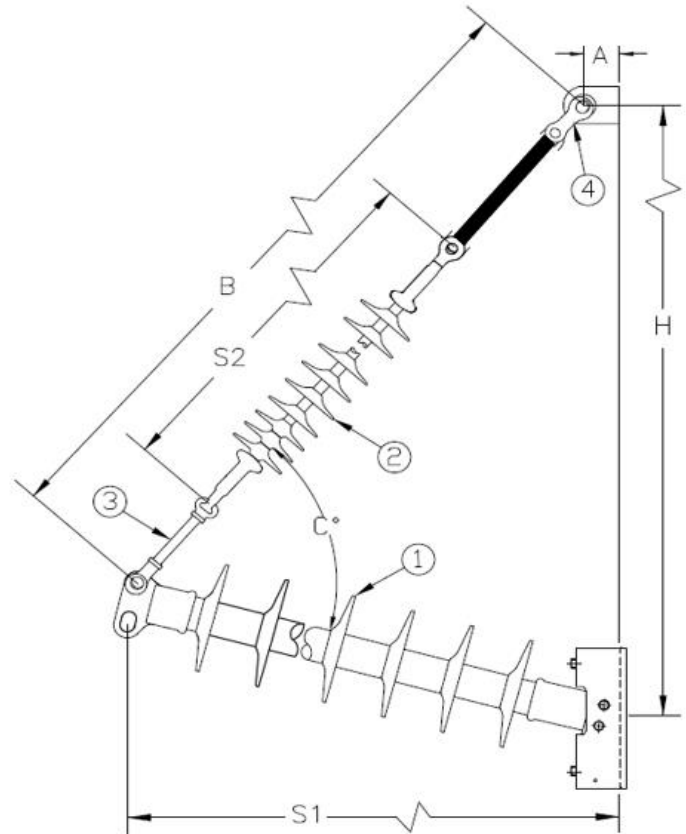
ASSEMBLY ELECTRICAL VALUES*

60 Hz Dry F.O. (Min. Withstand)	505	(474) kV
60 Hz Wet F.O. (Min. Withstand)	466	(370) kV
CIFO+ (Min. Withstand)	877	(779) kV
CIFO- (Min. Withstand)	924	(821) kV

*Values shown are based on minimum electricals for the assembly

ASSEMBLY MECHANICAL VALUES

Maximum Working Vertical Load	11303 lbs	50.3 kN
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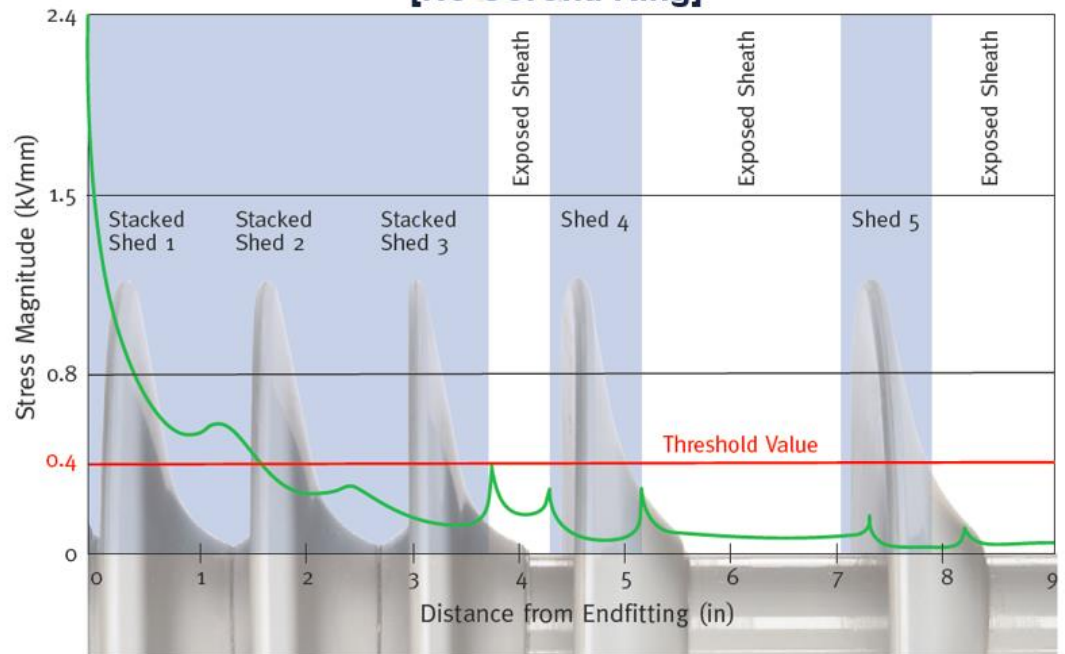


Appendix B:

STRESS PLOT – MPS STACKED SHED FEATURE



Line end sheath protection of Suspension insulator
[No Corona Ring]



< No Premature Aging of the Sheath due to E-Field Stress / Corona

MPS Stacked Sheds protect the sheath of the suspension insulator from electrical stress and corona, preventing the onset of premature aging of the silicone sheath. This protection of the sheath is applicable with and without corona rings. This feature was developed to offset the effects of Water Droplet Corona.

Appendix C:

SMART FIT CORONA RINGS



Corona Ball Feature

- Mini Corona Ring (Approx. 3.5" OD)
- Angles and radii of EF to match geometry of the corona rings
- Easy Installation in Steps 1-2-3