

Designing for DC

The evolution of transformer lead exits.



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LEAD EXIT DESIGN PHILOSOPHY RELATED TO HVDC PROJECTS

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DESIGNING FOR DC

HVDC Market Overview

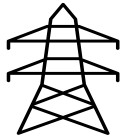
Bushing Test Arrangement (BTA) design philosophy related to HVDC projects

Lead Exit design philosophy related to HVDC projects

Weidmann's Engineering Services related to HVDC projects

Questions?

WHY ARE WE TALKING ABOUT HVDC TODAY?



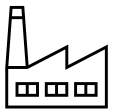
HVDC technology has existed for decades



Historically deployed in a limited number of large-scale projects



Growth in renewable generation, interconnections, and long-distance transmission drives new discussions



More utilities and OEMs are evaluating future HVDC opportunities

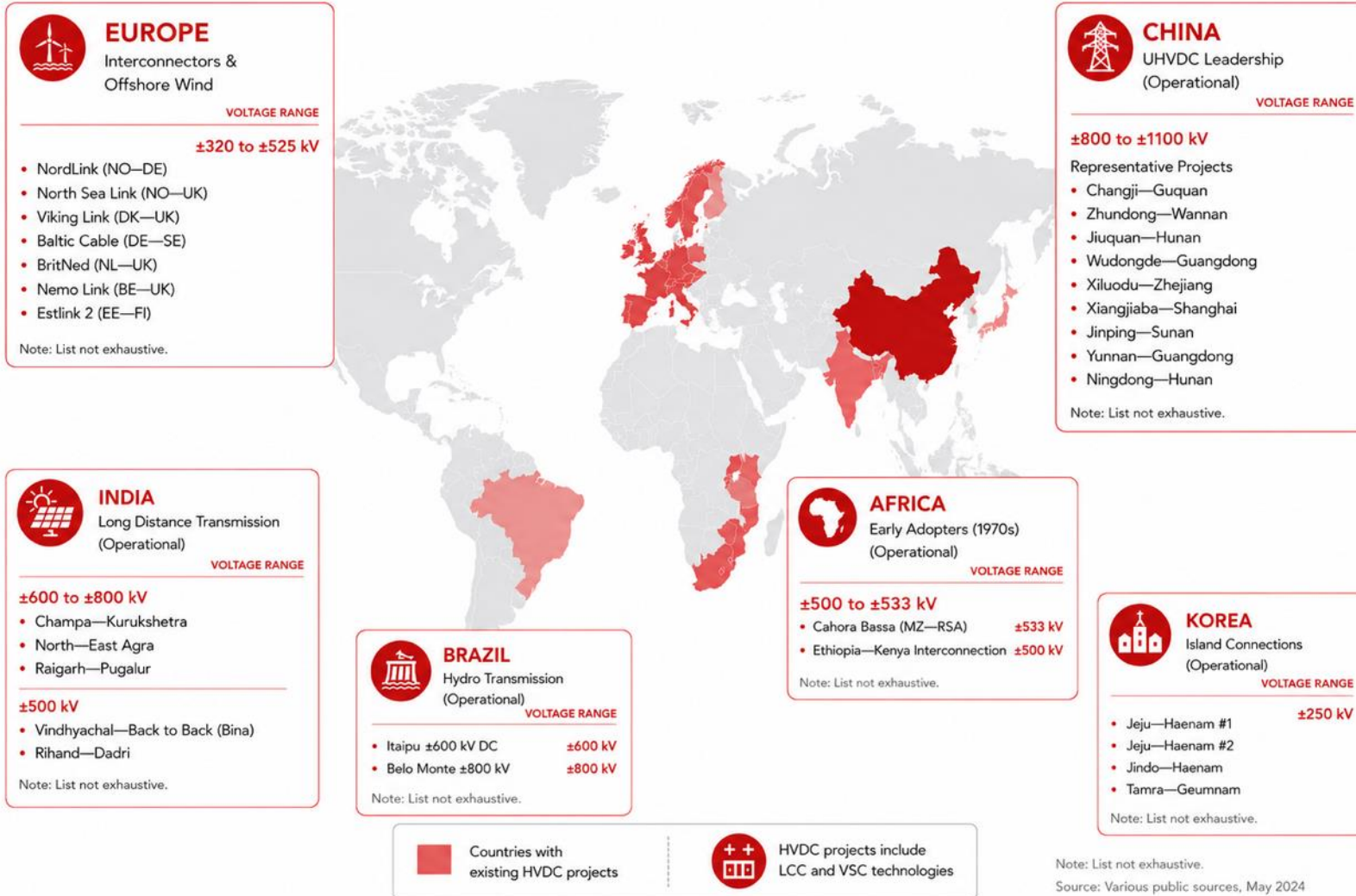


Many organizations are now building internal knowledge and capability

Source: Hitachi Energy

HVDC NETWORKS IN OPERATION

HVDC DEPLOYMENT REMAINS CONCENTRATED IN SPECIFIC REGIONS



WHAT CHALLENGES ARE DRIVING NEW HVDC DISCUSSIONS?

HVDC is typically selected when power must be moved over long distances or through transmission environments where conventional AC solutions become less practical.

Offshore Wind Expansion

Challenge: Wind generation is moving further offshore, and project sizes continue to increase

Why HVDC: Long submarine cable distances create increasing AC charging current losses, making HVDC the only possibility for applications with large distance requirements

Remote Renewable Generation

Challenge: Large wind, solar, and hydro resources are often located hundreds or thousands of kilometers from major load centers

Why HVDC: HVDC can efficiently transfer large blocks of power over very long distances

WHAT CHALLENGES ARE DRIVING NEW HVDC DISCUSSIONS?

Interconnecting Power Systems

Challenge: Countries and regions seek to exchange power while maintaining independent grid operation

Why HVDC: HVDC can control power flow, can support the generation of reactive power, and can connect asynchronous AC systems

Emerging Load Growth

Challenge: Electrification, manufacturing expansion, and large data center developments are creating concentrated demand growth

Why HVDC: Not because data centers require DC supply, but because utilities may need new transmission corridors capable of delivering large amounts of power from distant generation sources

WHAT DOES THIS MEAN FOR THE TRANSFORMER INDUSTRY?

HVDC is typically selected when power must be moved over long distances or through transmission environments where conventional AC solutions become less practical.



For OEMs:

- Growing customer interest in HVDC projects
- Entry into new market segments
- Different design and insulation considerations

For Utilities:

- Evaluation of future transmission options
- Increasing interaction with HVDC infrastructure
- Long-term reliability expectations

For the Industry:

- Knowledge transfer from established HVDC projects becomes increasingly valuable

While HVDC remains a specialized application, the number of organizations seeking to understand and participate in these projects continues to grow.



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Questions?

HVDC WEBINAR

BASICS

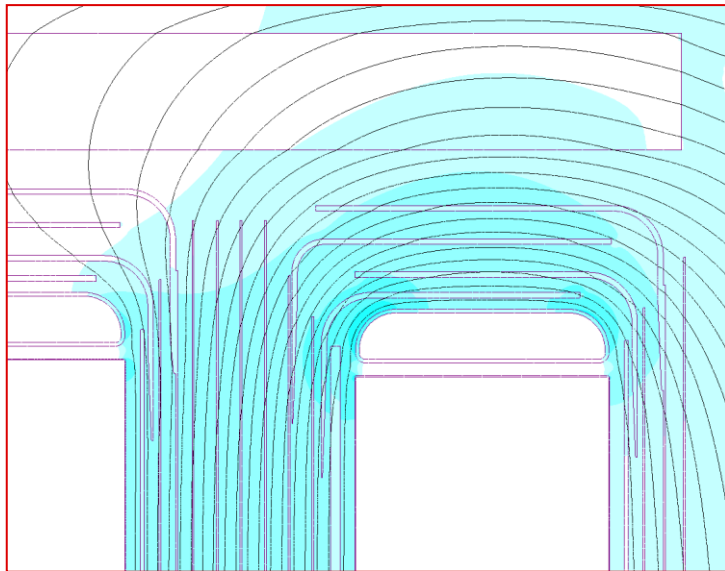
AC Field

(permittivity distribution

→ main field stress in oil)

pressboard / oil ϵ_r -ratio = 2:1

AC field plot



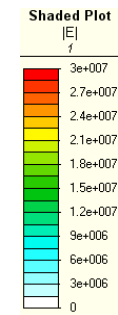
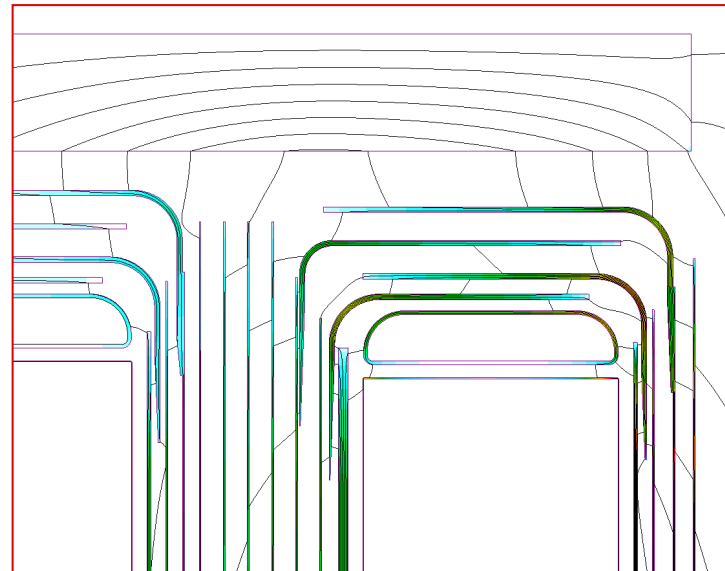
DC Field

(conductivity distribution

→ main field stress in board)

oil / pressboard σ -ratio = 100:1 (traditional)

DC field plot

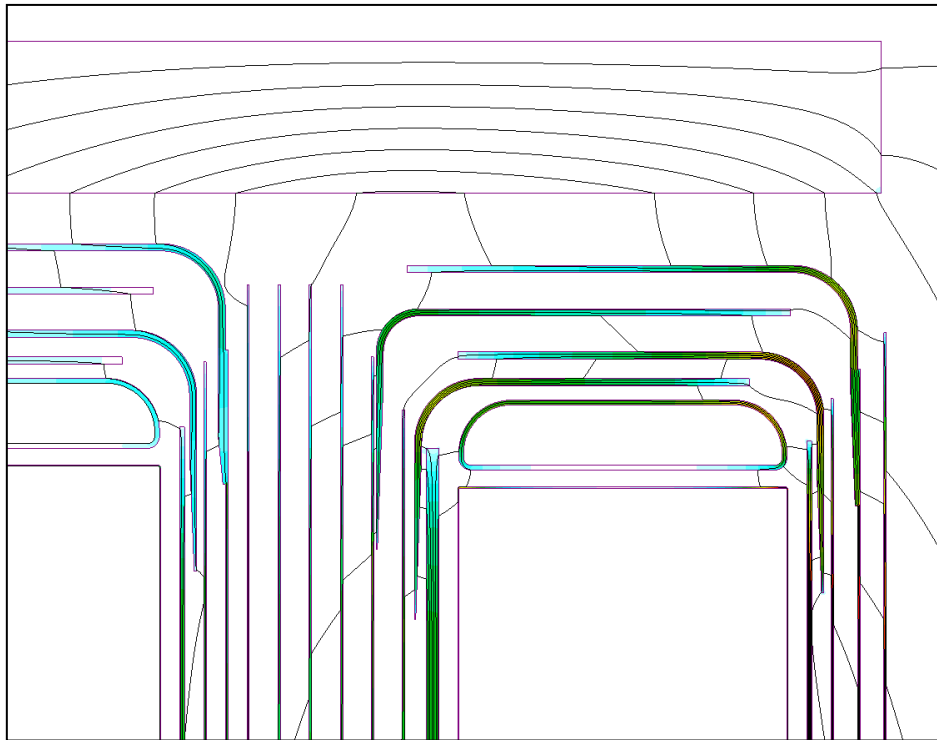


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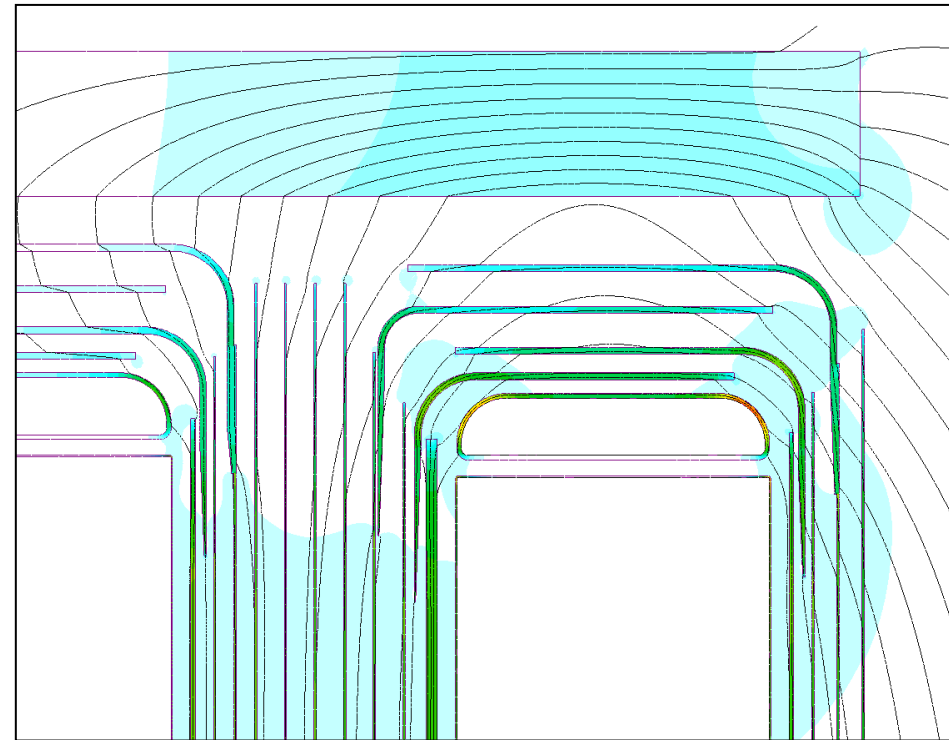
BASICS

EXAMPLE: DC FILED PLOT OF END DISTANCE HVDC INSULATION

Oil to board conductivity ratio



100:1 (traditional)
Oil with “high” conductivity



10:1
Oil with “low” conductivity

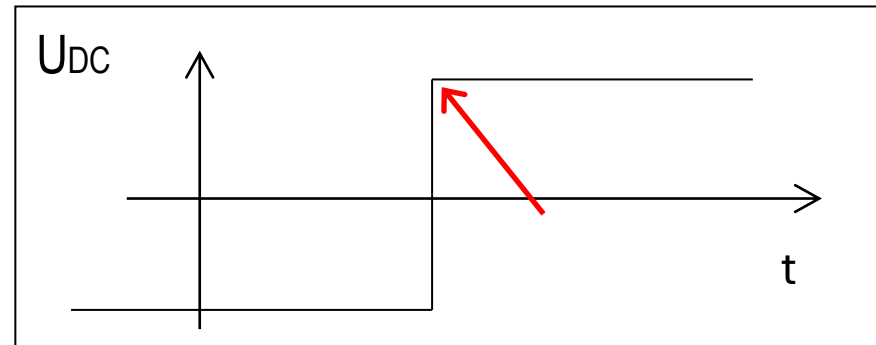
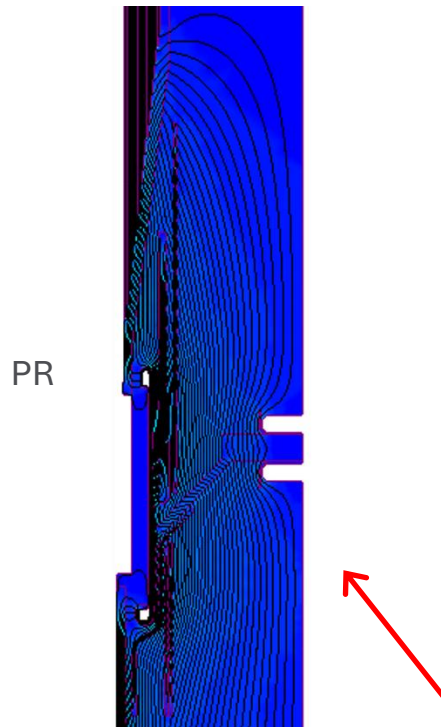
HVDC WEBINAR

BASICS

EXAMPLE: DC FIELD PLOT OF LEAD EXIT DURING POLARITY REVERSAL

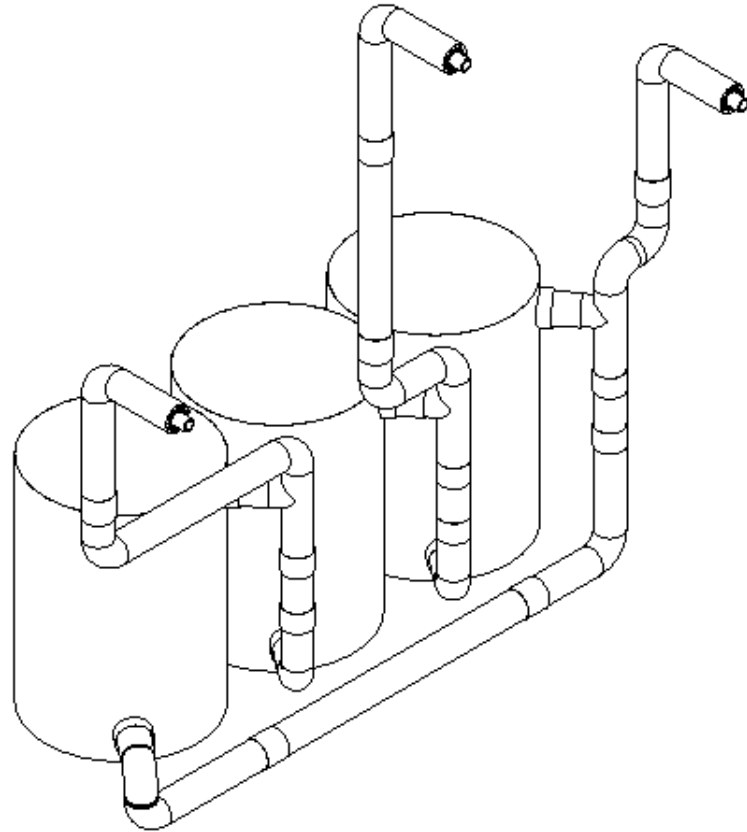
Knowing the conductivity and permittivity of oil/board insulation systems we can compute the electric field immediately before and after the polarity reversal.

→ The time constants can be in the order of hours

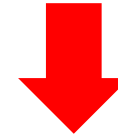


HVDC WEBINAR

DELIVERING AN HVDC BTA [BUSHING TEST ARRANGEMENT] AND LEAD EXIT



Development



Production



Transportation



Assembly

HVDC WEBINAR

WHY NEED BTA [BUSHING TEST ARRANGEMENT]

Bushing is critical part for HVDC transformer

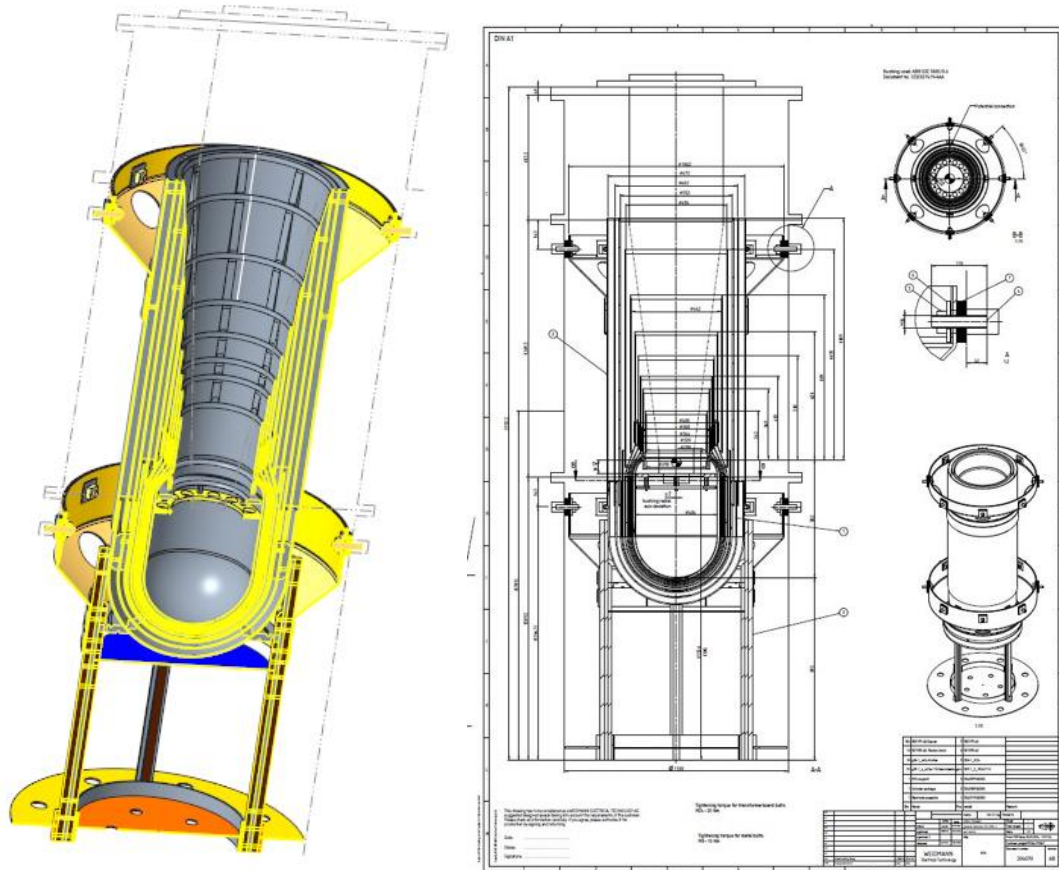
- DC bushing needs to withstand various voltage conditions (AC, LI, SI, DC, PR)
- Withstand the full current, challenges for thermal
- Connections from inside towards outside
- Cost
- Production lead time
- Impact on the whole project

Use BTA (bushing test arrangement) to verify with bushing test voltage level



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DEVELOPMENT OF HVDC BTA [BUSHING TEST ARRANGEMENT]



Used for bushing testing

- IEC/IEEE 65700-19-03
- Quote: “DC tests on converter transformer and reactor bushings shall be carried out with external insulation (barriers) and ground planes surrounding the lower end of the bushing in a position as similar as possible to that of the intended service condition.”

Semi-sphere design

- Turret has the same diameter as the one that will be used for Lead Exit
- Fixation points similar to the ones that will be used for Lead Exit

HVDC WEBINAR

DEVELOPMENT OF HVDC BTA [BUSHING TEST ARRANGEMENT]

Input data required to design a BTA

- bushing specification
 - internal construction
 - position of condenser layers / foils
- test voltages
- turret arrangement
- size
 - height
 - diameter
- fixation points



Additional design adjustments

Depending on the bushing specification following adjustments need to be done:

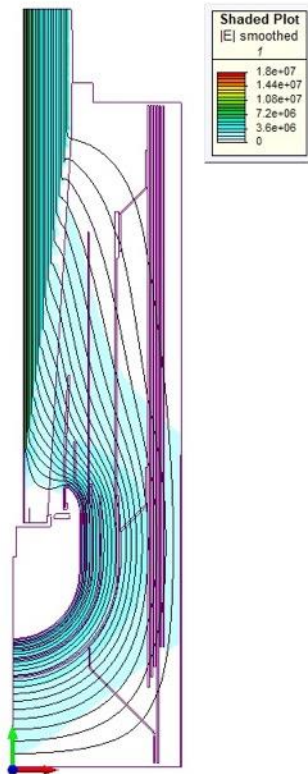
- positioning of the bushing relative to metal electrode
- internal connection within the electrode
- base insulation of the electrode
- barrier system around the electrode
- bushing insertion tolerances



HVDC WEBINAR

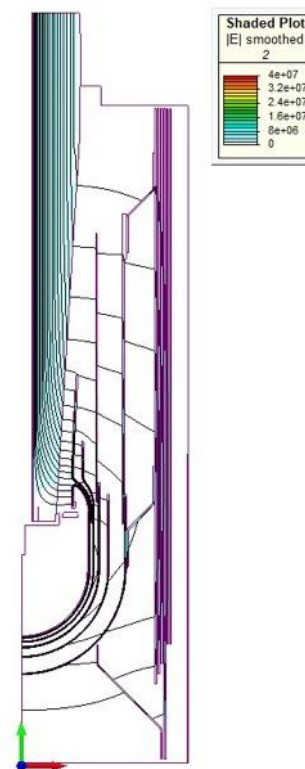
DEVELOPMENT OF HVDC BTA | HVDC CALCULATION – STEADY STATE

AC



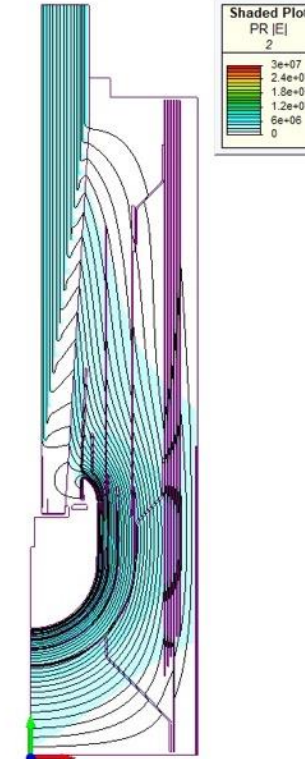
Higher field stress
in oil

DC



Higher field stress
in insulation

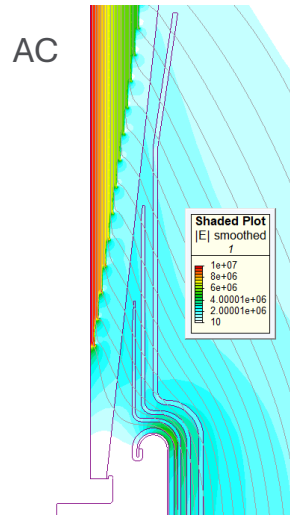
PR (Polarity Reversal)



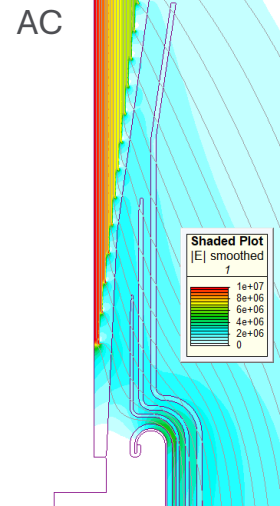
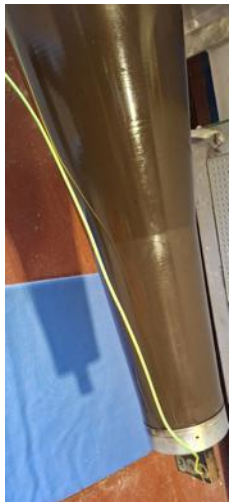
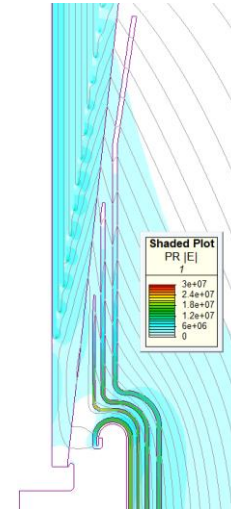
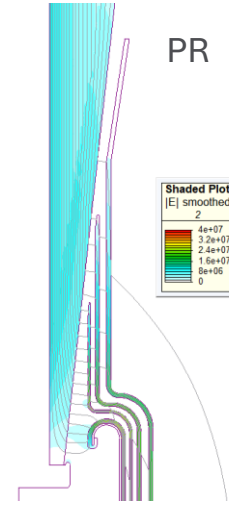
Field stress more equally
distributed in both oil and insulation

HVDC WEBINAR

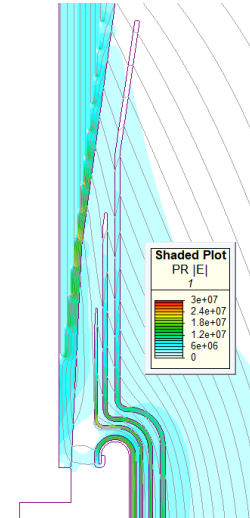
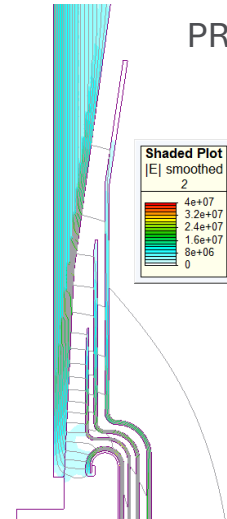
DEVELOPMENT OF HVDC BTA | HVDC BTA CALCULATION – STEADY STATE



DC



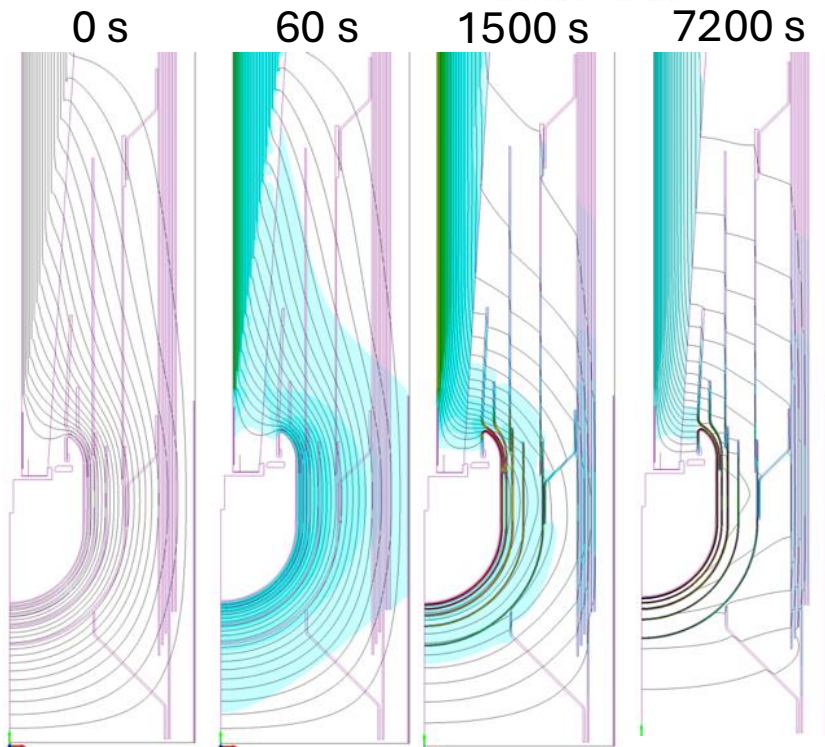
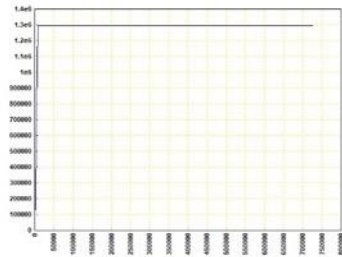
DC



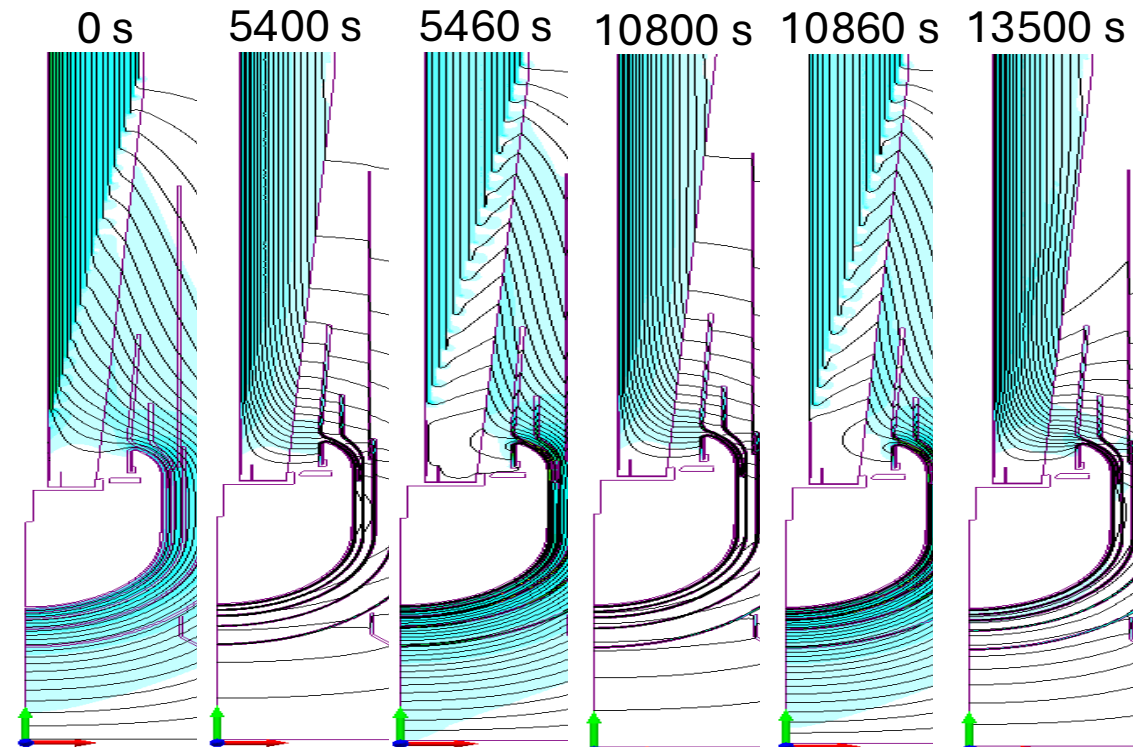
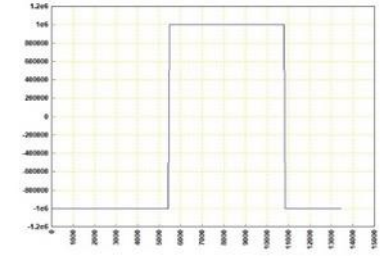
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DEVELOPMENT OF HVDC BTA | HVDC CALCULATION – TRANSIENT

DC
2 hours test



PR (Polarity Reversal)
90 min – 90 min – 45 min test



HVDC WEBINAR

VOLTAGE LEVELS IN HVDC PROJECT

400 kV



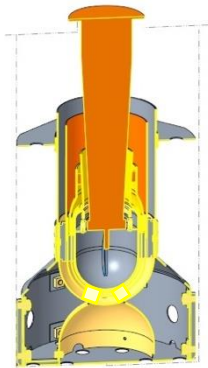
600 kV



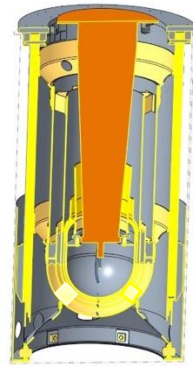
800 kV



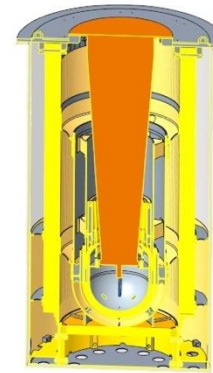
1000 kV



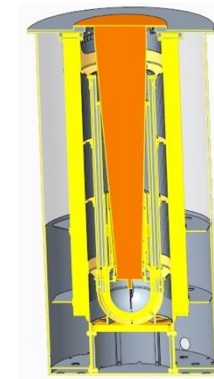
Weight: ~ 50 kg
Height: ~ 1200 mm



Weight: ~ 300 kg
Height: ~ 2000 mm



Weight: ~ 900 kg
Height: ~ 2300 mm



Weight: ~ 1700 kg
Height: ~ 3400 mm

HVDC WEBINAR

HVDC BTA PROJECTS IN WEIDMANN

Design

- requested specification
- project management
 - understanding the project needs
 - setting project goals
 - delivery date
- HVDC BTA development
 - design stage
 - electrical analysis
 - mechanical analysis
 - production
- transportation

IDA=insulation dielectric analysis

Design review

- define the IDA scope
- receiving the 2D/3D modelling
- material properties
- test voltage levels and boundary conditions
- IDA FEM results and reporting
- step into HVDC lead exit design review



DESIGNING FOR DC

HVDC Market Overview

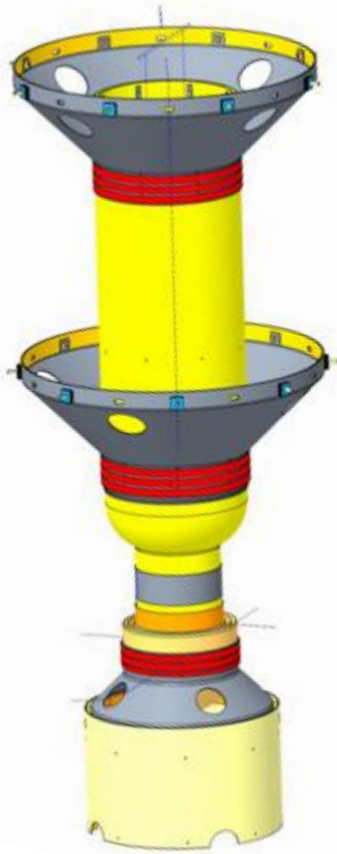
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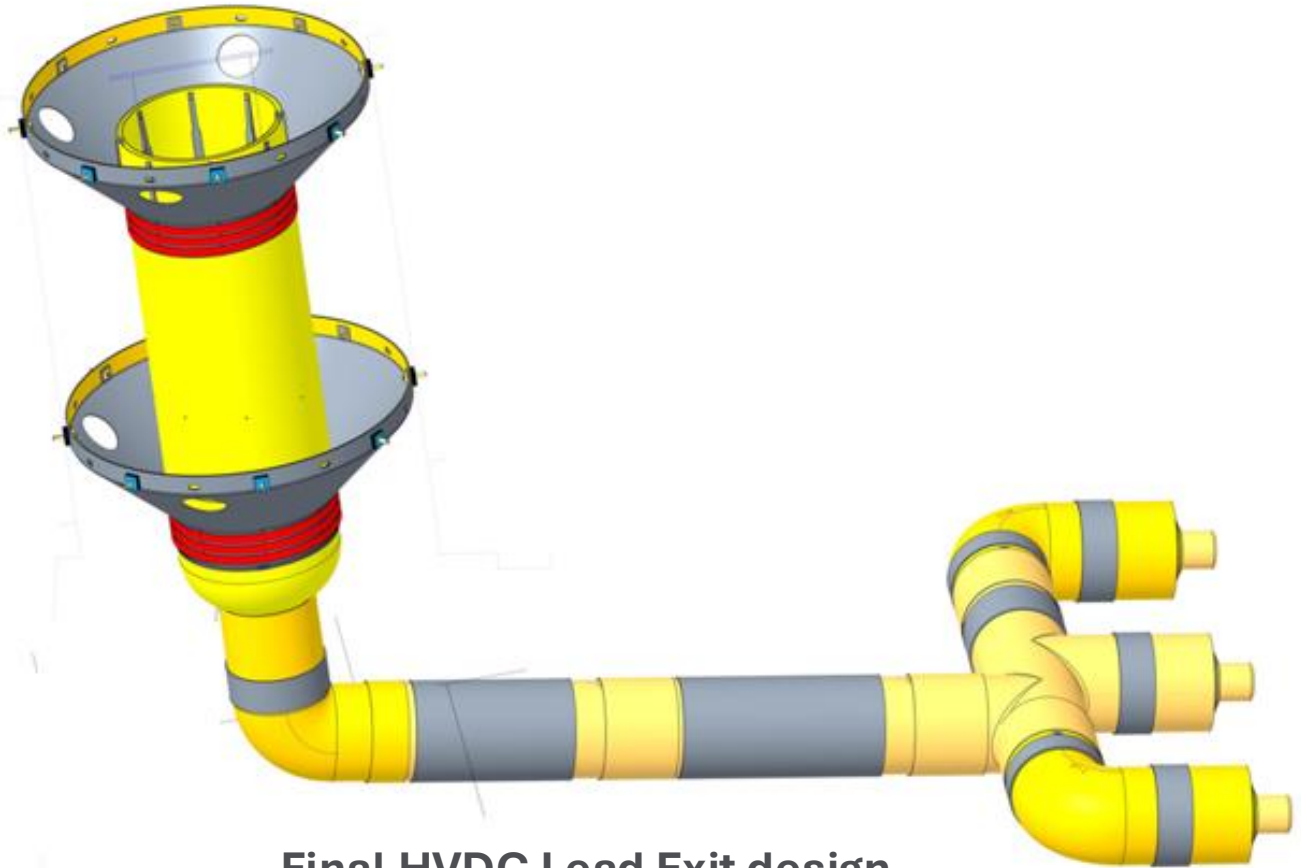
Weidmann's Engineering Services related to HVDC projects

Questions?

FROM BTA TO HVDC LEAD EXIT



Barrier arrangement for the
Bushing Test



Final HVDC Lead Exit design

DIFFERENTIATION OF COMPONENTS

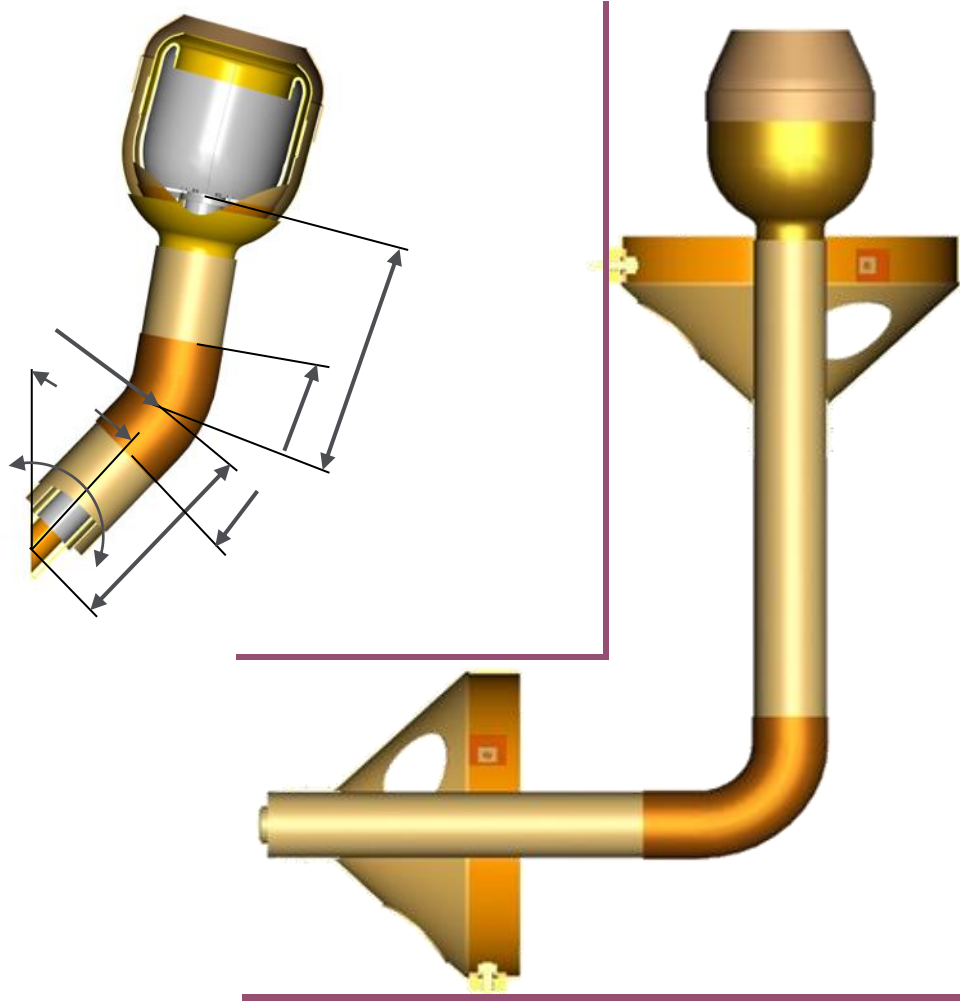
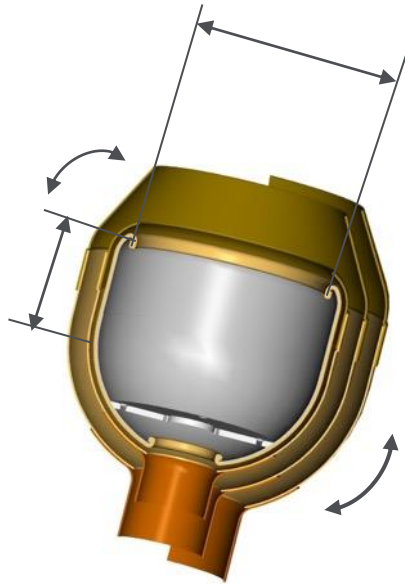
MACHINED – FORMED – ASSEMBLED



- **Machined:** State of the art machinery required
- **Formed:** Knowhow intensive, special processes involved
- **Assembled:** Combination of molding/machined, often design involved

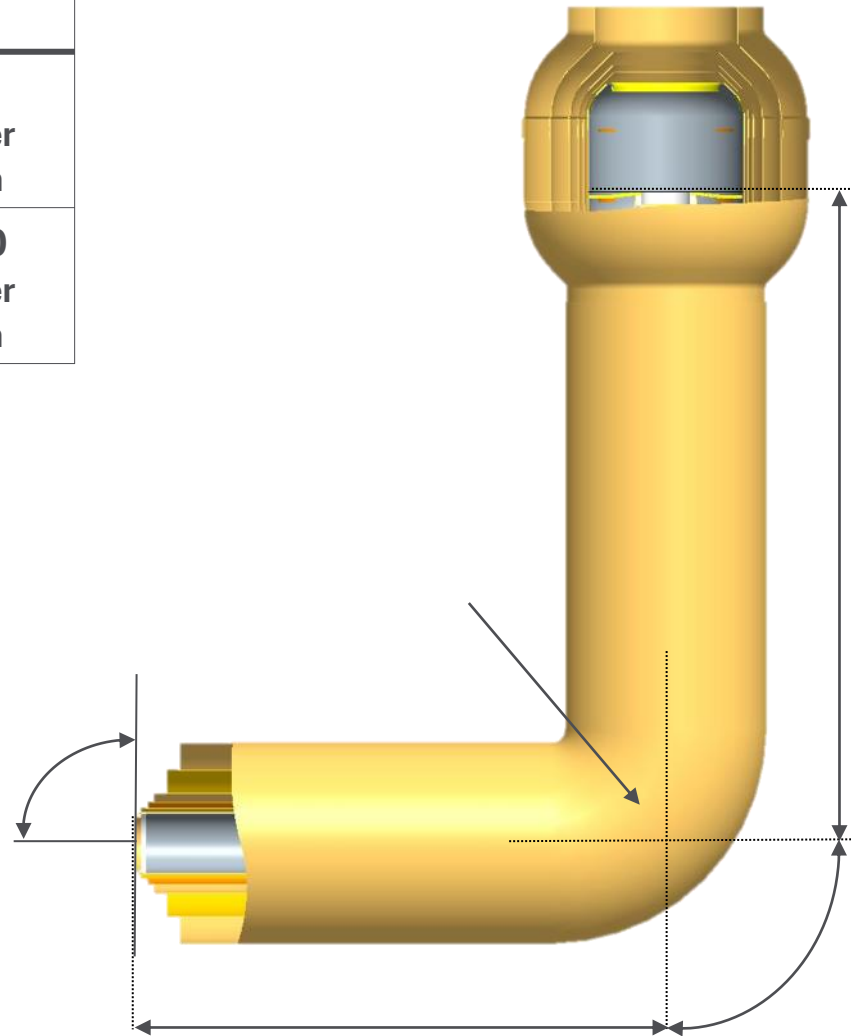
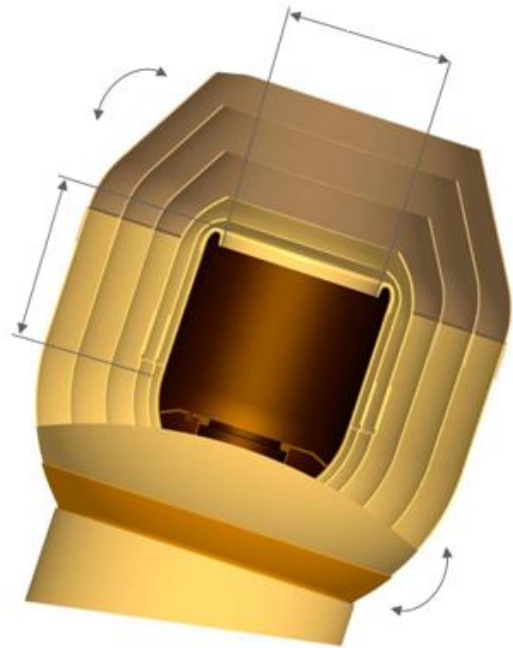
WEIDMANN AC LEAD EXIT FAMILY

Highest voltage for equipment U_m	Lead Exit Type
420 kV	MLE 400 2-barrier system
550 kV	MLE 500 3-barrier system

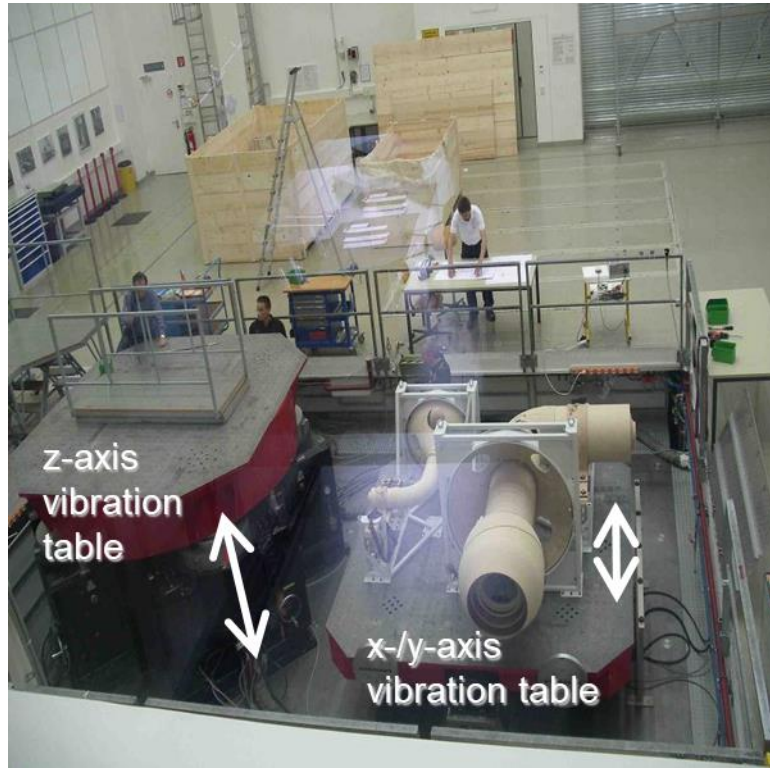


WEIDMANN AC LEAD EXIT FAMILY

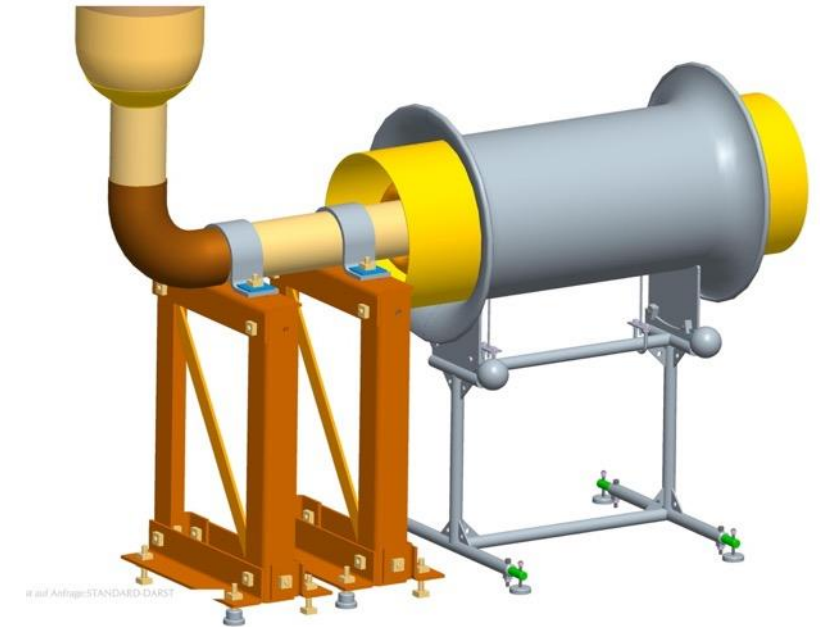
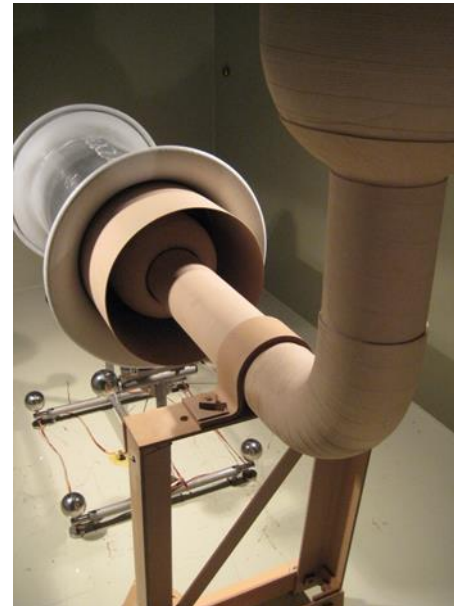
Highest voltage for equipment U_m	Lead Exit Type
800 kV	W800 4-barrier system
1000 kV	W1000 5-barrier system



WEIDMANN AC LEAD EXIT FAMILY

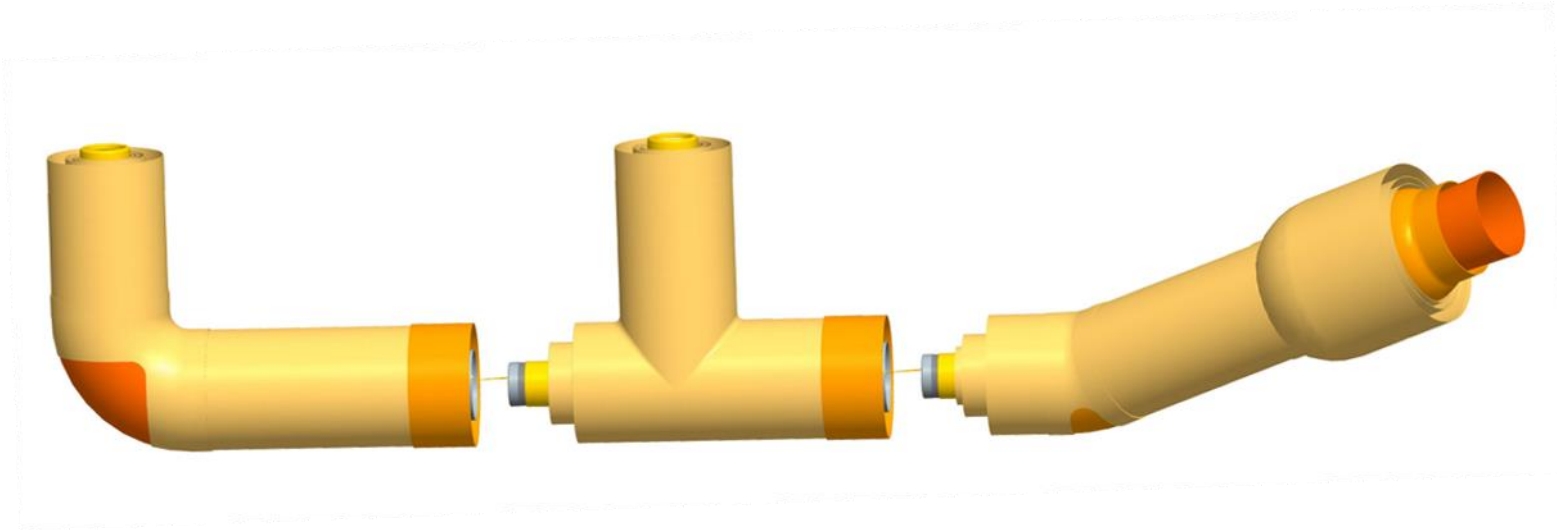


Mechanical tests
(Vibration Transportation
and Vibration Earth Quake)

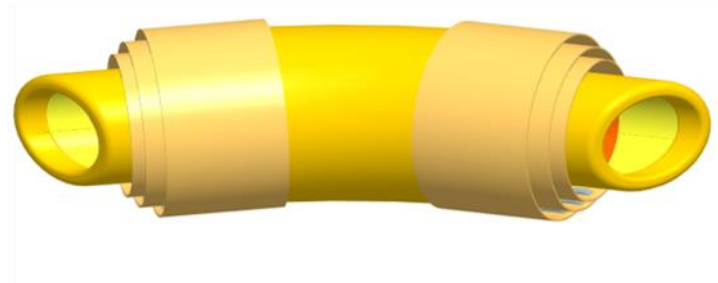


Electrical tests
(IEC 60076-3)

DESIGN OF MODULAR HVDC LEAD EXITS

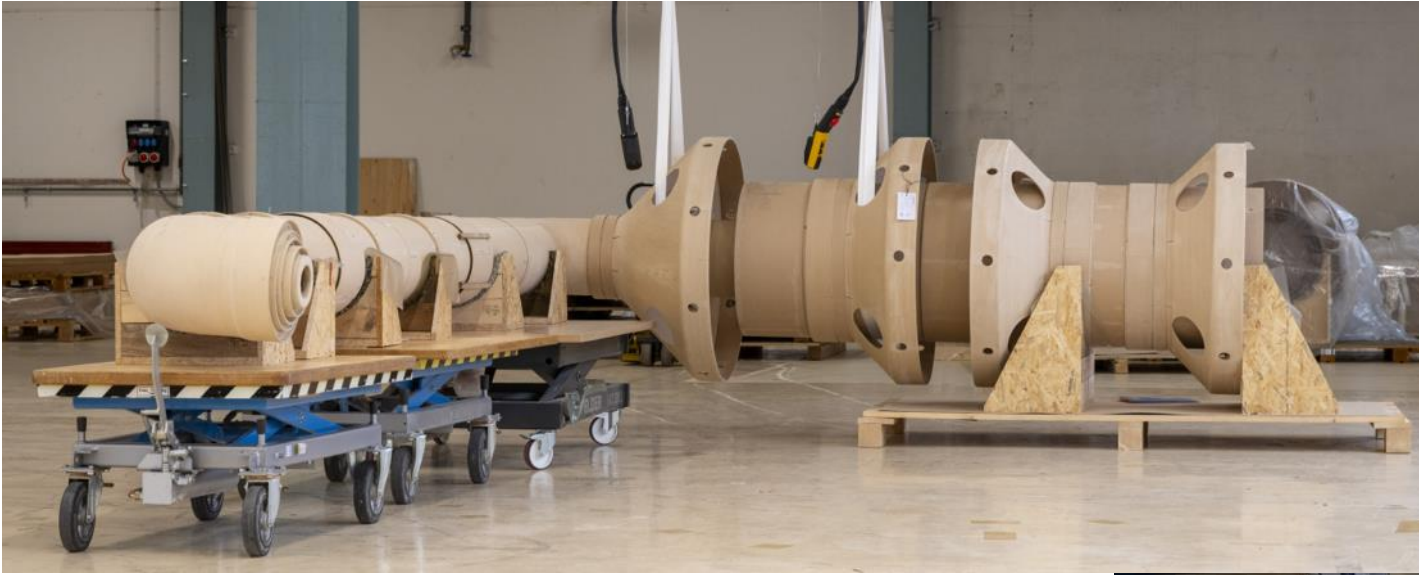


Designed and tested modular elements



WEIDMANN DC LEAD EXIT FAMILY

CUSTOMIZED

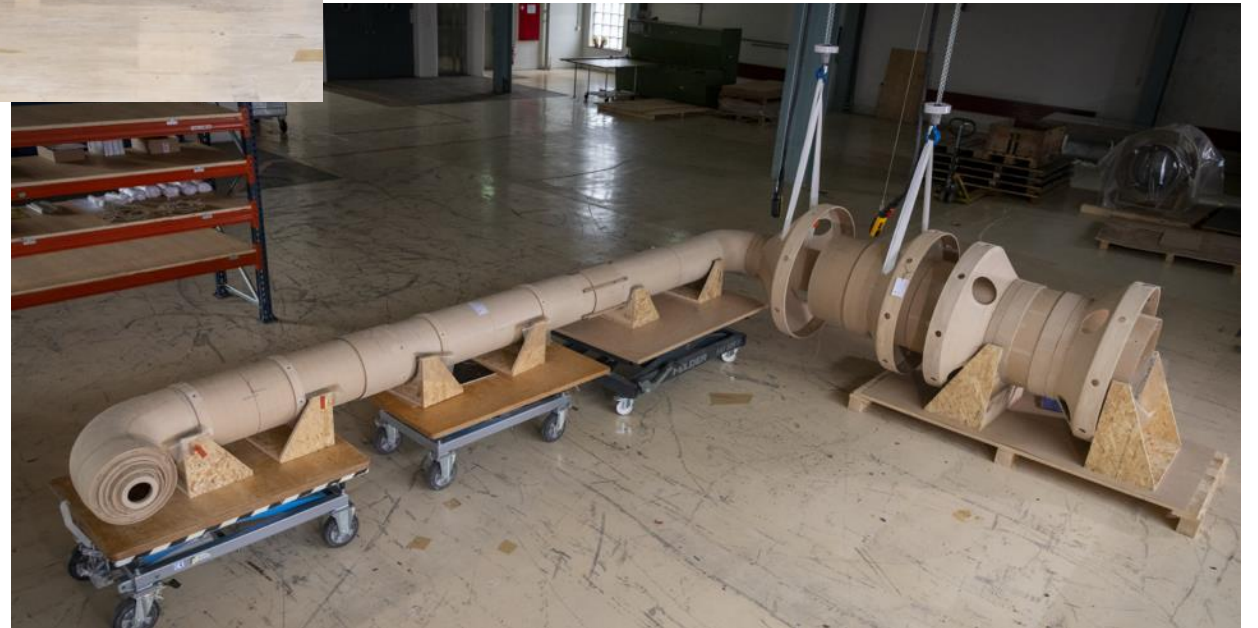


Same structure as on BTA where the bushing is inserted

- Test voltages lower than on BTA

Different variations possible

- base insulation type
- number of phases



WEIDMANN HVDC INVESTMENT

Investments:

- Oven for molded parts (some LE tubes are ~4m long)
- Barrier system assembly
- Advanced tools



WEIDMANN HVDC LEAD EXIT FAMILY

400 kV



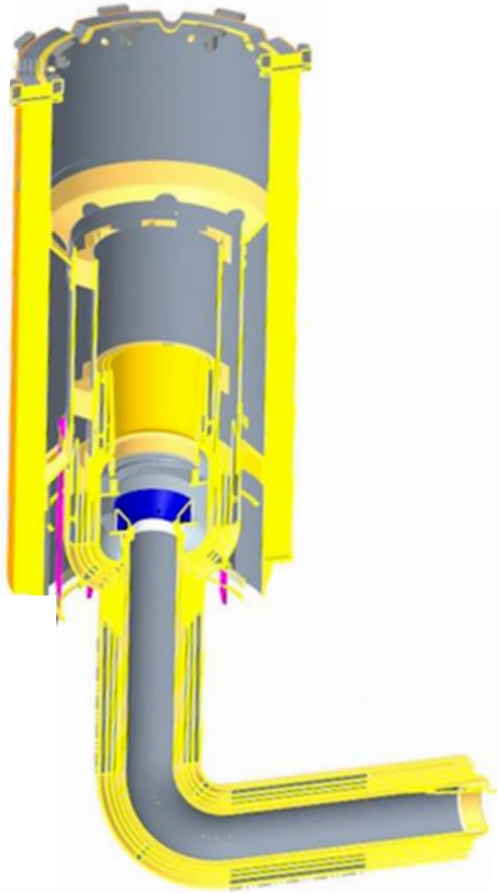
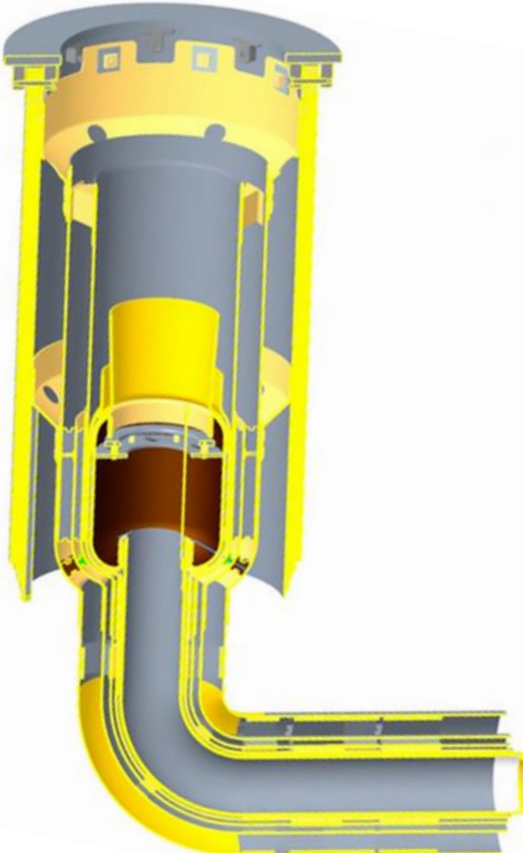
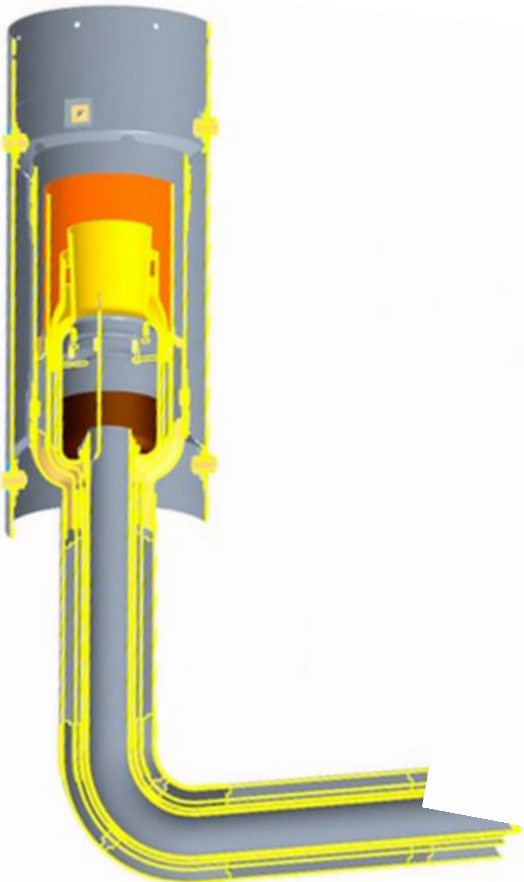
600 kV



800 kV



1000 kV



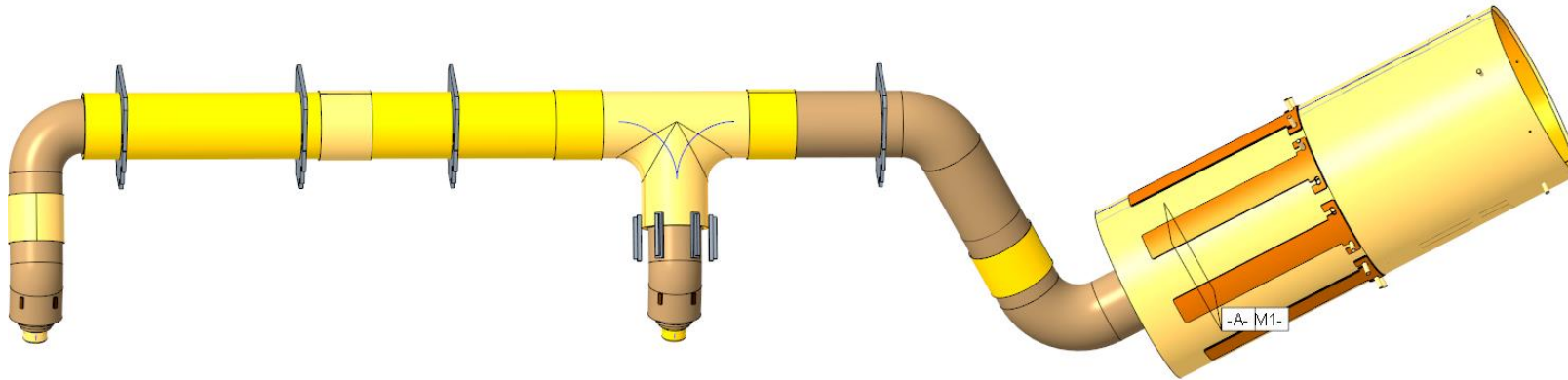
HVDC LEAD EXIT ASSEMBLY

Some of the challenges that may occur during HVDC Lead Exit assembly

- limited number of cranes
- narrow distances / tolerances
 - staggered barriers
 - guiding sticks
- leads cross section within the Lead Exit tube
 - joints
 - bends / elbows



HVDC LEAD EXIT JOINT DESIGN



During the joint design following points are considered

- connection type between sectors
- distance for cable connection
- position of the joint within transformer
- ease of assembly
- movement
 - axial
 - radial
 - rotational

Design stage

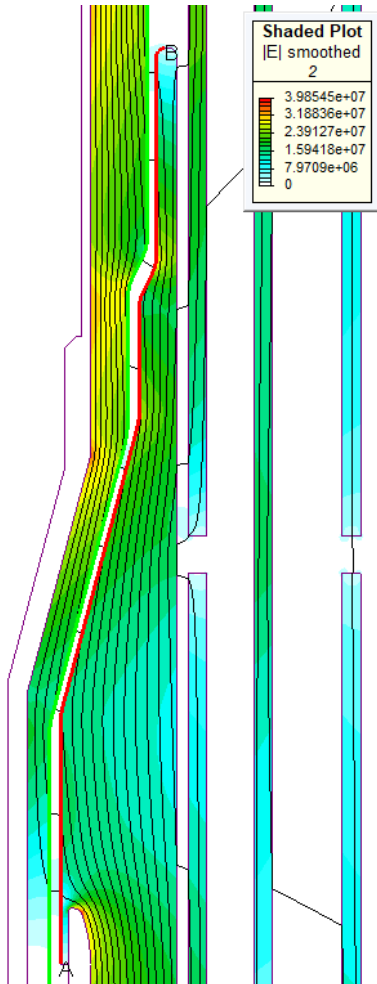
- electrical analysis
- mechanical analysis



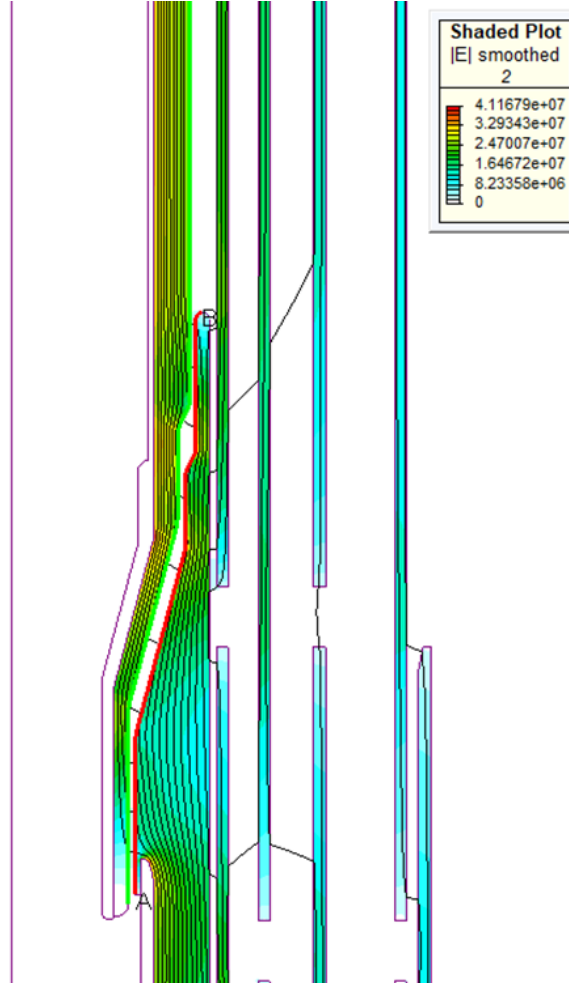
DEVELOPMENT OF HVDC LEAD EXIT JOINT

HVDC CALCULATION – STEADY STATE

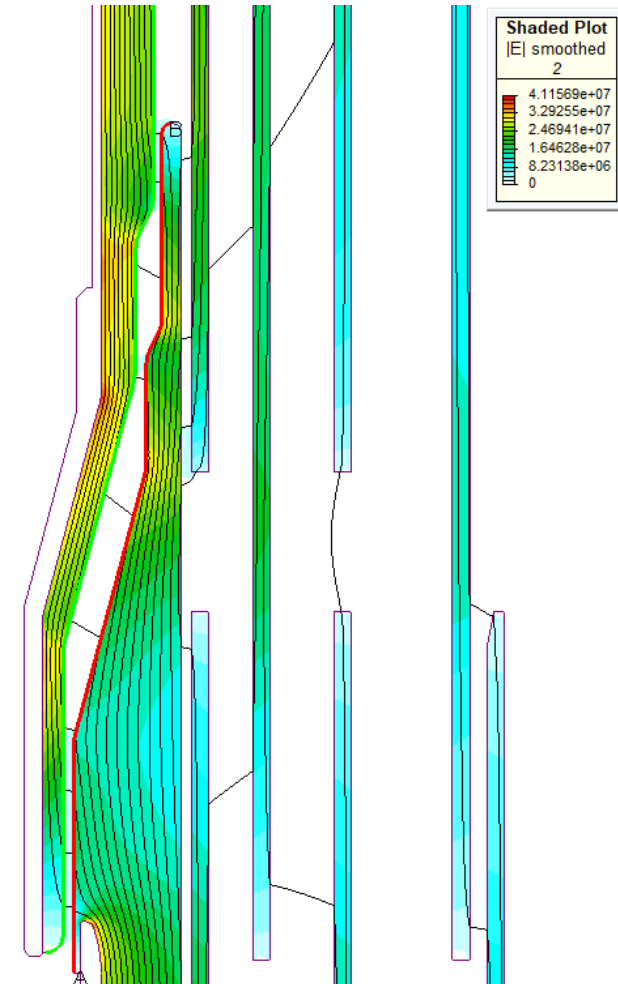
DC – MINUS POSITION



DC – NOMINAL POSITION

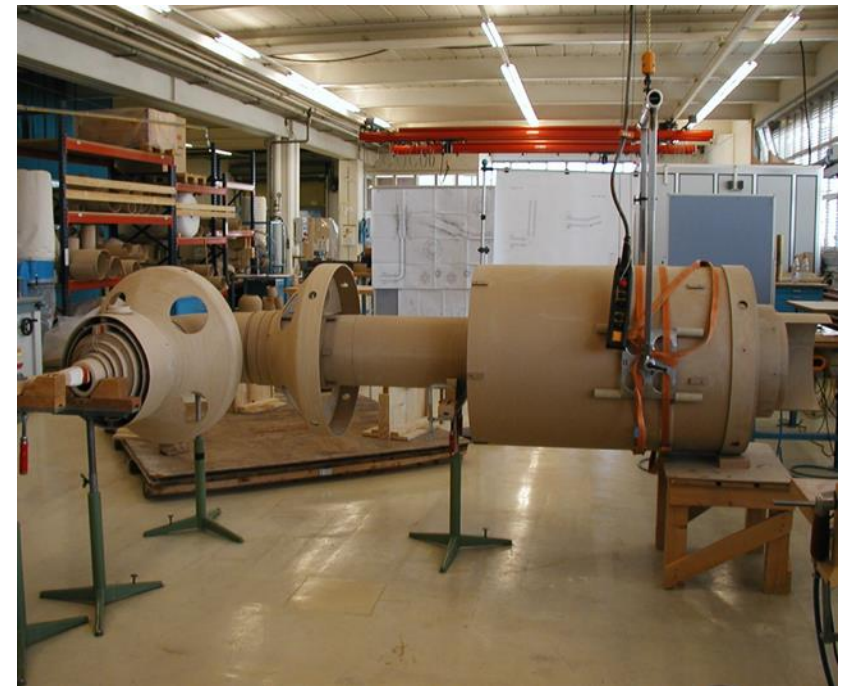


DC – PLUS POSITION



SUMMARY

- Complexity level of HVDC Lead Exits is higher than on AC Lead Exits
- Production tolerances of HVDC Lead Exits are narrower than on AC Lead Exits
- HVDC Lead Exits are mostly custom made, they are adjusted for a transformer and not vice versa
- HVDC Lead Exits for the same voltage level can be completely different
- Transformerboard plays a bigger role within the HVDC Lead Exit





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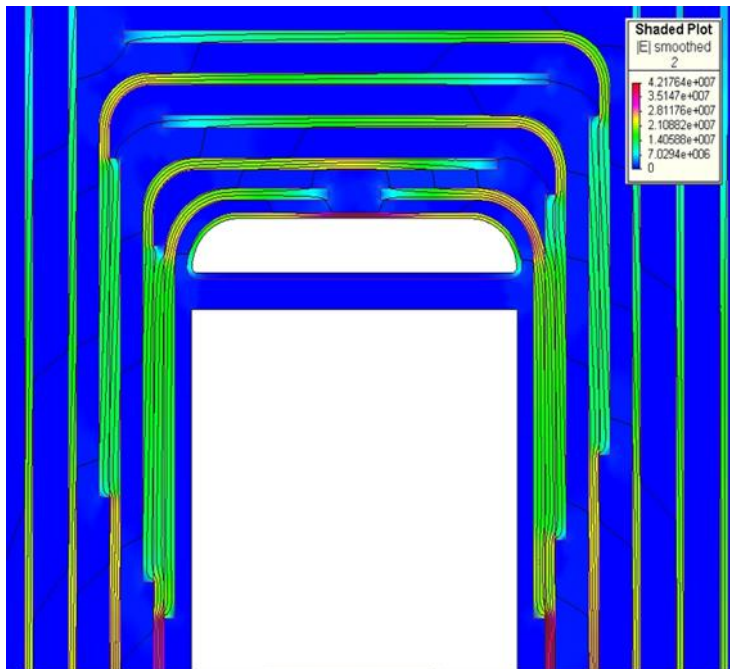
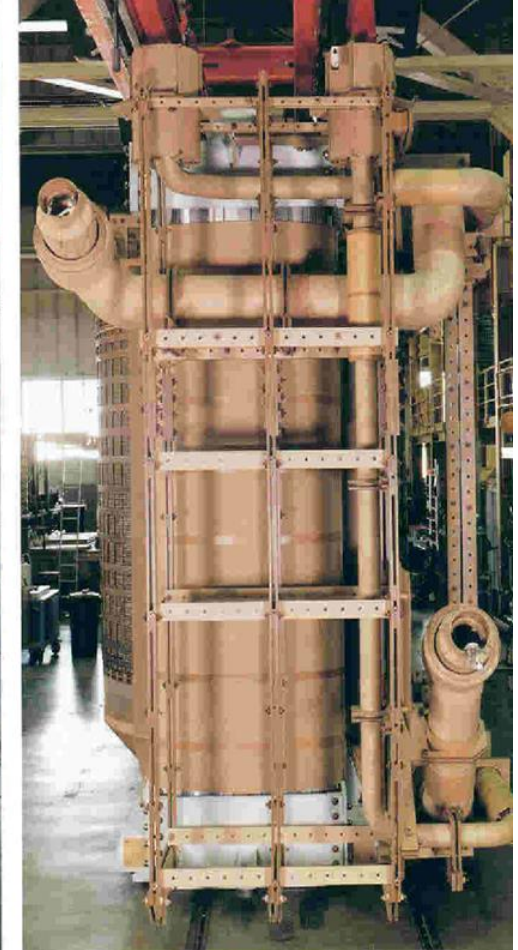
Lead Exit design philosophy related to HVDC projects

Weidmann's Engineering Services related to HVDC projects

Questions?

ENGINEERING SERVICES

- Design review
- Design verification
- Manufacturing inspection
- Factory Acceptance Test witnessing
- Failure investigation





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WEIDMANN

THANK YOU