Simulation-Driven Design of Switchgear Components

Case Studies with NX Magnetics

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About me

Recently joined Siemens SI EA R&D in Wendell, NC, USA

23+ years in electrical design, product development and testing

Worked in New Zealand & India

Experience with Power Transformer, MV IT & Sensors, Electric locomotives

6 Patents in the field of IT & Sensors

Member of IEEE PSIM Sensor sub-committee, HVTT

Led several R&D projects

Experience in COMSOL Multiphysics for electromagnetic & electrostatic studies

3 Technical papers in COMSOL Simulation Forum

Current focus: Simulation-driven design to speed up development

Outside work: motorcycle riding & pencil sketching

Introduction

Simulation is a vital tool in the switchgear design and development process. It enables engineers to analyze electrical, thermal, and mechanical performance under various operating conditions—without relying on physical prototypes. Through simulation, potential design issues can be identified early. This approach reduces development time and cost, enhances product reliability, and supports compliance with industry standards.

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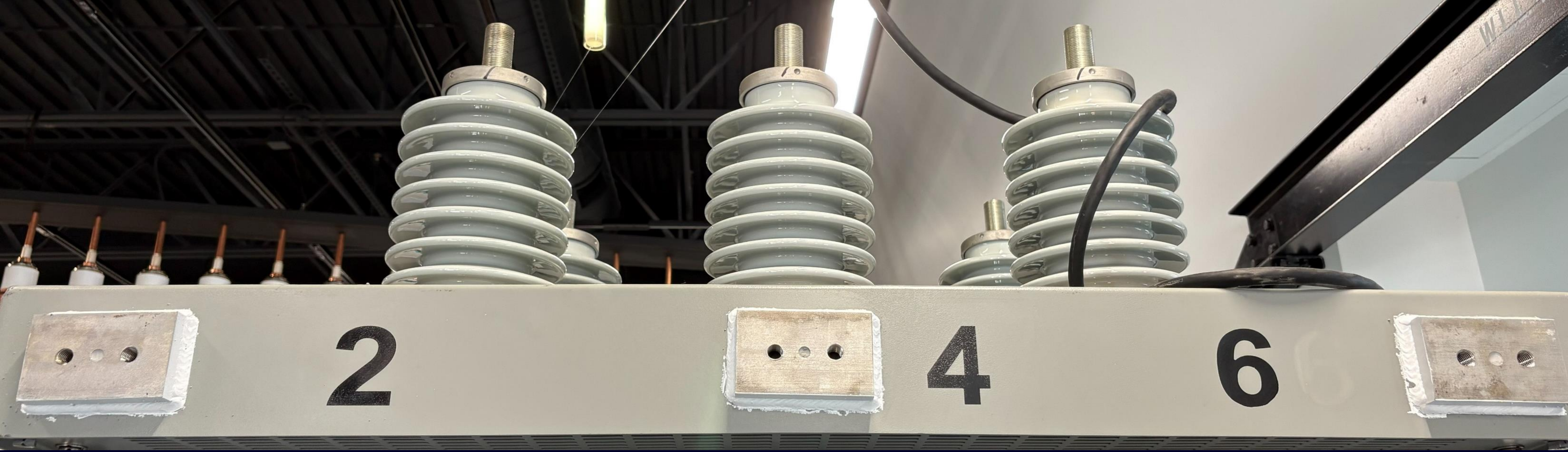
Simulation-Driven Designs

Two case studies are presented to demonstrate simulation-driven optimization for switchgear reliability. NX Magnetics module is used for the simulation study and results are validated against available measurement data.

- Case Study 1: Bushing Conductor optimization considering the Skin Effect
- Case Study 2: Geometry optimization for Outdoor Cutout



Case Study 1
Bushing Conductor Optimization

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Bushing Conductor Optimization

Simulation Study of Bushing Conductor

Presently a solid copper conductor is used as bushing conductor. Due to skin effect the current distribution is not uniform and material is under utilized. Scope of simulation study is as below.

- Current density distribution in presently used solid conductor.
- Temperature rise during steady state condition.
- Geometry optimization of conductor cross section for better material utilization while maintaining the temperature rise condition.

Geometry optimization will present options which will be evaluated in view of commercially available shapes, material and manufacturing costs.

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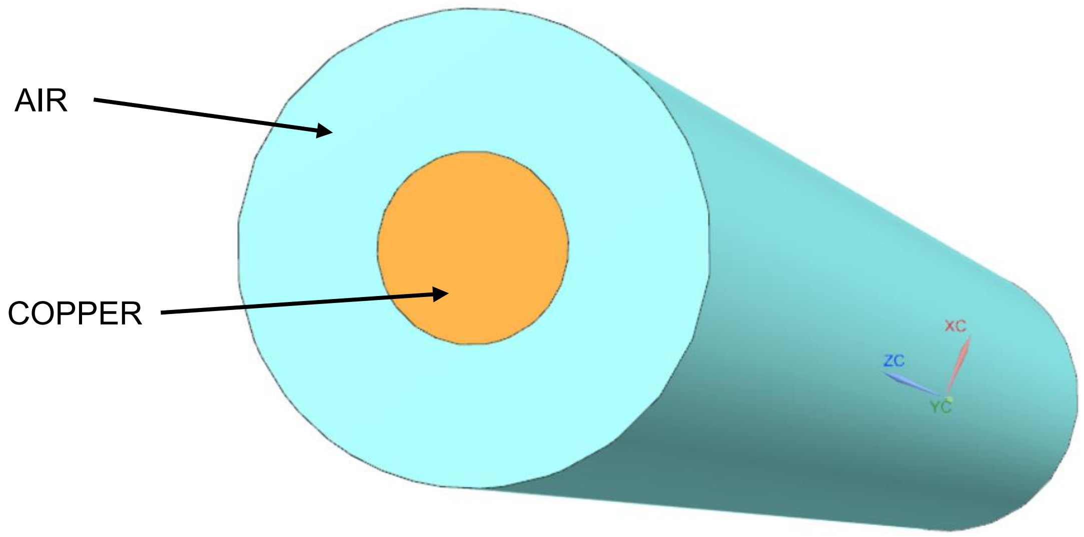
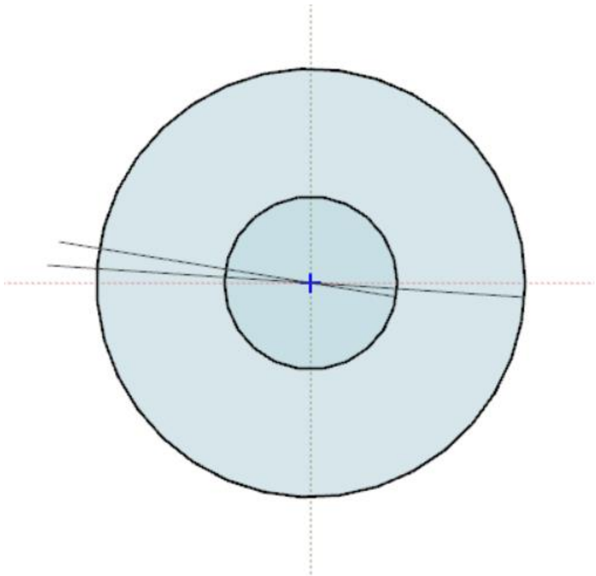
Bushing Conductor Optimization

Geometry & Model Simplification

First simulation is created for establishing the base line. A conductor is modelled as presently used copper conductor inside a porcelain bushing with air pocket around it. Following simplification are considered for modeling.

- Approximation of air around conductor, simplified geometry.
- Heat transferred is limited by porcelain material of structure around copper conductor.
- Copper resistivity dependance on temperature is included in material property.





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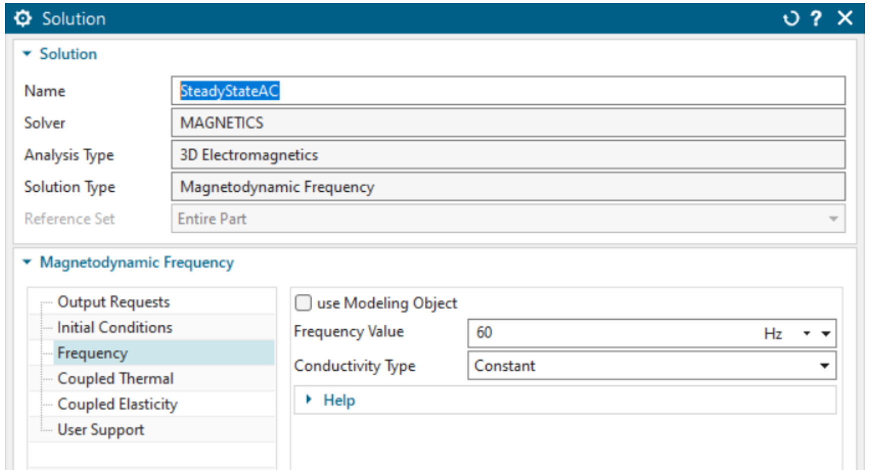
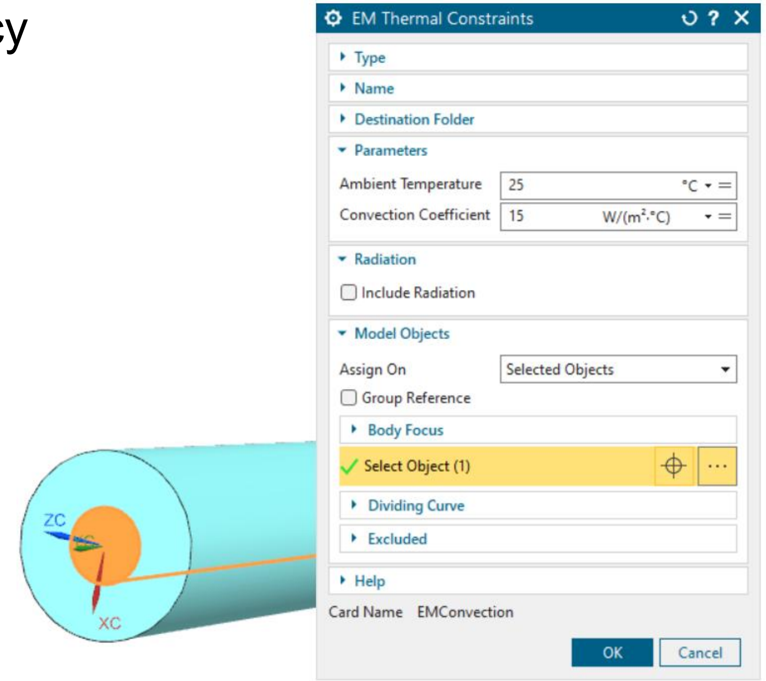
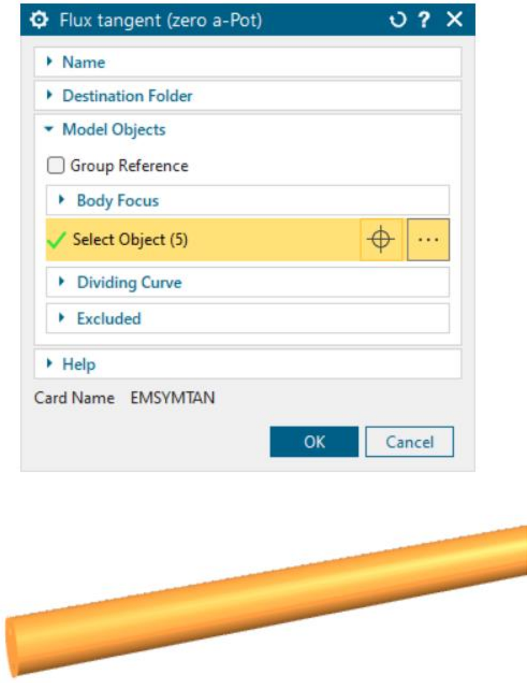
Bushing Conductor Optimization



Boundary Conditions

Flux Tangent	All outer surfaces
Thermal EM	Only at Air-Copper interaction
Study	Magnetodynamic Frequency
Frequency	60 Hz





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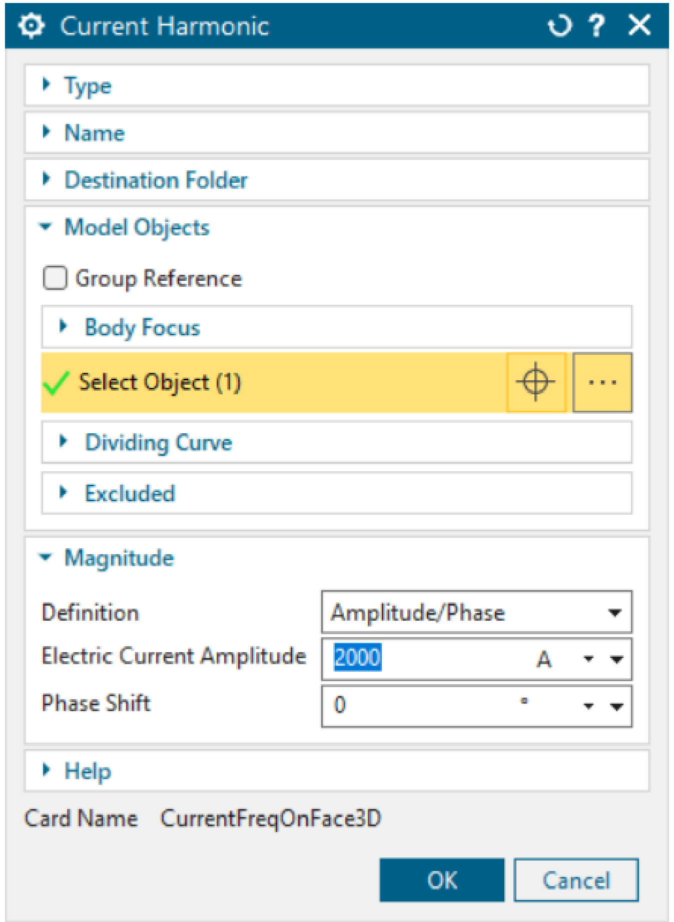
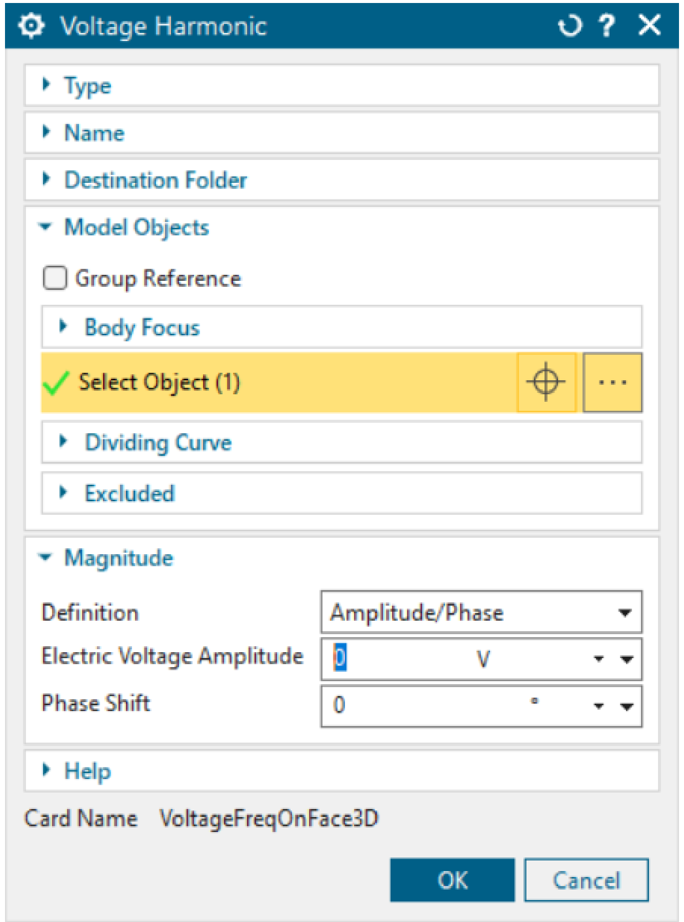
Bushing Conductor Optimization

Load Conditions

Current Load	2000A
Voltage Load	0V





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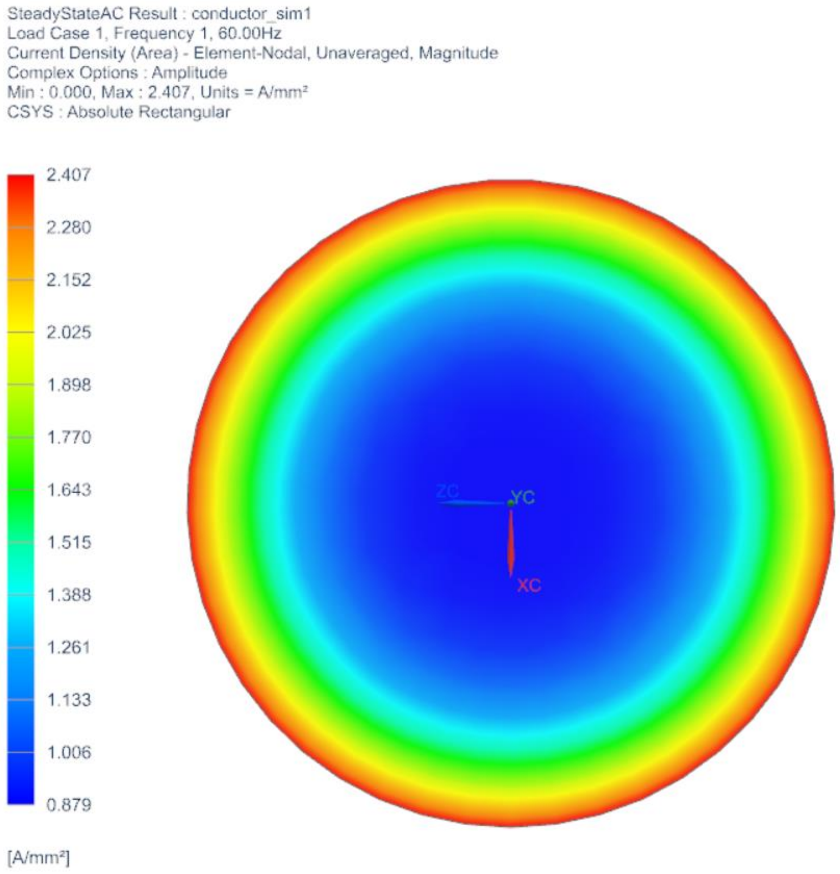
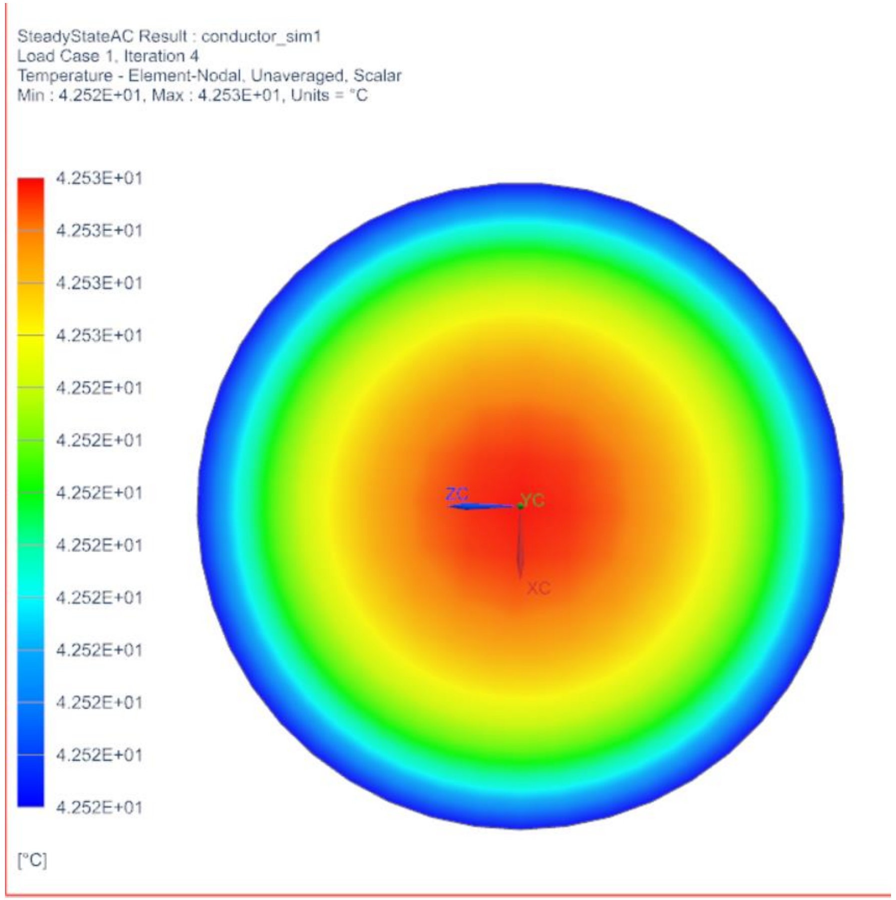
Bushing Conductor Optimization

Results



CURRENT DENSITY PLOT



TEMPERATURE PLOT

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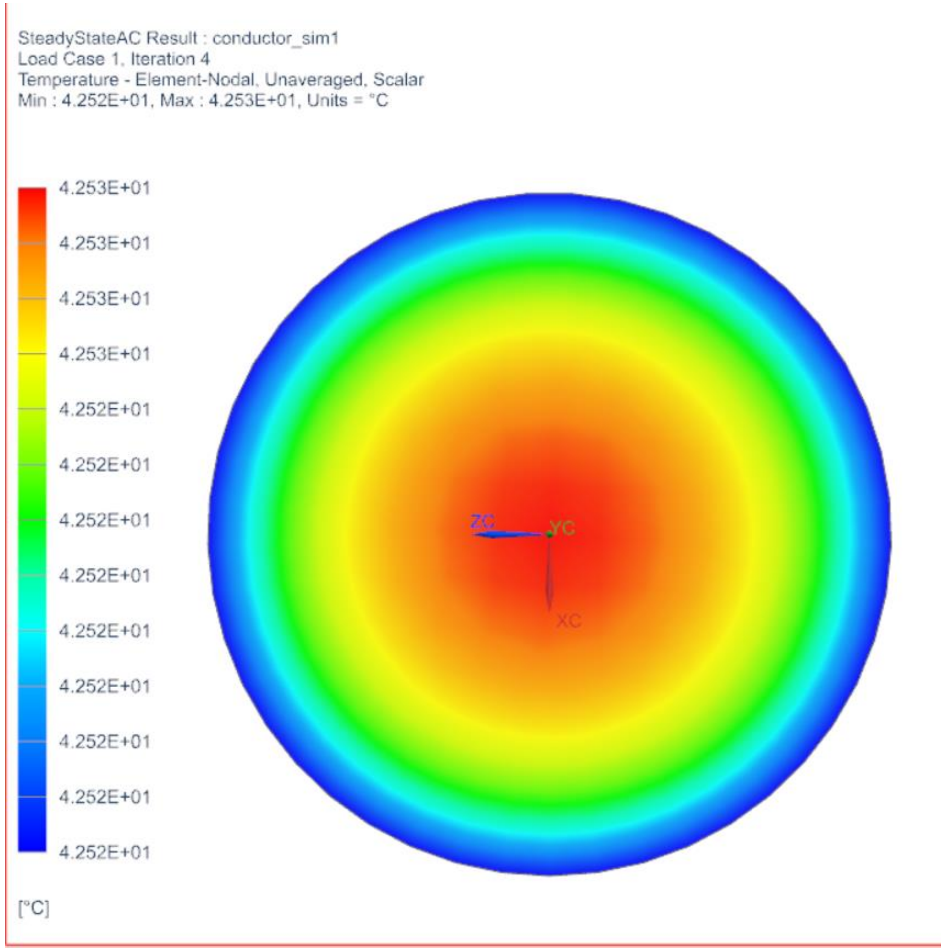
Bushing Conductor Optimization

Tunning with Test Data

Base simulation results are closing matching with actual test data. Differences due to location of measurement probe and bushing conductor surrounding and actual heat convection.



TEMPERATURE PLOT

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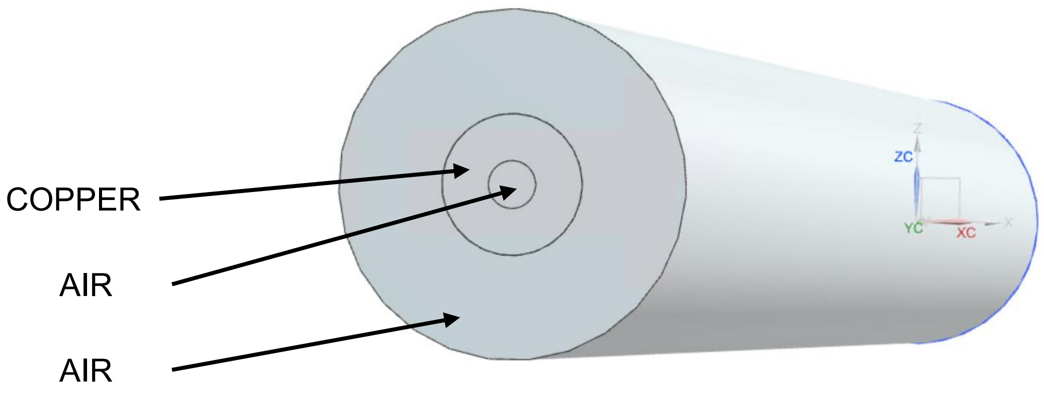
Conductor Optimization Iteration

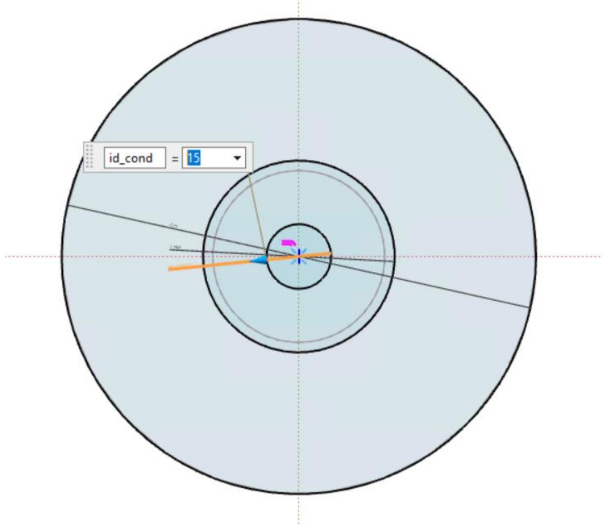
Bushing Conductor Optimization

Geometry and model simplification

Now a Hollow copper conductor is used as bushing conductor to better utilize the material due to skin effect. A parametric study is done with variation of inner air pocket diameter.

- A cavity for air pocket is created at the inner side of conductor.
- The diameter of this inner region is varied by using parametric variation of conductor.prt file.
- An optimum cross section is found with acceptable temperature rise of conductor in steady state condition.





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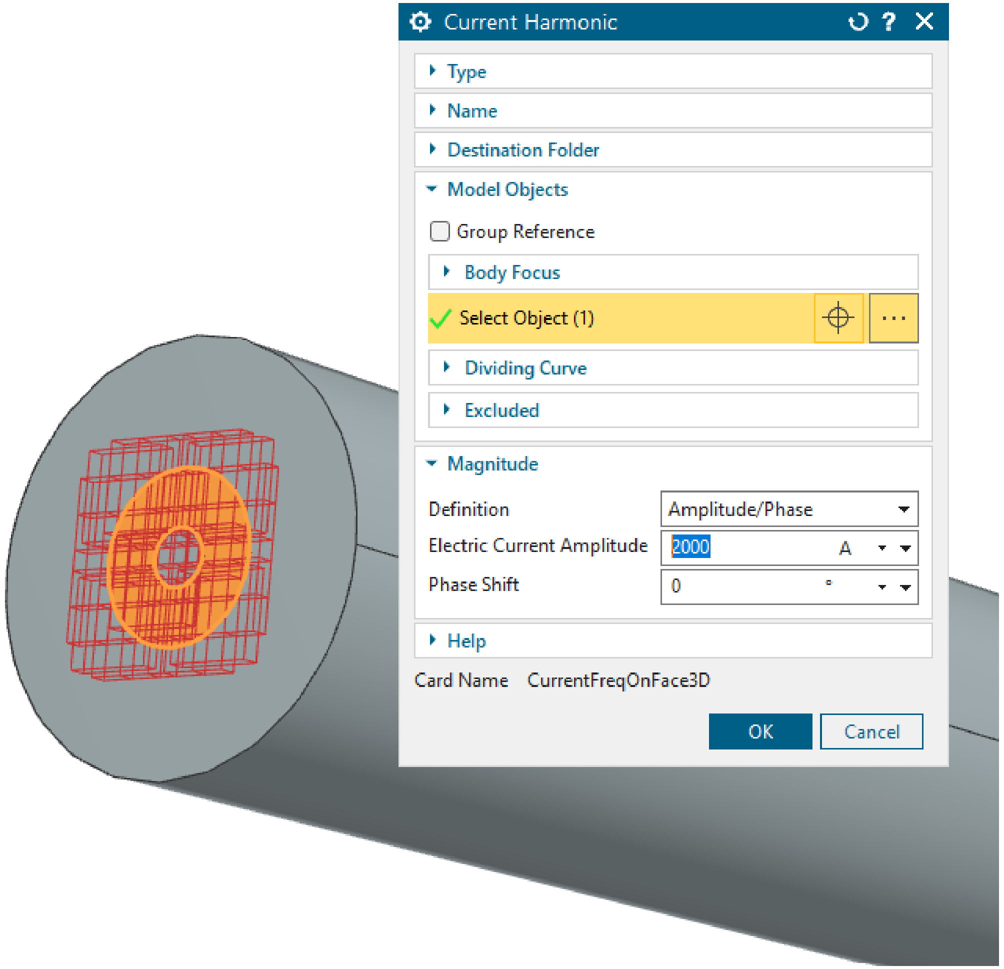
Bushing Conductor Optimization

Load & Boundary Conditions

Current Load	2000A applied at COPPER
Voltage Load	0V applied at COPPER



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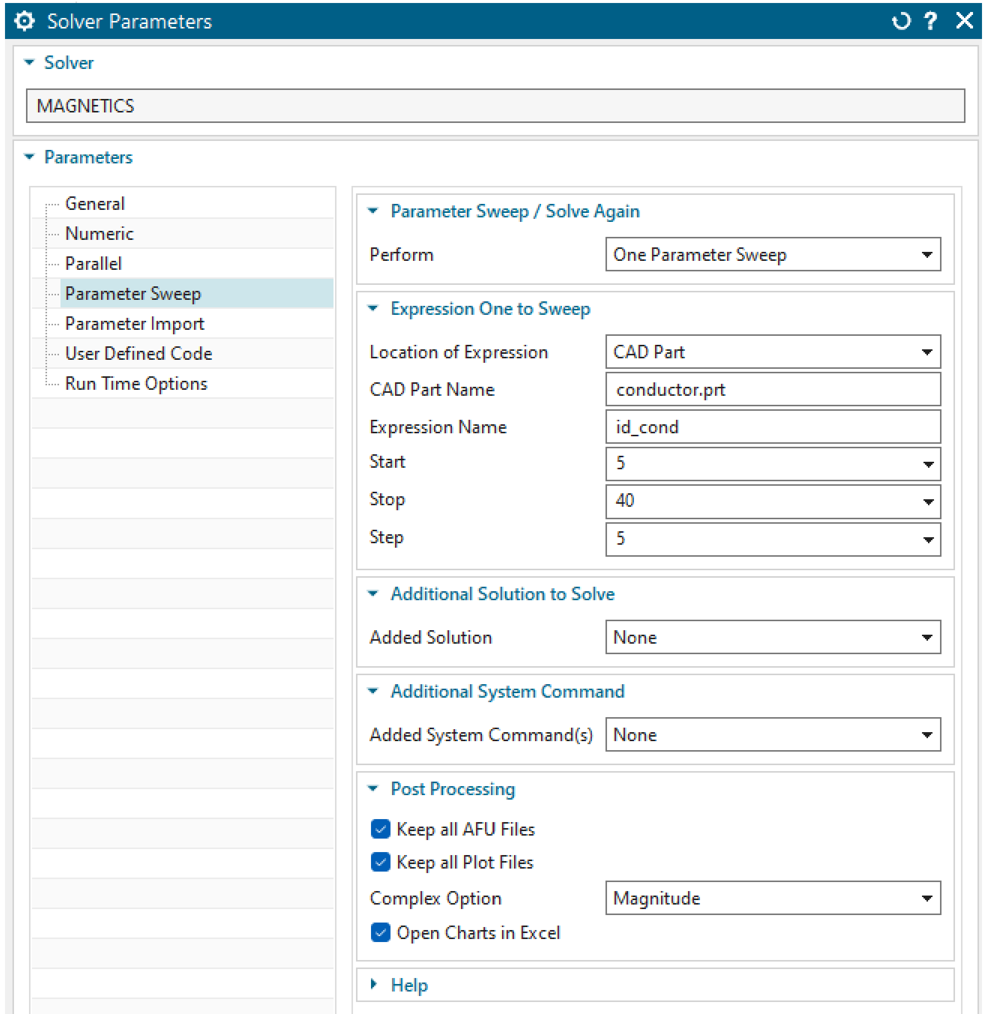
Bushing Conductor Optimization

Parametric variation of inner air cavity

Start	5 mm
Stop	40 mm
Step	5 mm



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Results

Bushing Conductor Optimization

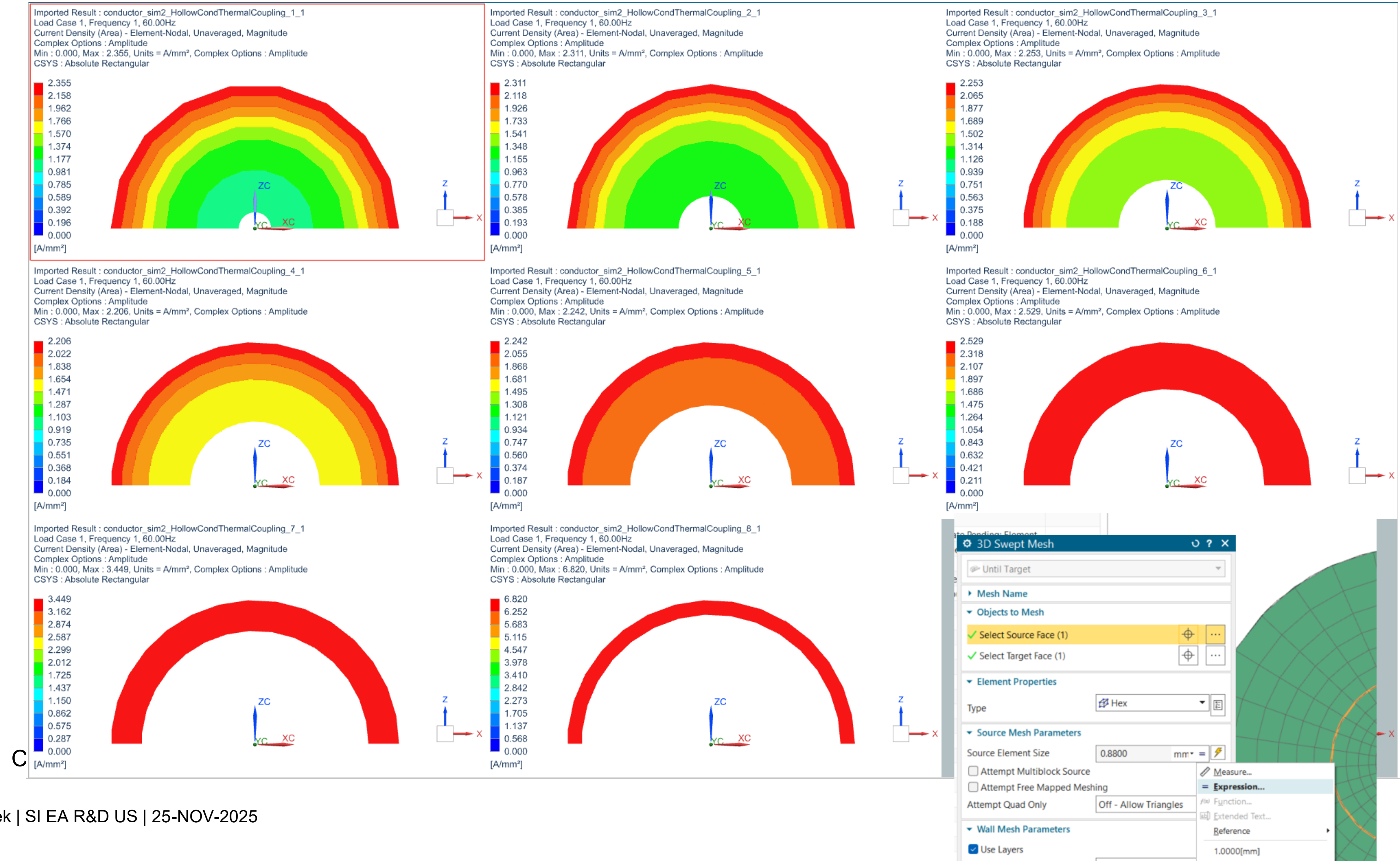
Current Density Plot for Hollow Conductor

Parametric sweep for Cavity ID

Start - 5 mm

Stop - 40 mm

Step - 5 mm

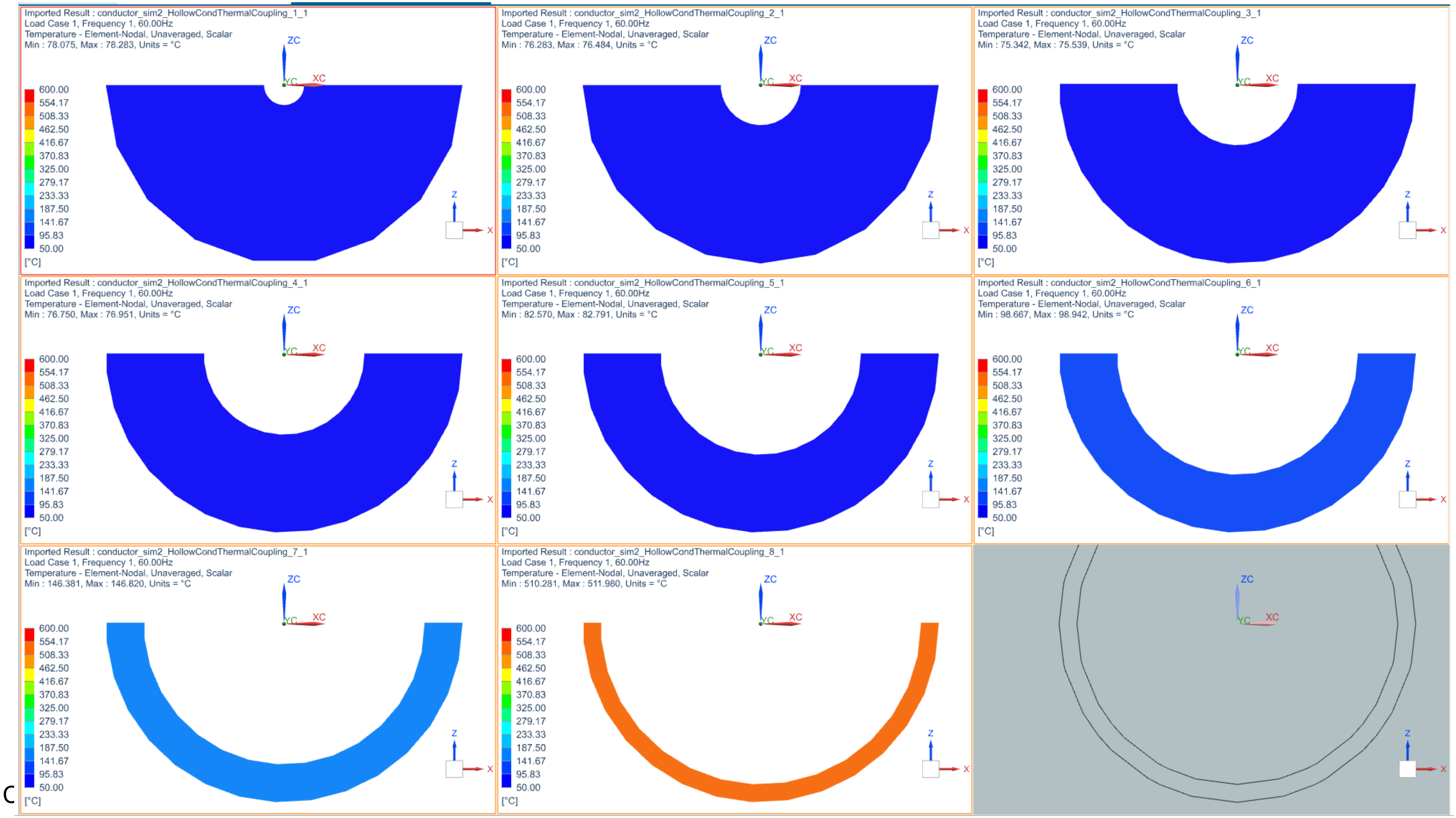


Bushing Conductor Optimization

Temperature Plot for Hollow Conductor

Parametric sweep
Cavity ID

Start - 5 mm
Stop - 40 mm
Step - 5 mm



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Bushing Conductor Optimization

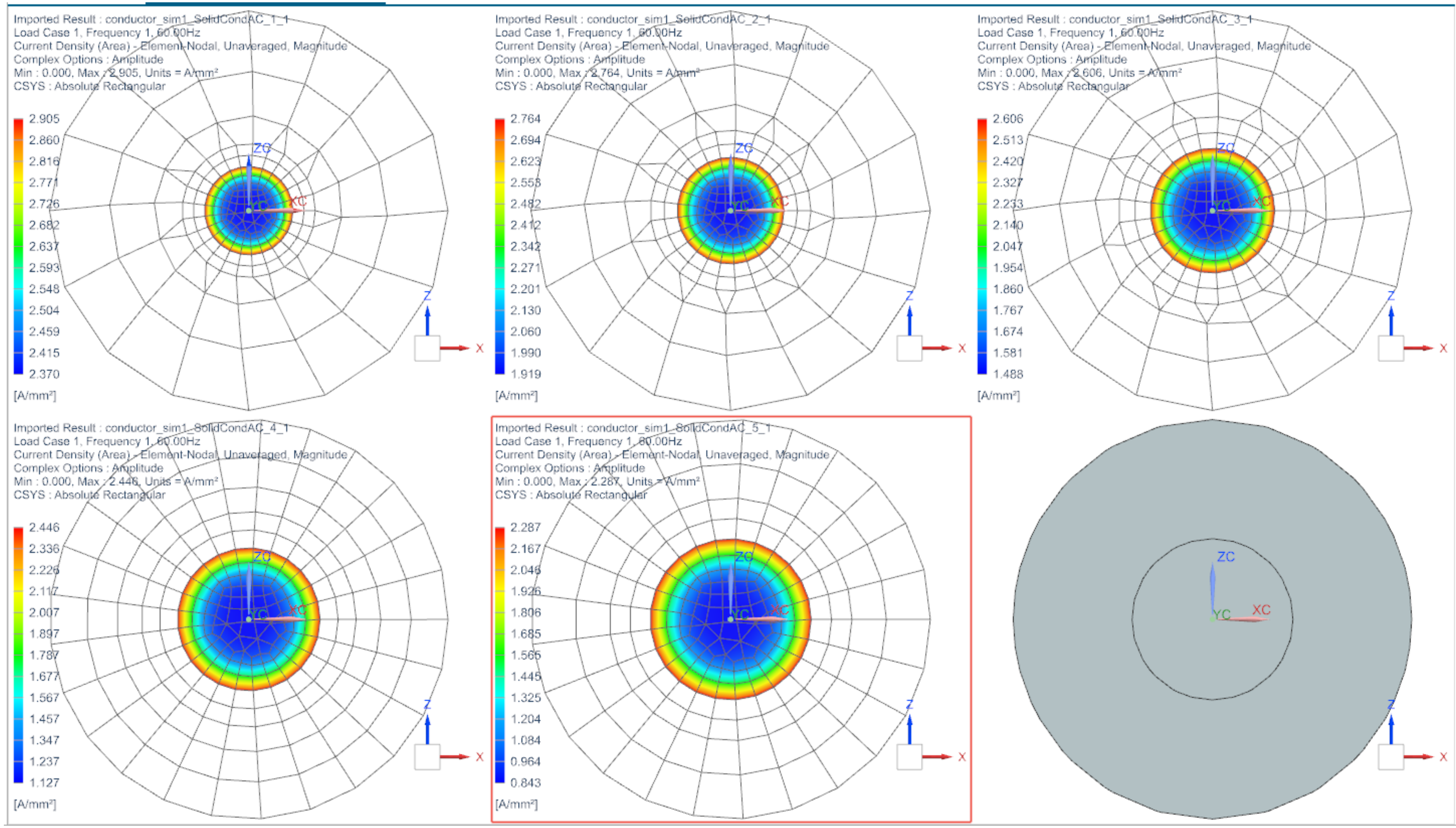
Current Density Plot for Solid Conductor

Parametric sweep for Conductor OD

Start - 25 mm

Stop - 45 mm

Step - 5 mm



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Bushing Conductor Optimization

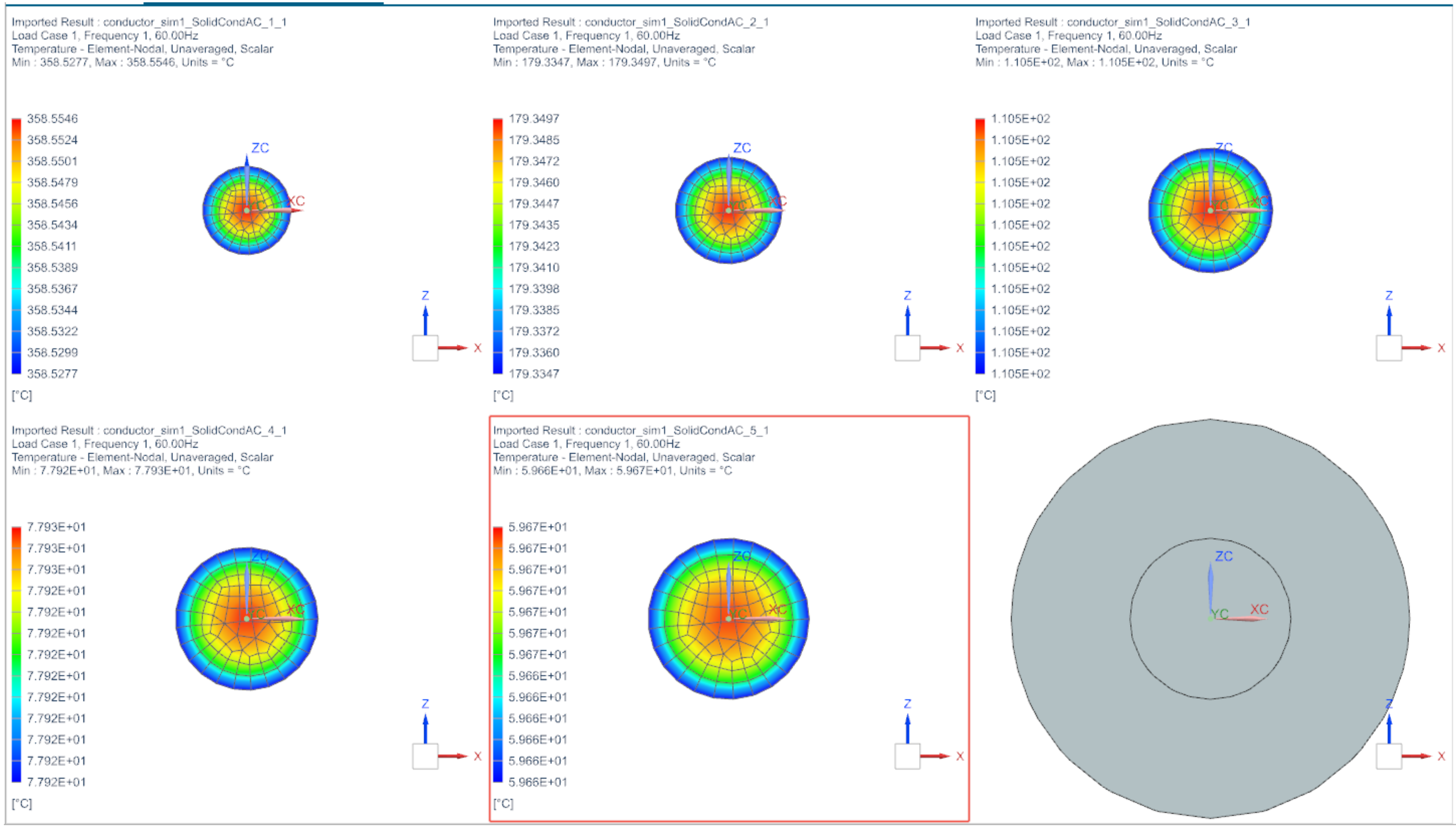
Temperature Plot for Solid Conductor

Parametric sweep for Conductor OD

Start - 25 mm

Stop - 45 mm

Step - 5 mm



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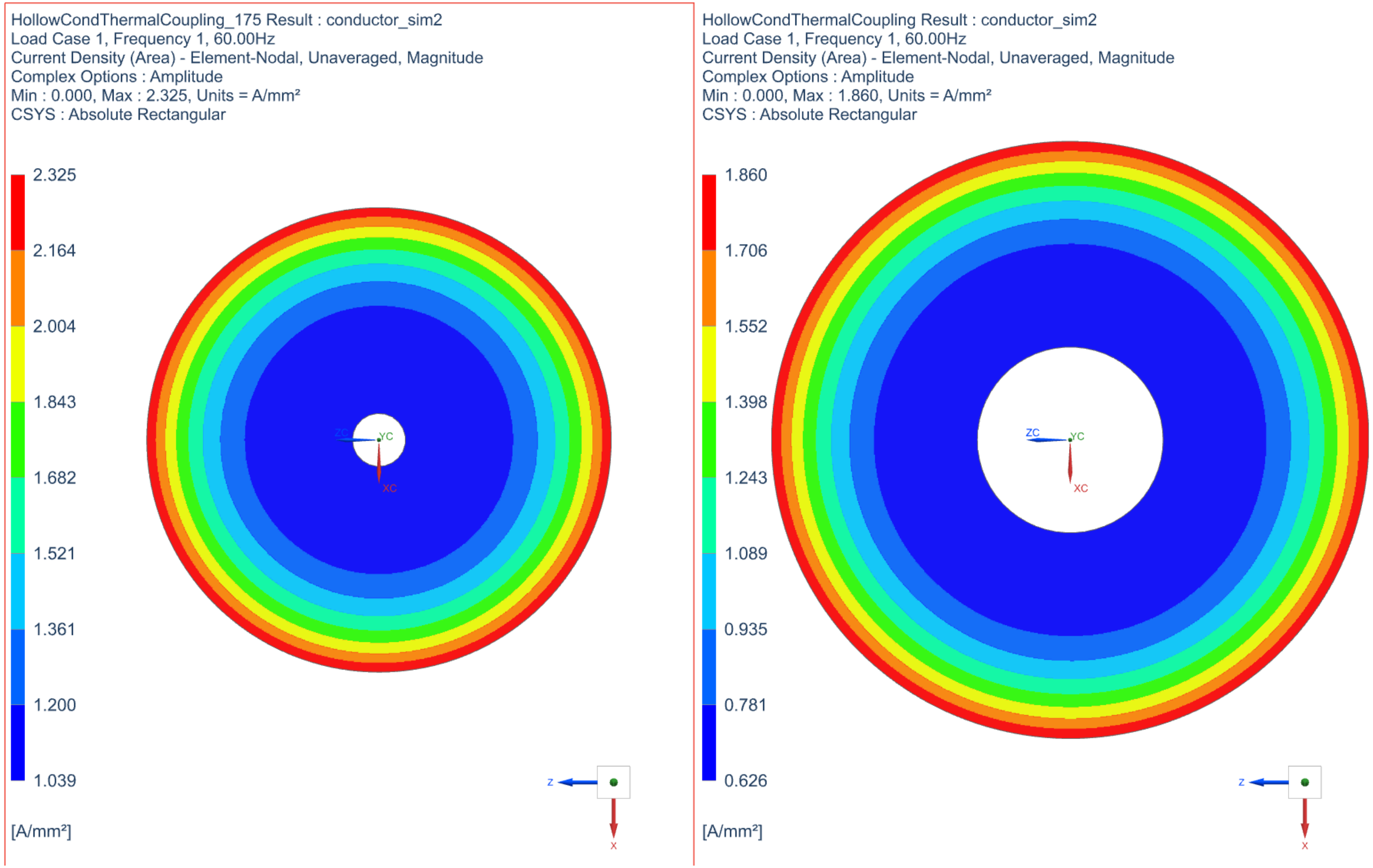
Bushing Conductor Optimization

Current Density Plot for Hollow Conductor & same thickness

Parametric sweep for Conductor OD

Start – 2.25”

Stop – 1.75”



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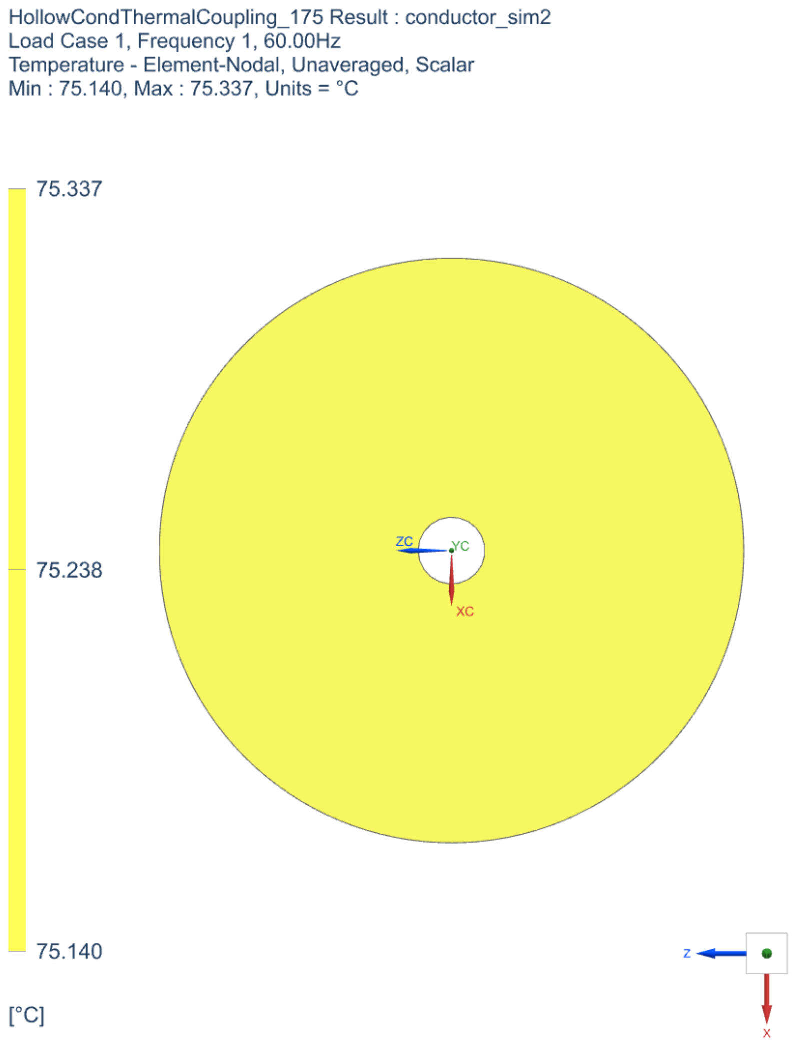
Bushing Conductor Optimization

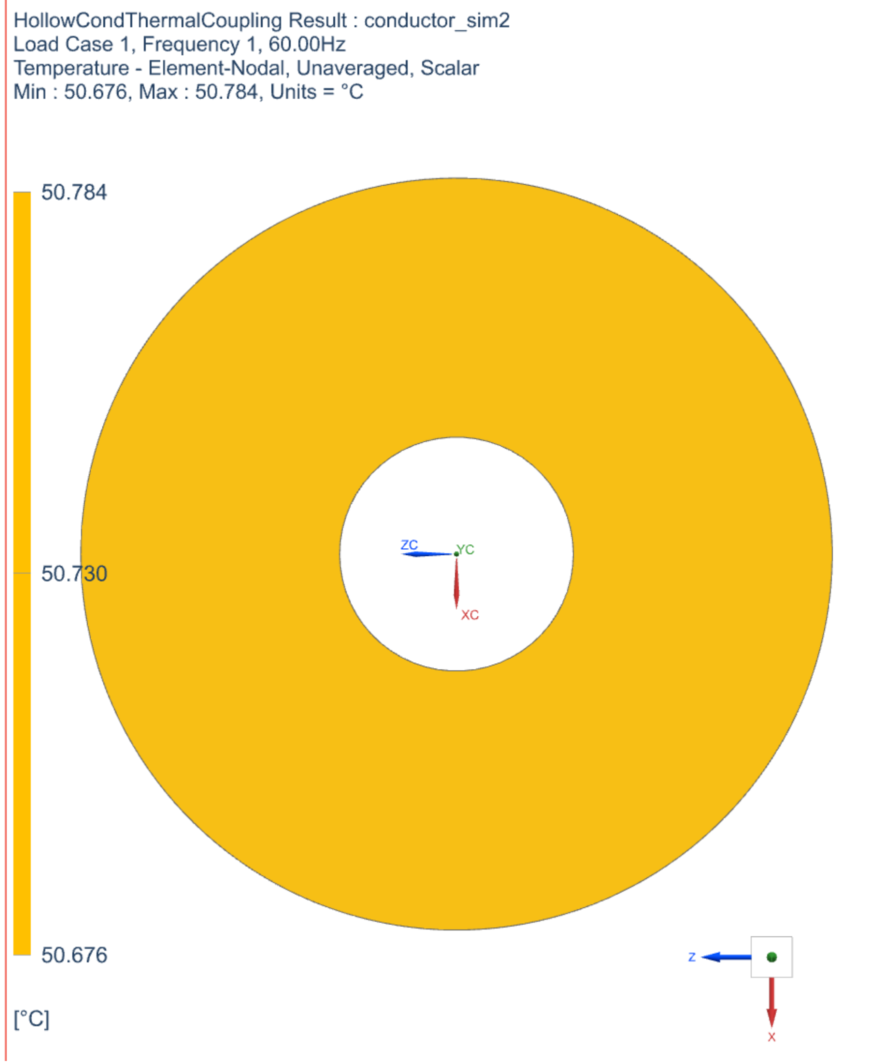
Temperature Plot for Hollow Conductor & same thickness

Parametric sweep for Conductor OD

Start – 2.25”

Stop – 1.75”





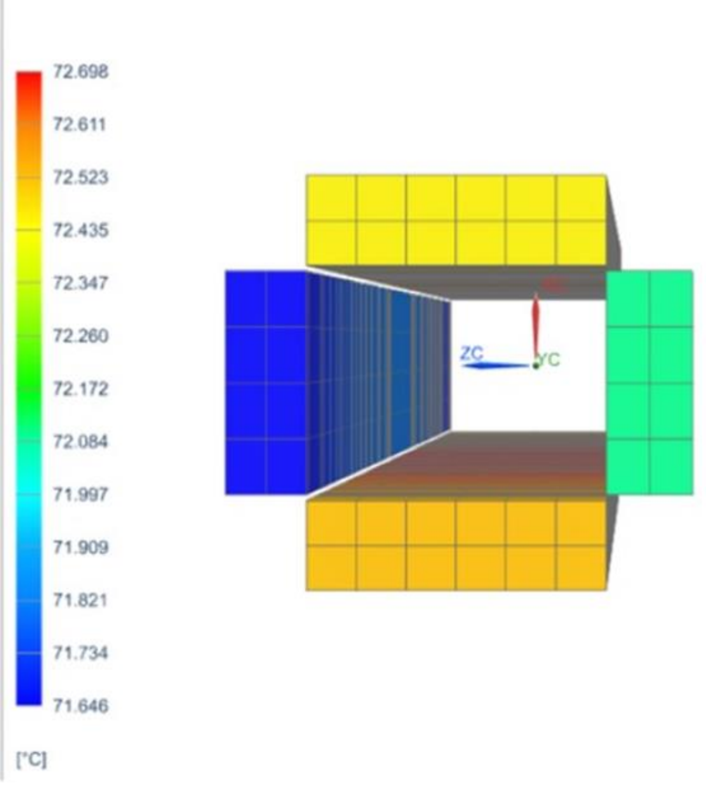
Bushing Conductor Optimization

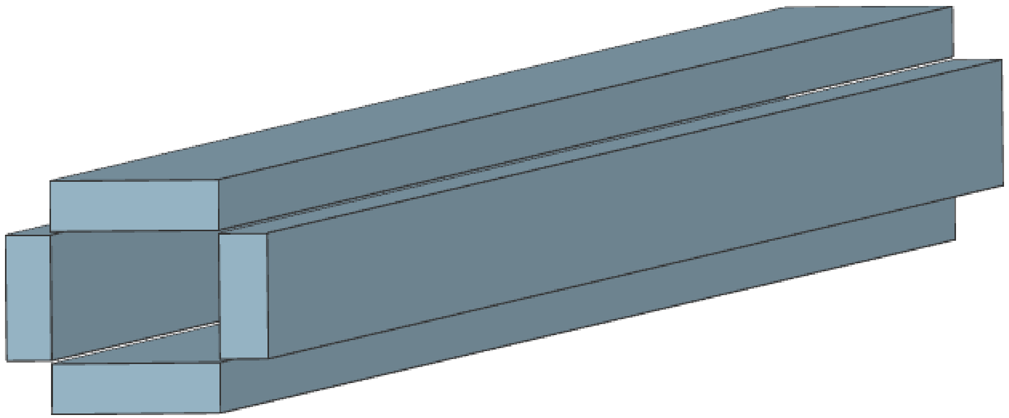
Temperature Plot for Copper Flats

Copper flats are used in simulation to estimate the temperature rise. The copper flats dimensions are taken such that they can be accommodated in the porcelain bushing structure.

Max Temp 72.7 ^{0}C

Any other shape can be further simulated.





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Summary and Conclusion

Bushing Conductor Optimization

Summary & Conclusion

- In simulation study, a base line is created for current density & temp rise in a bushing conductor. The temp rise value is compared with test measurement. Current density & Temperature plots for parametric study is completed for hollow conductors inner dia, conductor dia, and with copper flats.
- The base line can be further tweaked with experimental results to match the temperature measurements. The inconsistencies in temp plot may be caused by mesh sizes of changing air cavity and dur to different location of temp probes during actual testing.
- Parametric study shows that material reduction can be achieved with reduced conductor cross-section while complying to temperature rise criteria.
- Simulation can be further done with any other suggested cross-section geometry and with any 3D shape suggested by user.

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Case Study 2
Outdoor Cutout Geometry Optimization

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Outdoor Cutout Geometry Optimization

Simulation Study of Outdoor Cutout

According to C37.62 Clause 7.3.1, the rated insulation levels for cutout-mounted FIs are based in part on the rating of the cutout support.

System-Level Rating Approach

The overall insulation rating of the assembly is not just based on the cutout alone. It's derived from the combination of:

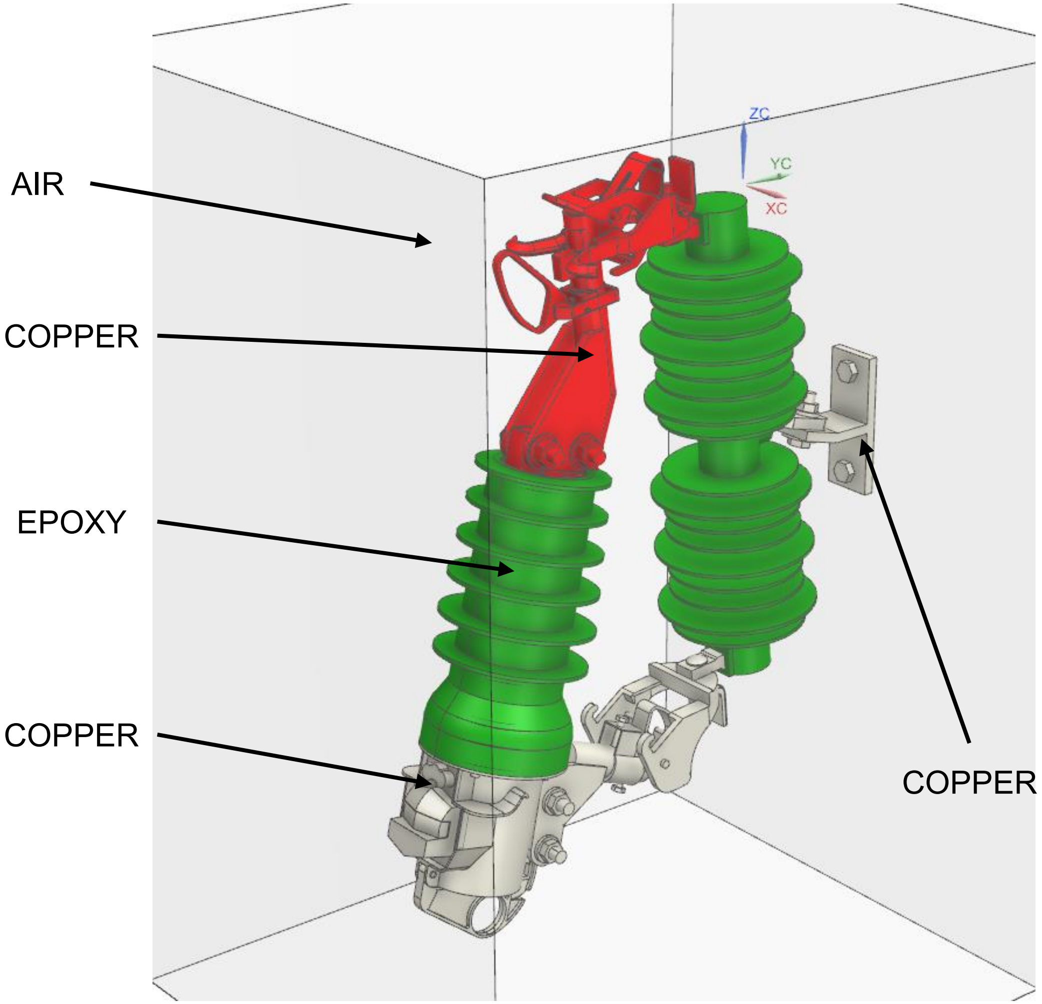
- The cutout insulation capability
- The insulator insulation capability
- Spatial positioning of all parts relative to each other

The final system rating is limited by the weakest component and components arrangement in the assembly.

Outdoor Cutout Geometry Optimization

Geometry & model simplification

First simulation is created for establishing the base line. The detailed outdoor structure is used for electrostatic study. For simplification, only copper, epoxy and air is considered in study.



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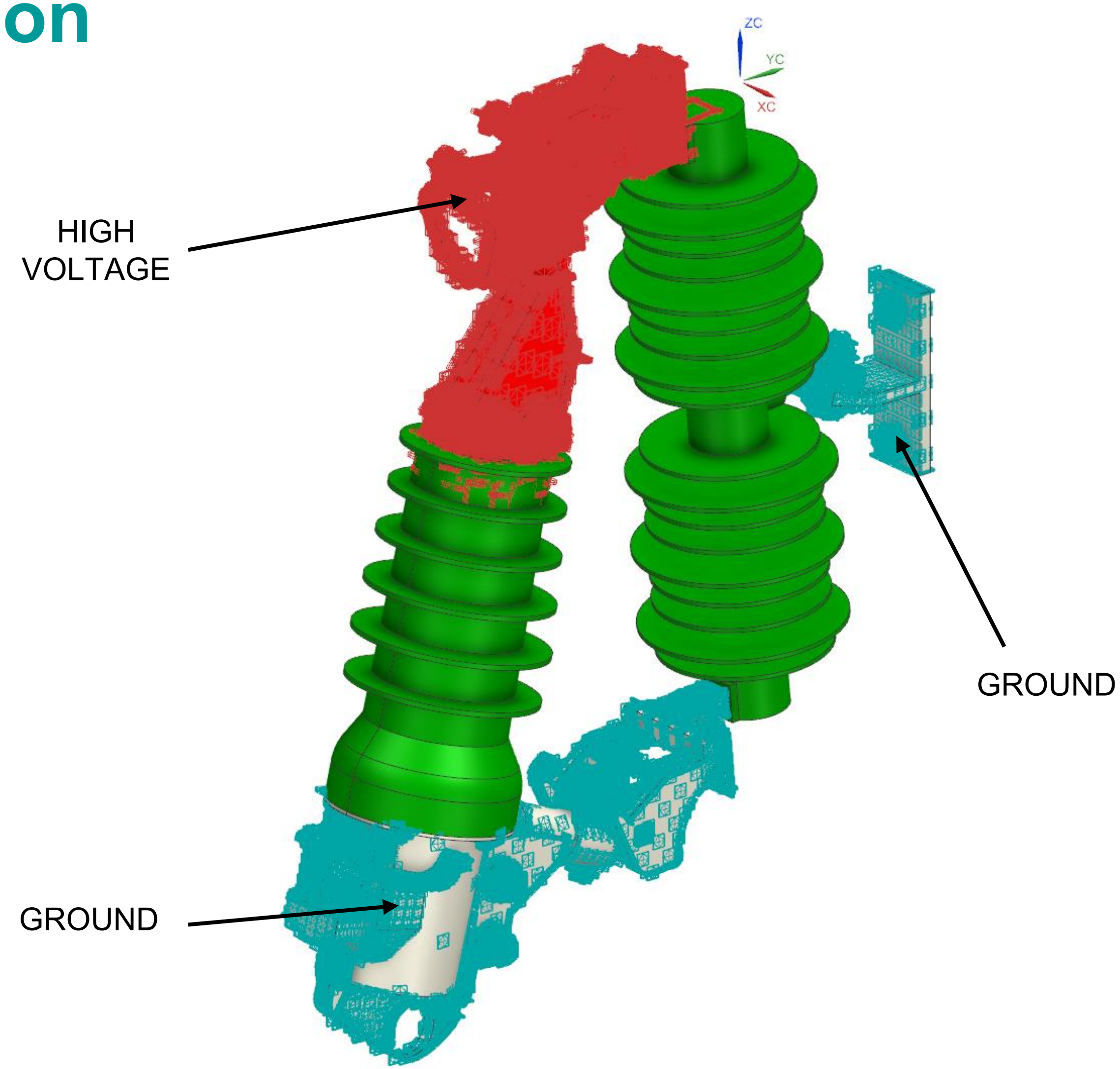
Outdoor Cutout Geometry Optimization

Load assignment for OPEN Condition

Voltage Loads

High Voltage	60 kV
Ground	0V



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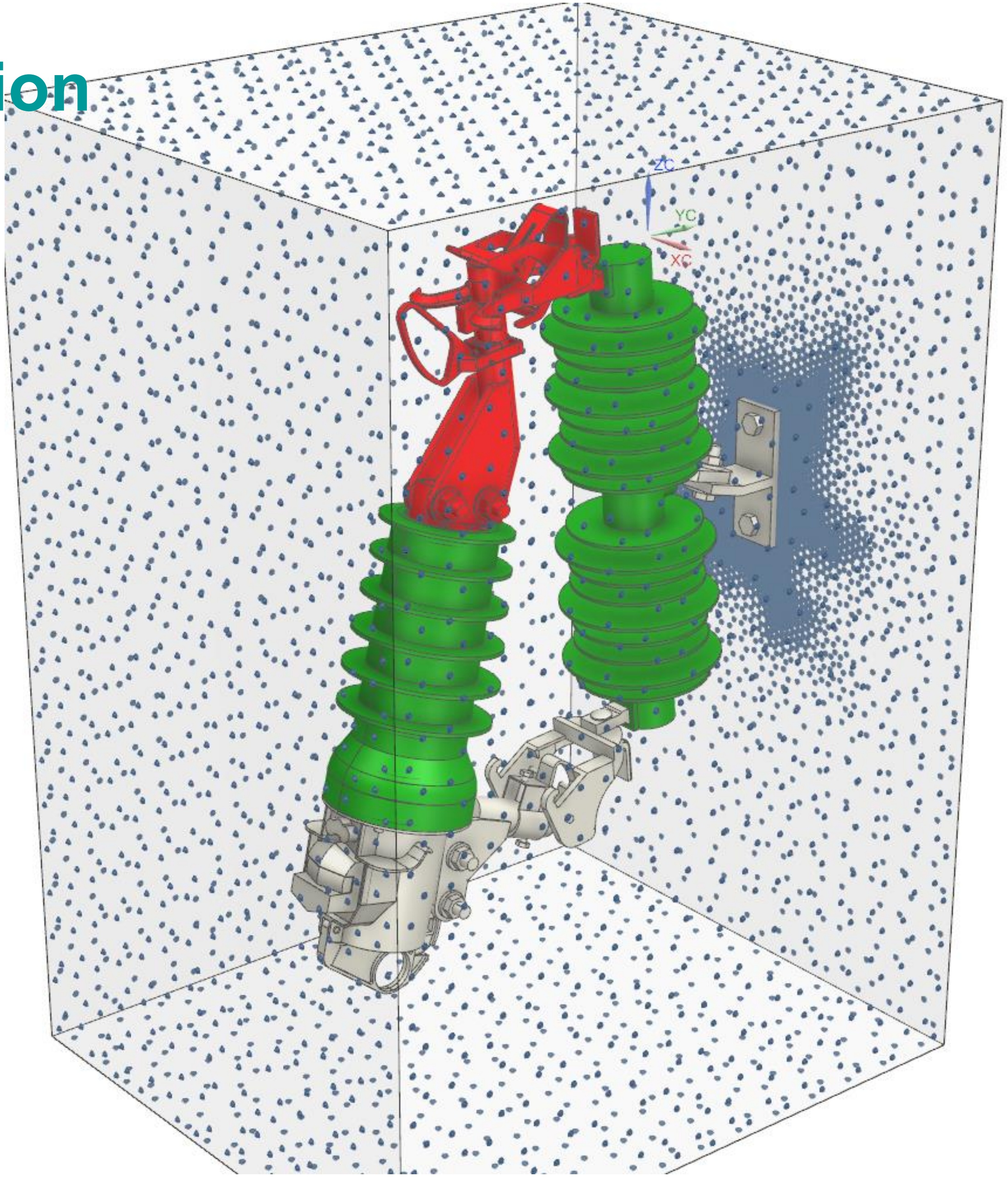
Outdoor Cutout Geometry Optimization

Boundary assignment for OPEN Condition

Boundary Assignment	
PEC Boundary	All outer surfaces
Study	Magnetodynamic Frequency
Frequency	60 Hz



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Results

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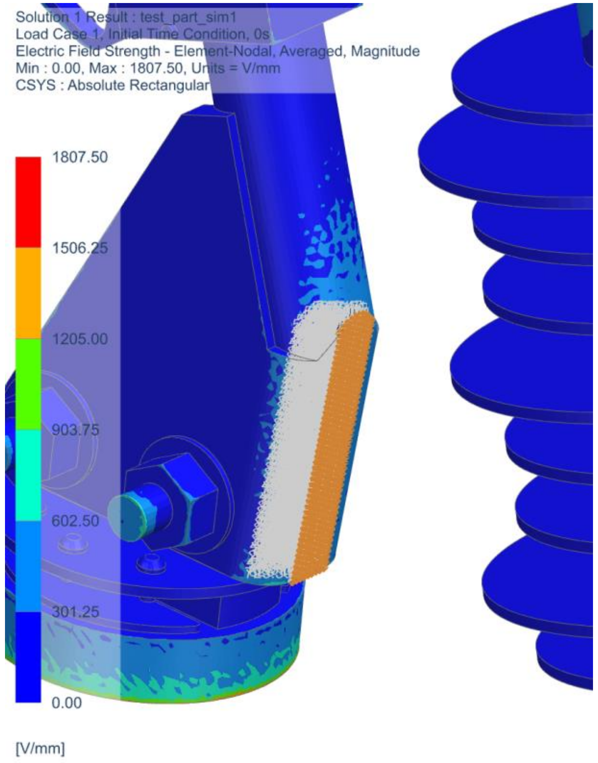
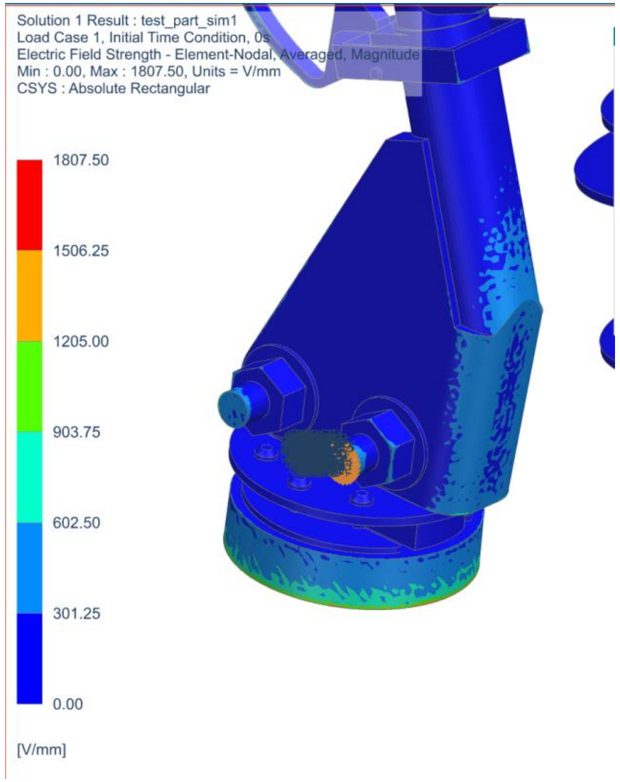
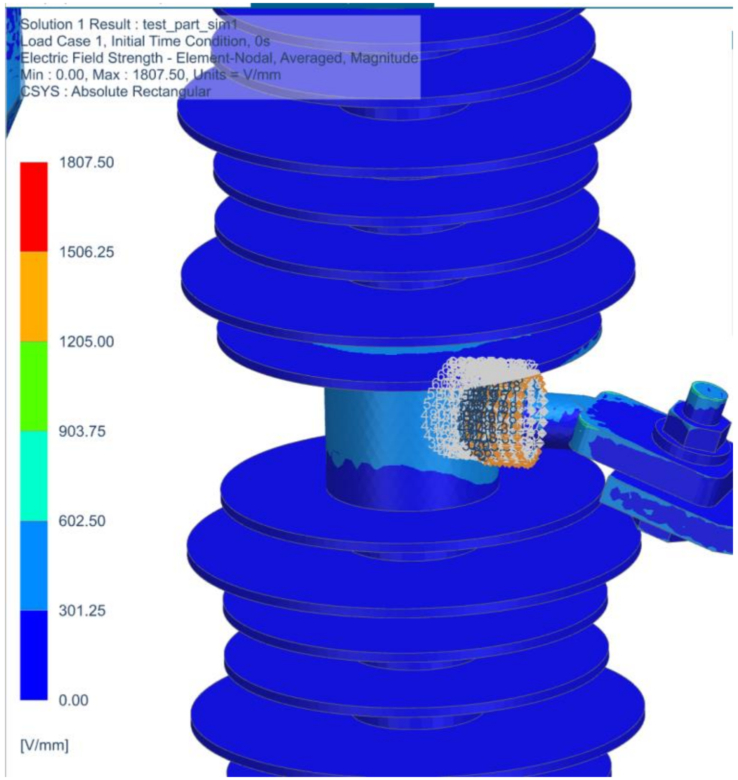
Outdoor Cutout Geometry Optimization

Electric Field Plot

High E-Field is observed at high voltage bracket, hardware and near mounting bracket.







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Geometry Optimization

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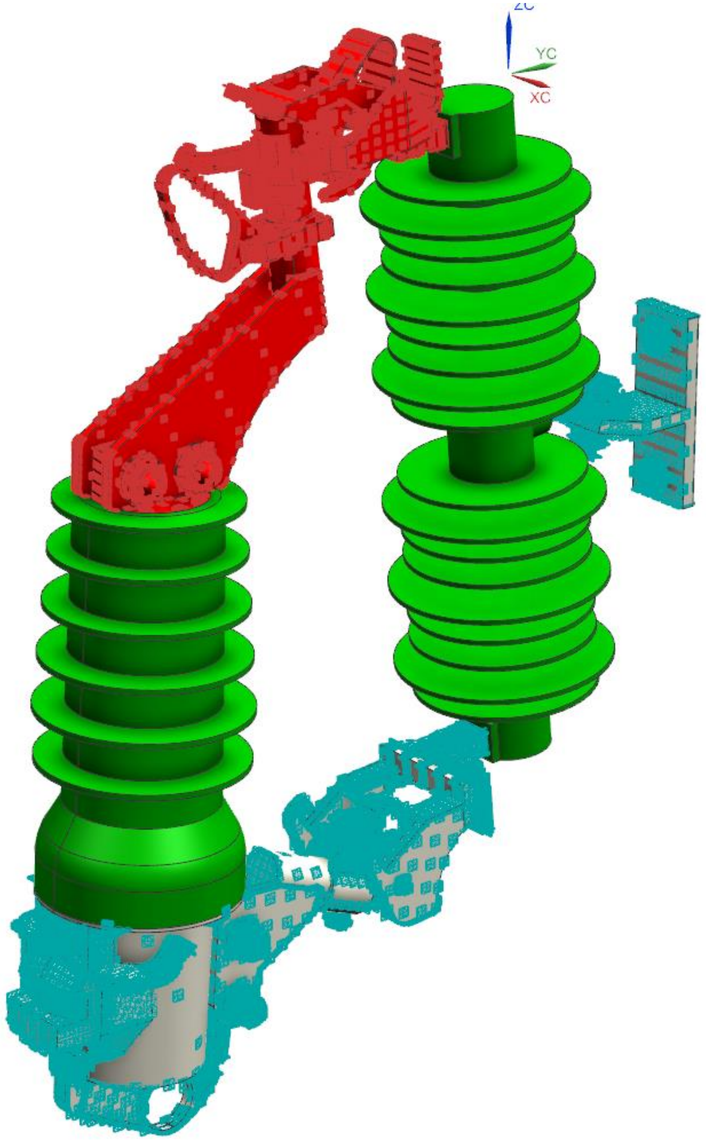
Outdoor Cutout Geometry Optimization

Geometry Variation

Two design variations are tried in simulation study.

For first design iteration, bracket face towards insulator is modified to achieve higher clearance. For second design variation, Cutout body is rotated away from the insulator to achieve higher even clearance from the grounded mounting bracket.



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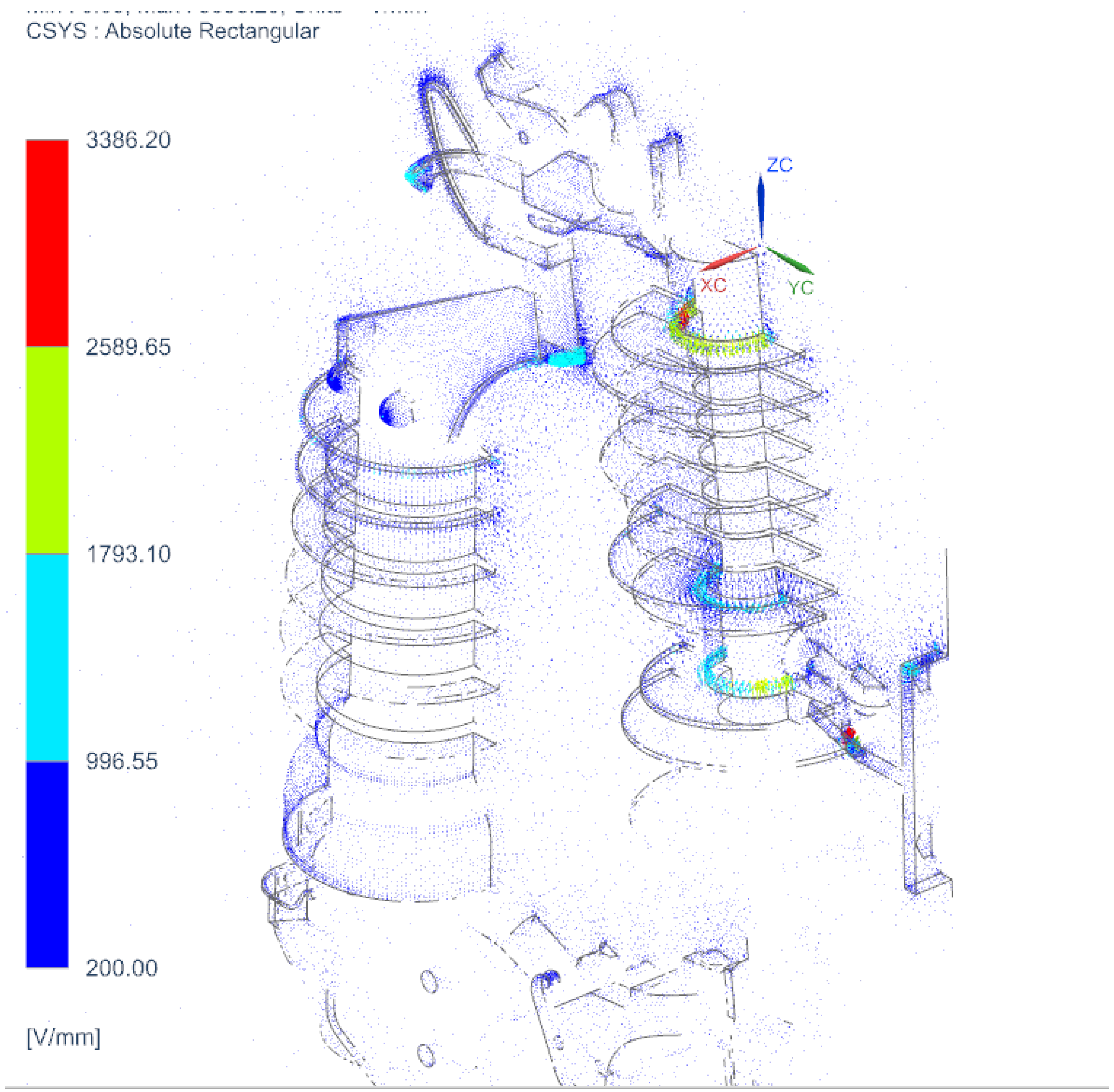
Outdoor Cutout Geometry Optimization

Electric Field Plot



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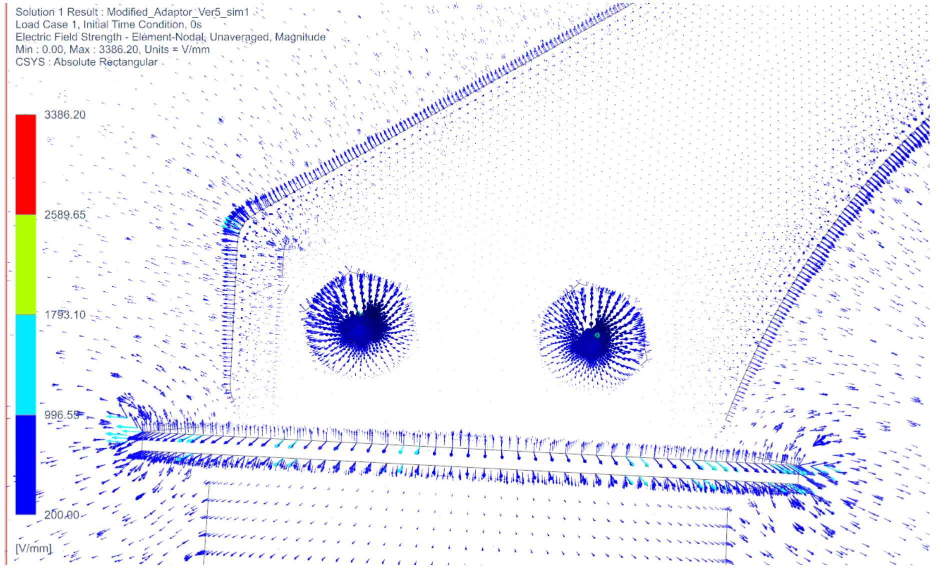
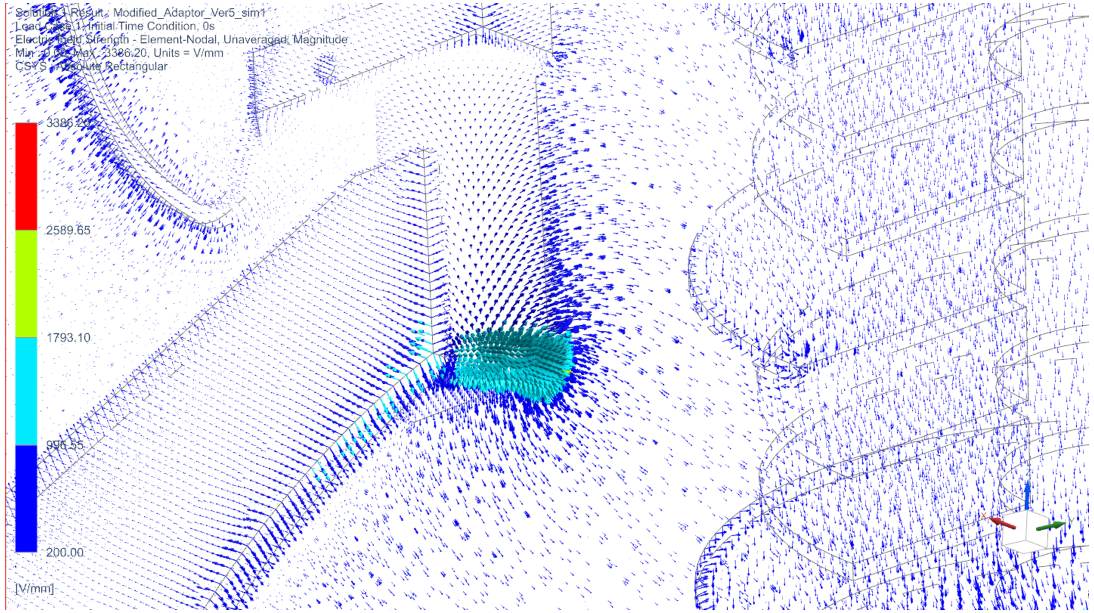
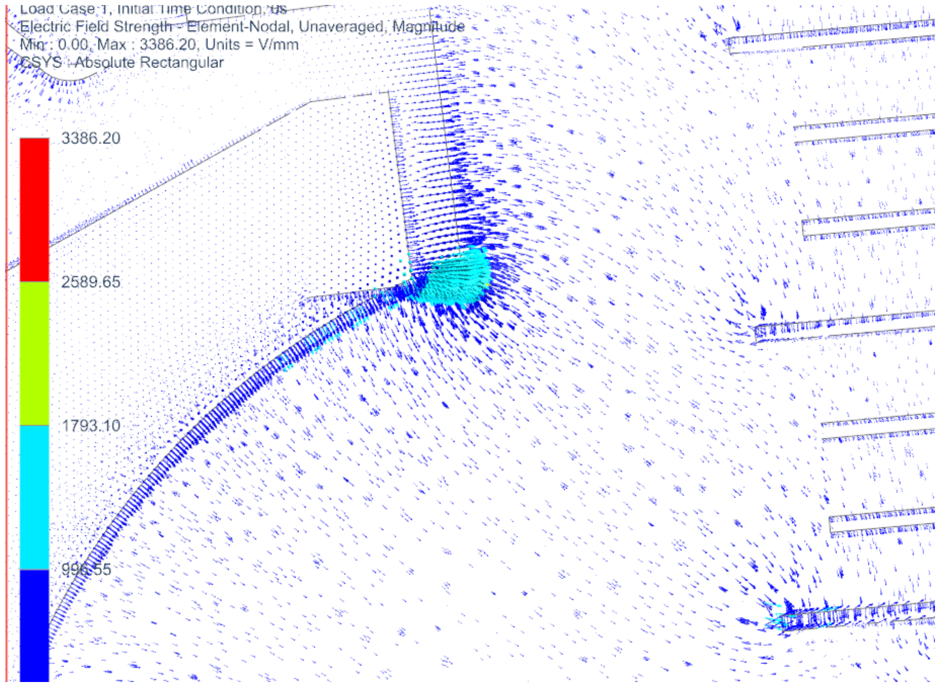
Outdoor Cutout Geometry Optimization

Electric Field Plot

Highest E-Field is found near the bracket & hardware.







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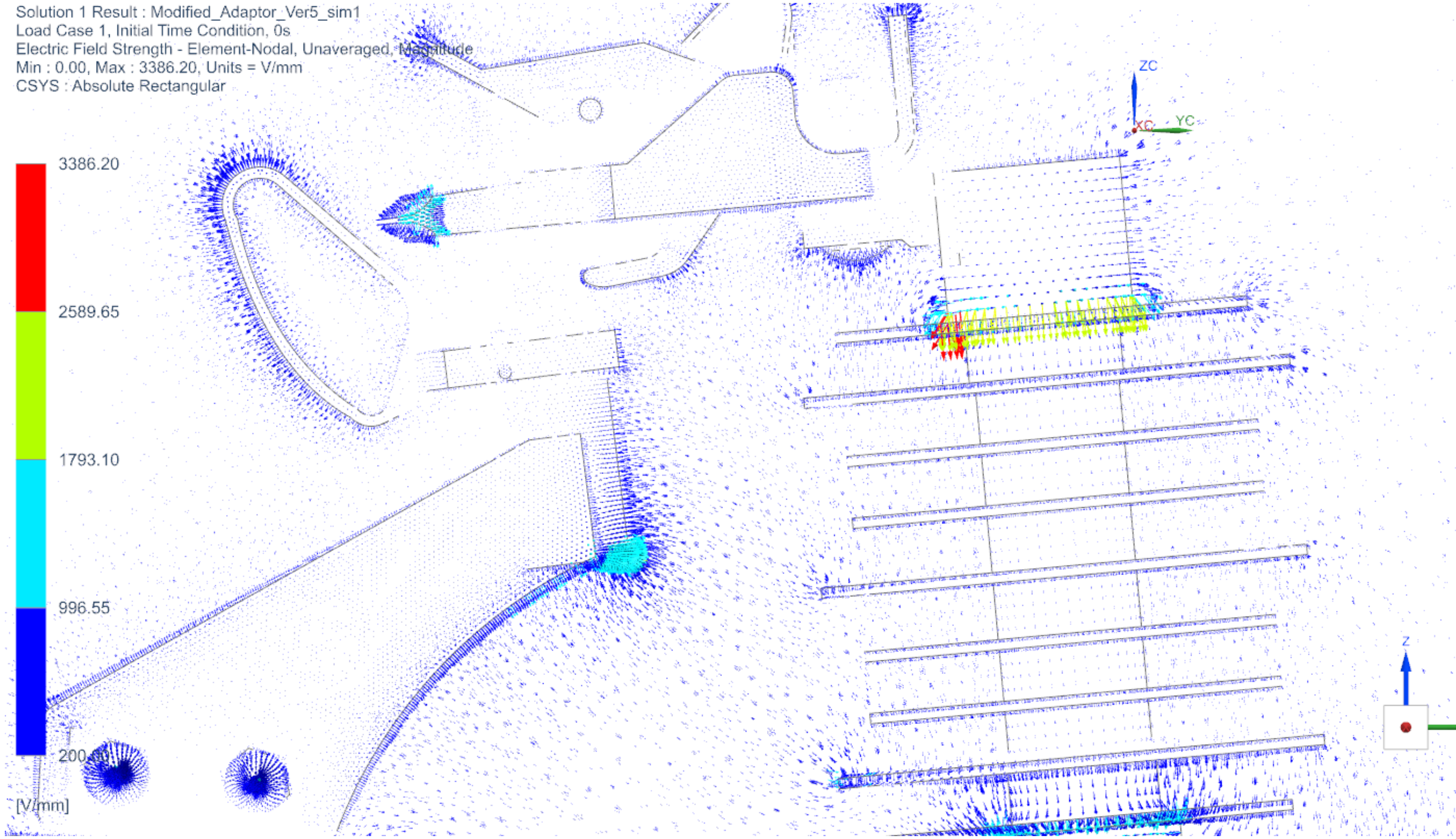
Outdoor Cutout Geometry Optimization

Electric Field Plot



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Outdoor Cutout Geometry Optimization

Geometry Change

To achieve lower E-Field, major changes in bracket design are introduced.

- Rotation of Cutout body
- Bracket extension and curved edge
- Use of rounded screw heads and covers for hardware

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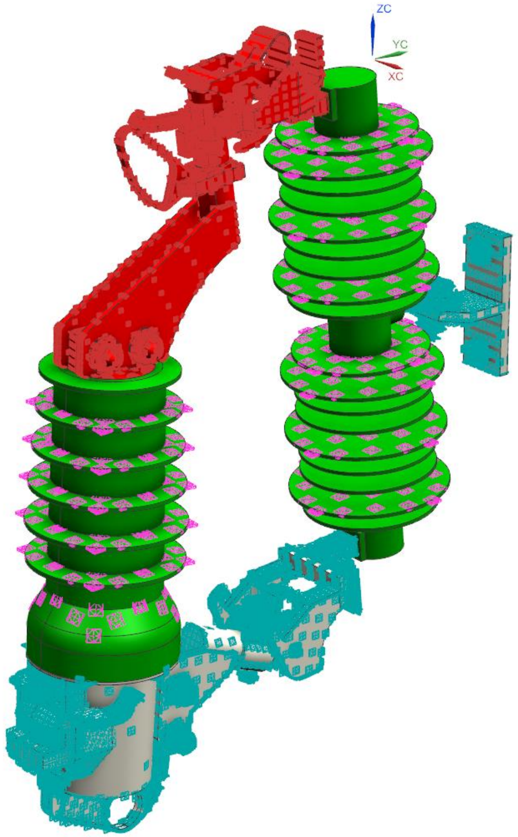
Outdoor Cutout Geometry Optimization

Simulating Wet Voltage Withstand Conditions

Floating potential surfaces are applied as load assignments to replicate wet test condition.

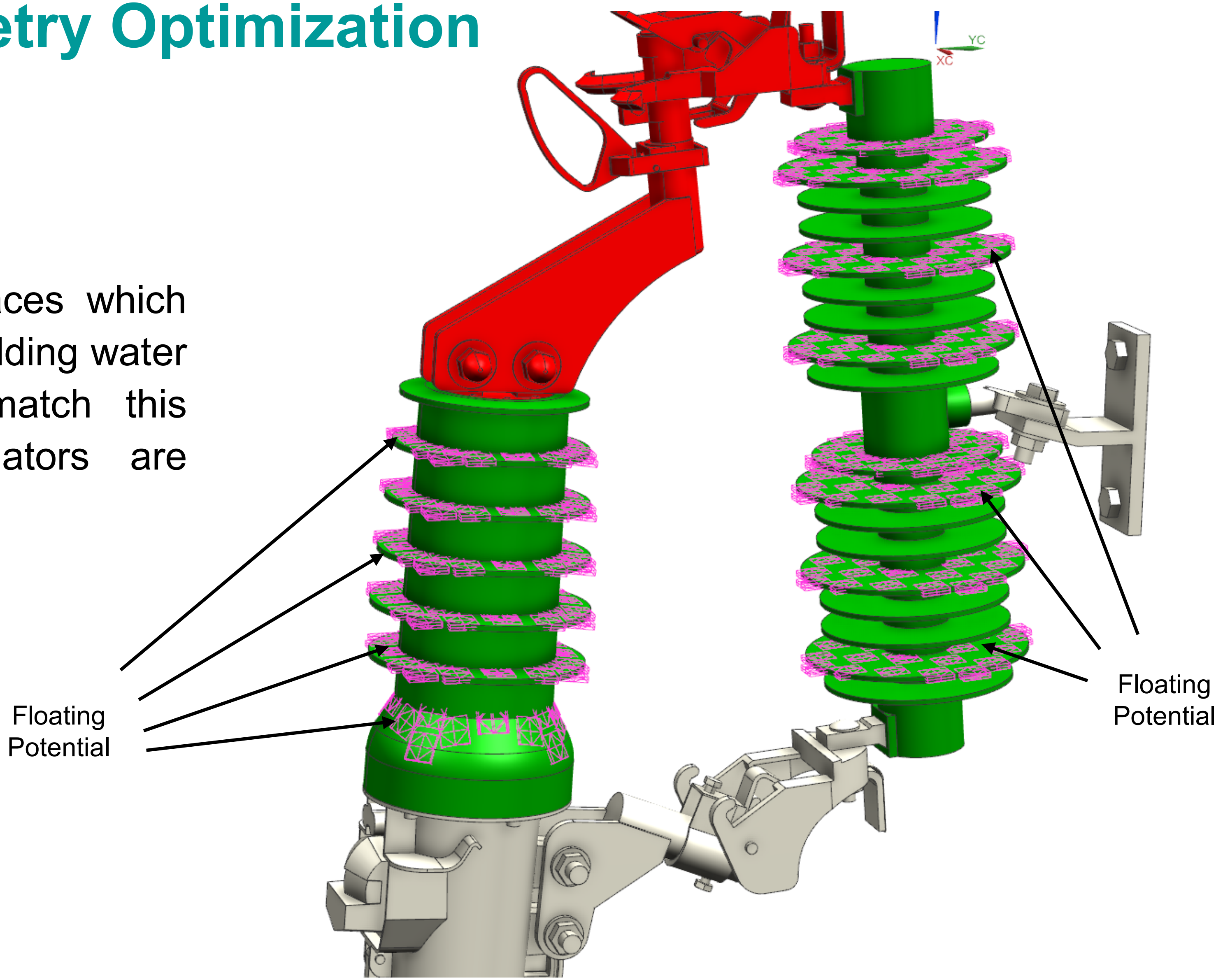
This method serves as a close approximation of moisture-induced surface conductivity, providing a practical and effective simulation approach.



Outdoor Cutout Geometry Optimization

Floating Potential Surfaces

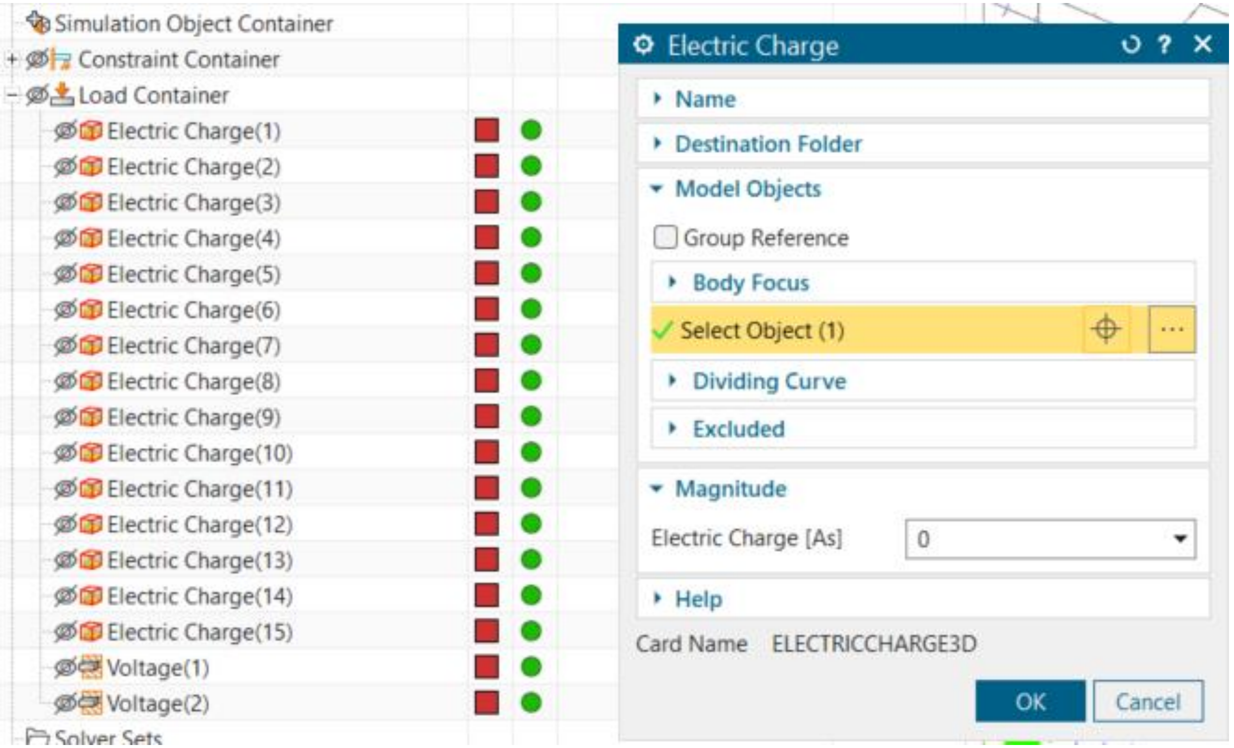
Floating potential are used on surfaces which are more probable for being wet or holding water droplets during test. To closely match this condition, larger shades of insulators are assigned.



Outdoor Cutout Geometry Optimization

Load - Electrical Charges

Electrical Charge is used for creation of floating potential surfaces. The feature is available in NX Magnetics Module and can be applied multiple times as needed for the geometry.



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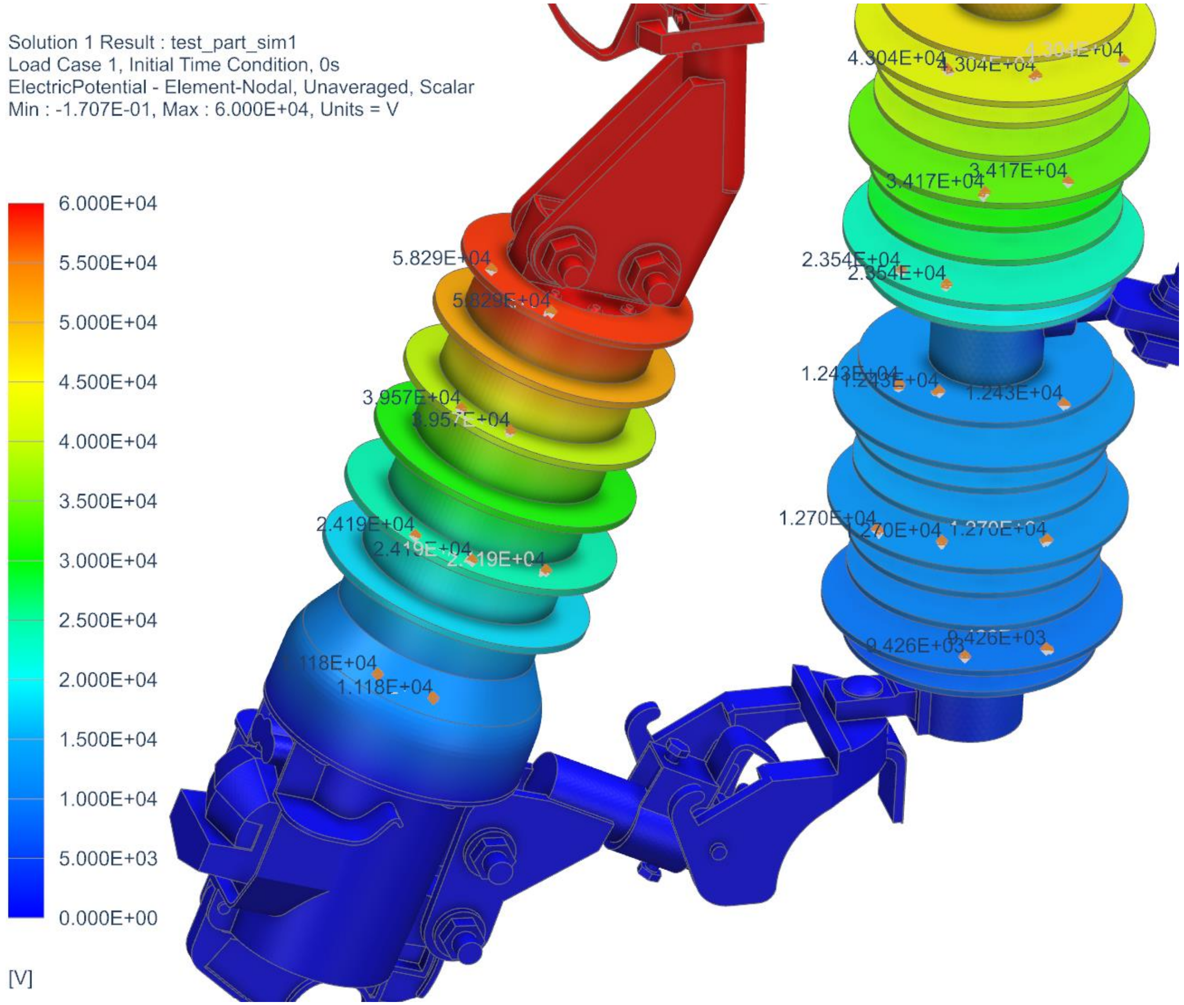
Results

Outdoor Cutout Geometry Optimization

Voltage Distribution Plot

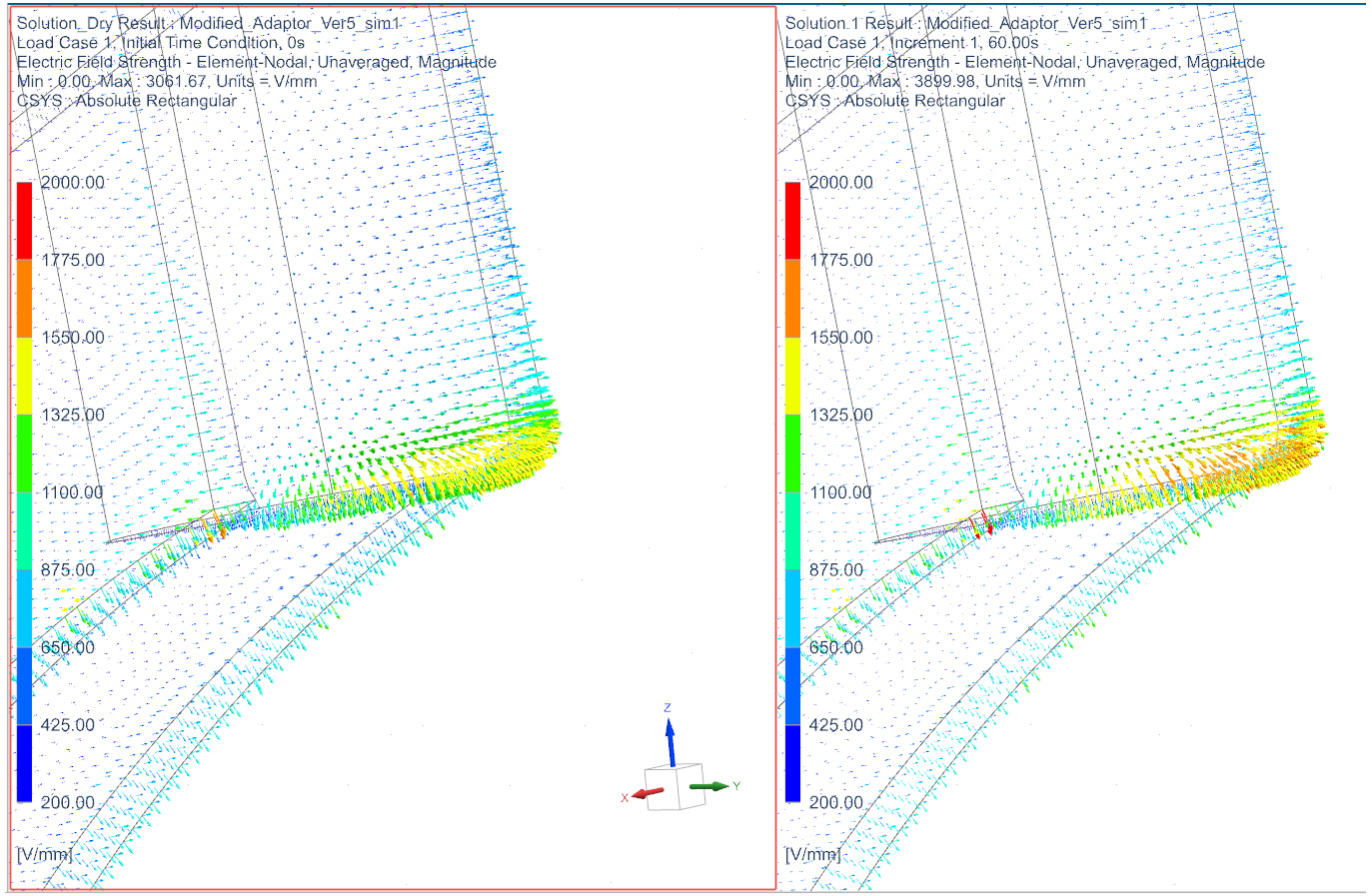
- The presence of floating potential surfaces causes a non-linear voltage distribution across insulating surfaces.
- Floating surfaces simulate wet conditions, where water droplets create localized conductivity.
- This approach closely approximates real-world wet surface behavior and is effectively implemented using the NX Magnetics module.
- The method is simple, practical, and enhances the accuracy of wet voltage withstand simulations.



Outdoor Cutout Geometry Optimization

Electric Field Plot Comparison

- Electric field plots for the second design variation are presented under both dry and wet voltage test conditions.
- Under wet conditions, the electric field intensity is approximately 10% higher than in dry conditions.
- This comparison highlights the impact of surface conductivity due to moisture and reinforces the need for the geometry optimization for wet test condition.



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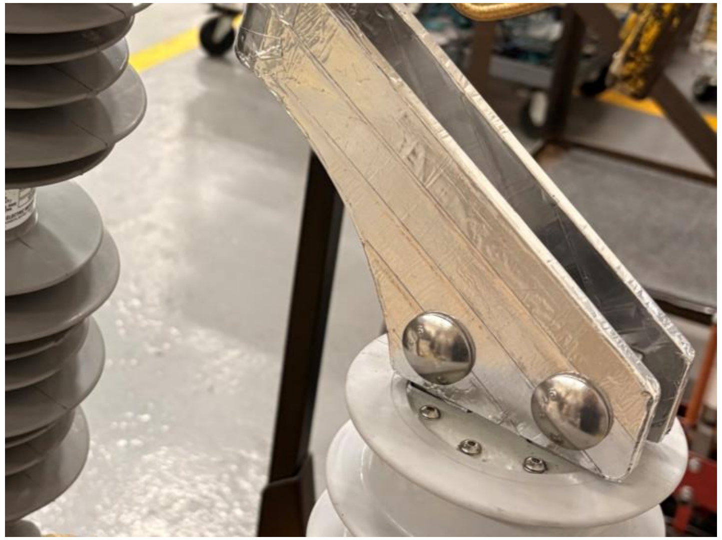
Outdoor Cutout Geometry Optimization

Bracket design and assembly

From incremental changes to big leap.

Original Design

1st Design Iteration



2nd Design Iteration

Summary and Conclusion

Outdoor Cutout Geometry Optimization

Summary & Conclusion

In this simulation study, the geometry of cutout is optimized for power frequency voltage withstand test condition. First, baseline was established by simulating the existing geometry and plotting the electric field distribution. Areas with the highest electric field stress were identified, and design modifications were proposed accordingly. For each design variation, the electric field was plotted, and high-stress zones were analyzed. The geometry was incrementally revised based on these findings.

To simulate wet voltage withstand conditions, floating potentials were applied to surfaces most likely to become wet during testing. This approach allowed for a realistic representation of test conditions.

The simulation enabled geometry optimization without the need for multiple physical prototypes or design iterations. It also highlighted the differences between dry and wet voltage withstand test conditions.

Thank you

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