Simulation-Based Design
in
Electrical Engineering

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2018

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Simulation-Based Design in Electrical Engineering

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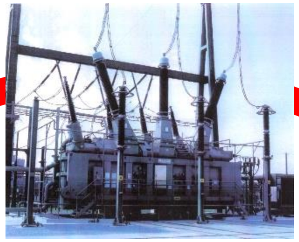
Simulation-Based Design



- Dielectric Design -> Electro-Static
- Temperature hot spots -> Electro-Thermal
- Short-circuit Forces -> Electro-Mechanics
- Shock-structure -> Mechanics
- Acoustics

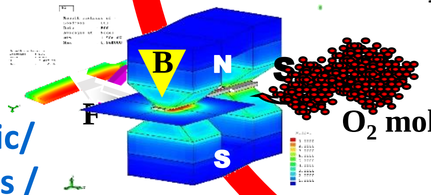
Prediction of paint application
ElectroDyn.-CFD

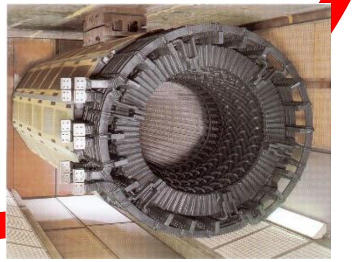
- Prototype design
- Product design
- Design upgrade

- Dielectric Design -> Electro-Static
- EM / SM Design -> Coupled Analysis
- Cooling of switchgear -> Electro-Thermal
- Explosion-proofing -> Shock-Structure

MEMS Desing

Coupled EM / Fluidic/
Molecular Dynamics /
Mechanic Simulation





- Overheating problems -> Electro-Thermal
- ON/OFF Switching problems -> Coupled Analysis
- Explosion-proofing -> Shock-structure

SBD: What are the key business drivers in the engineering design?

1. Achieve **top device performance** with **minimal development costs**,
2. Minimize **Time2Market**, i.e. maximal reduction of the product development time.

These two requirements can be mostly fulfilled by replacing the traditional Experimentally-Based Design (EBD) with the advanced Simulation-Based Design (SBD) through:

1. Accelerating the design process for xxx% - **avoiding prototypes**
2. Better design through **better understanding** of the physical phenomena
3. Recognizing and **eliminate the product's weak points** already at the design stage

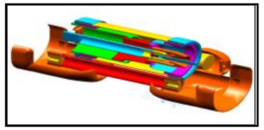
To stay at the competitive edge, the SBD has to be equipped with the accurate, robust and fast numerical technologies suited for:

1. Analysis of the **real-world 3D problems**, preserving the necessary structural and physical complexity
2. … but, using such numerical technologies that are enough **user-friendly** to be accepted by the designers
3. … and, using the numerical technologies suitable for the **daily** design process

Simulation-Based Design

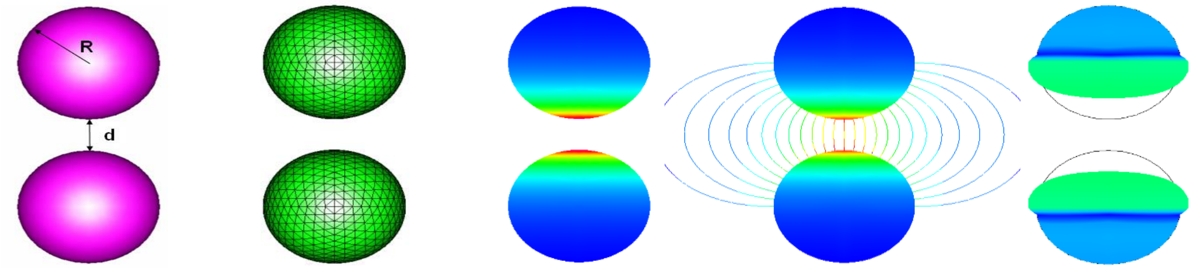
Experimentally-based prototyping

Simulation-Based Design



Digital "prototype"

SBD Roadmap



Geometry Design → **Mesh Generation** → **Analysis** → **Criteria Evaluation** → **Optimization**

CAD
- PTC (Pro/E)
- Catia
- SolidWork
- SolidEdge
- …

- CADfix
- ProE
- Patran
- …

FEM
- ANSYS
- Infolytica
- Vector Fields
- …
- **BEM**
- **Polopt (PT)**

PT
- FLC
- CVC
- CPC

PT
- FFO
- Parametric Opt.
- FFO & ParOPT

Simulation-Based Design

The physics behind …

Acoustics

Fluid-Dynamics

Elasto-Dynamics

Heat Transfer

"*Single-physics*" *processes*

"*Multi-physics*" *processes*

Electro-Magnetismus
(Maxwell Equations)

High frequency

- Antennas radiation
- Wave-guides
- Scattering problems
- EMC
- …

Low freq

Steady-State

- Eddy-Current problems

Static / Quasi-Static

- Electro-Static problems
- Magneto-Static problems

Transformers, Switchgears, Sensors, …

Avoid **breakdown appearance** in all operational conditions

Dielectric Design

Simulation-Based Design

The physics behind …

“Single-physics” processes

Fluid-Dynamics

Elasto-Dynamics

Heat Transfer

s” processes

Avoid **mechanical deformations** caused by the short-circuit appearance

Electro-Magnetismus
(Maxwell Equations)

Electro-Magnetismus
High frequency

- Antennas radiation
- Wave-guides
- Scattering problems
- EMC
- …

Electro-Magnetismus
Low frequency

Steady-State

- Eddy-Current problems

Static / Quasi-Static

- Electro-Static problems
- Magneto-Static problems

El-Mech. Design

Dielectric Design

Simulation-Based Design

The physics behind …

"Single-physics" processes

Elasto-Dy

Avoid material degradation caused by the thermal overheating

Heat Transfer

"Multi-physics"

Electro-Magnetismus
(Maxwell Equations)

Electro-Magnetismus
High frequency

Electro-Magnetismus
Low frequency

Steady-State **Static / Quasi-Static**

- Antennas radiation
- Wave-guides
- Scattering problems
- EMC
- …

- Eddy-Current problems

- Electro-Static problems
- Magneto-Static problems

Thermal Design

El-Mech. Design

Dielectric Design

Thermal Design

El-Mech. Design

Dielectric Design

Simulation-Based Design in Electrical Engineering

- Simulation-Based Design in Engineering Praxis
- **Dielectric Design of HV Products**
- Magnetic Design in EE
- Coupled Problem
- Optimization 1
- Optimization 2

SBD in ED: Dielectric Design of HV Products

Main technical challenges

- When designing the HV apparatus (like switchgear, transformers), it is important to properly design the dielectric insulation with respect to possible **overvoltages**.

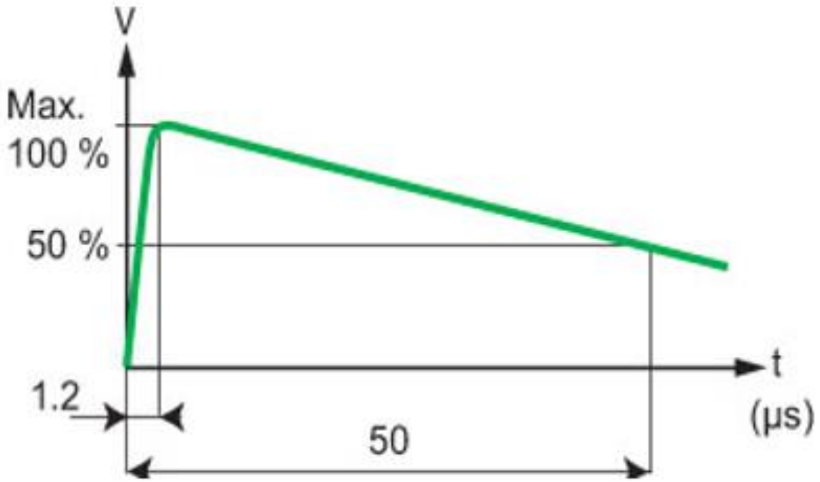
- Typically, two class of problems relate to the dielectric design:
  1. Determination of the **voltage stress** which the insulation must withstand
  2. Determination of the **response of the insulation,** when subjected to these voltages stresses

The balance between the **electrical stress** on the insulation and the **dielectric strength** of the insulation is a key task of the **insulation coordination** within dielectric design!

SBD in ED: Dielectric Design of HV Products

Within DD of HV products, each HV devices' series has to be tested against:

- **Power frequency voltage** (*1min. test under 50Hz (60Hz*))
- **Switching impulse** – recommended for the equipment under the voltages above 300kV
- **Lightning impulse voltage**



Form of the lightning impulse voltage. Peak is reached within $1.2\mu s$

SBD in ED: Dielectric Design of HV Products

- Those kinds of tests are usually carried out in the specialized HV lab. One of the very well know is **KEMA** in Holland / USA.
- An equivalent laboratory in Italy is **CESI**.

HV testing laboratory KEMA, Holland

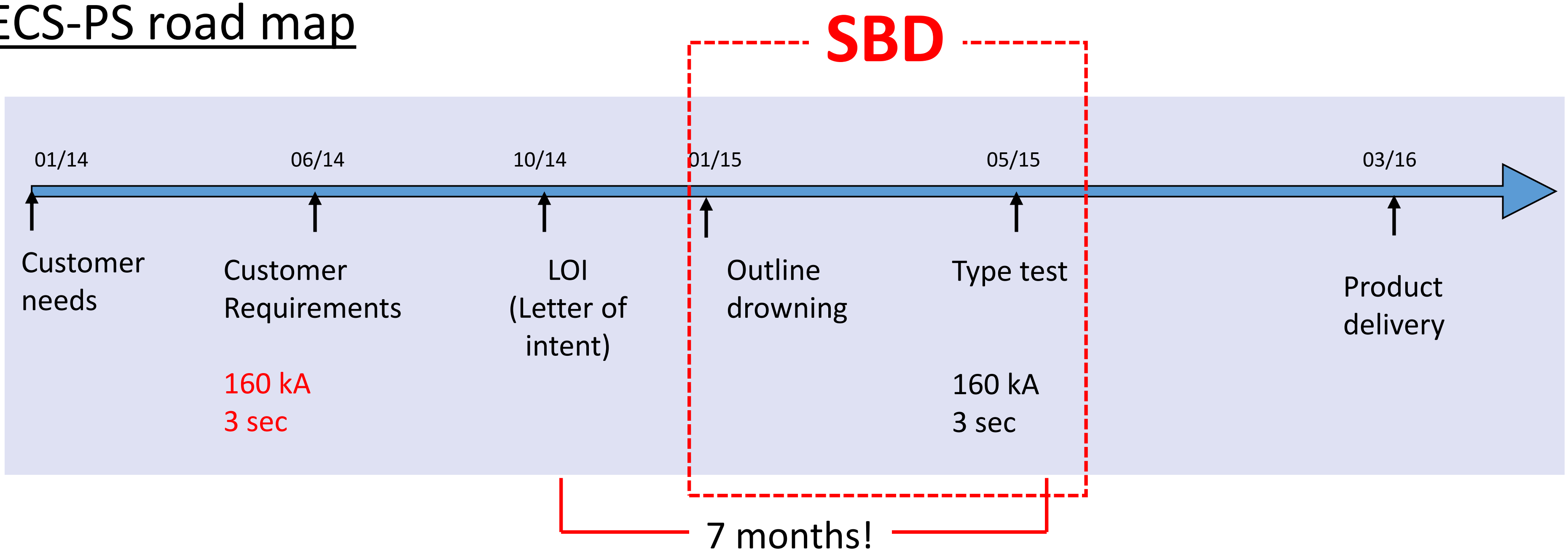
SBD in ED: Dielectric Design of HV Products

How the design process of one the HV products looks like?

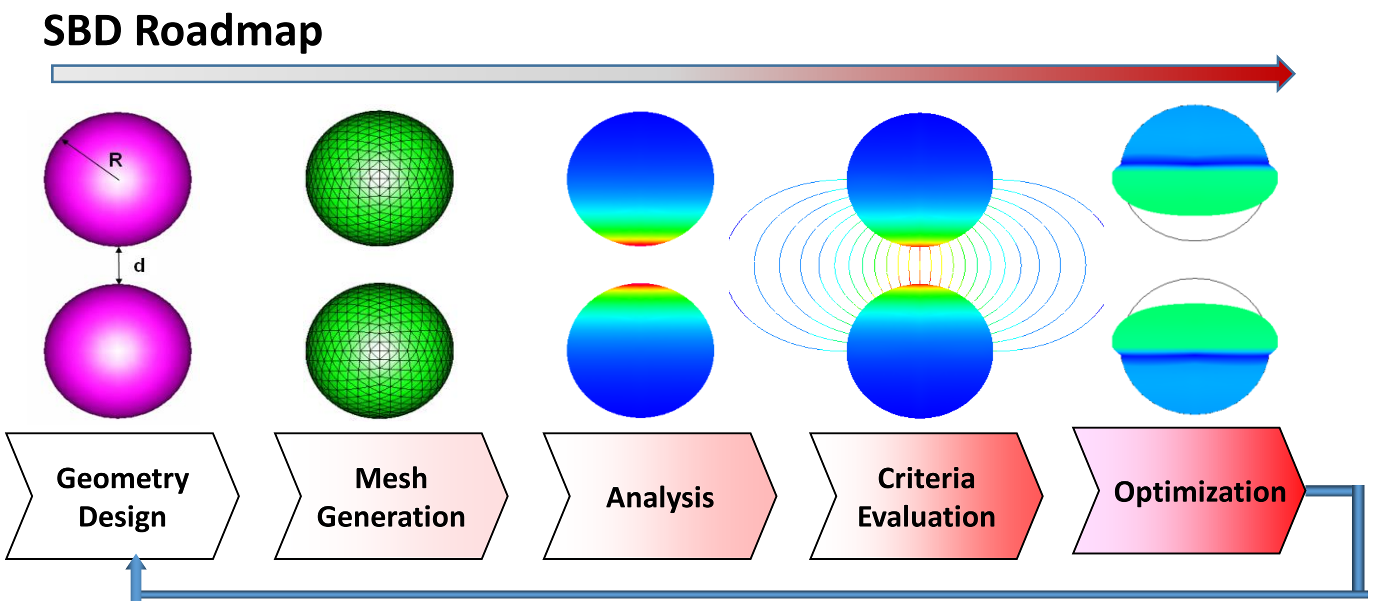
SBD in ED: Dielectric Design of HV Products

HECS-PS: new product in ABB GCB environment!

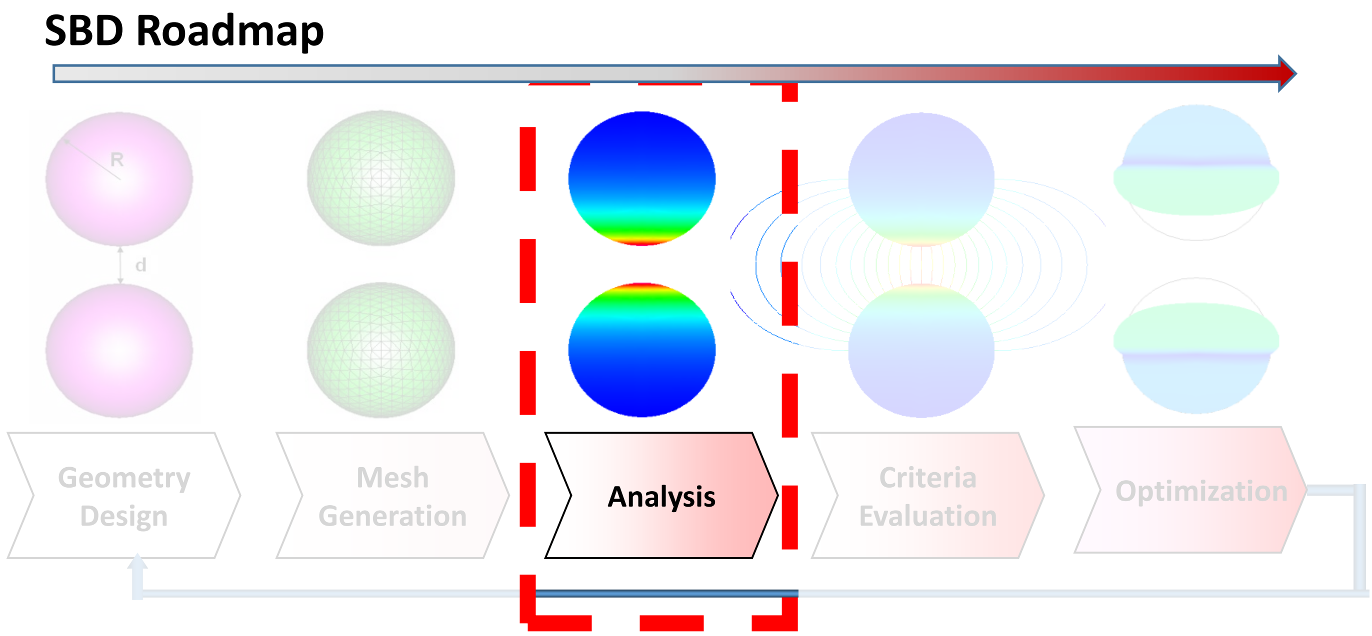
HECS-PS road map



SBD in ED: Dielectric Design of HV Products

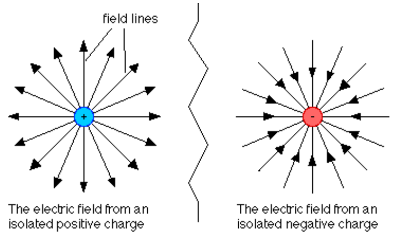


SBD in ED: Dielectric Design of HV Products



- Mathematical model
- Numerical representation
- Some examples

Maxwell Equations



$$Gauss'\ law\ for\ electricity:\ \nabla \cdot \mathbf{D} = \rho_e \quad \begin{bmatrix} \mathbf{D} = \varepsilon_0 \mathbf{E} + \mathbf{P} & \mathbf{D} = \varepsilon_0 \mathbf{E} \text{ - Free space} \\ \text{General case} & \mathbf{D} = \varepsilon \mathbf{E} \text{ - Isotropic linear dielectric} \end{bmatrix}$$

The electric flux leaving a volume is proportional to the charge inside.

$$Gauss'\ law\ for\ magnetism:\ \nabla \cdot \mathbf{B} = 0 \quad (\text{no magnetic monopoles!})$$

The total magnetic flux through a closed surface is zero

$$Faraday's\ law\ of\ induction:\ \nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

The voltage induced in a closed loop is proportional to the rate of change of the magnetic flux that the loop encloses.

$$Amper's\ law:\ \nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t} \quad \begin{bmatrix} \mathbf{B} = \mu_0 (\mathbf{H} + \mathbf{M}) & \mathbf{B} = \mu_0 \mathbf{H} \text{ - Free space} \\ \text{General case} & \mathbf{B} = \mu \mathbf{H} \text{ - Isotropic linear magnetic media} \end{bmatrix}$$

The magnetic field integrated around a closed loop is proportional to the electric current plus displacement current

Electrostatics

Assuming that there is no magnetic field, (B=0)

$$Gauss' \ law \ for \ electricity: \ \nabla \cdot \mathbf{D} = \rho$$

$$Faraday's \ law \ of \ induction: \nabla \times \mathbf{E} = 0$$

Different Notation:

$$\begin{bmatrix} div\mathbf{D} = \rho \\ \mathbf{curlE} = 0 \end{bmatrix} \begin{bmatrix} div\mathbf{D} = \rho \\ \mathbf{rotE} = 0 \end{bmatrix}$$

Gauss' law for electricity

$$\nabla \cdot \mathbf{D} = \rho \Rightarrow \nabla \cdot \mathbf{E} = \rho / \varepsilon \Rightarrow \left| \mathbf{E} = -\nabla \varphi \right| \Rightarrow \nabla^2 \varphi = -\rho / \varepsilon$$

Poisson's equation

Boundary conditions

$$\varphi_1 = \varphi_2$$

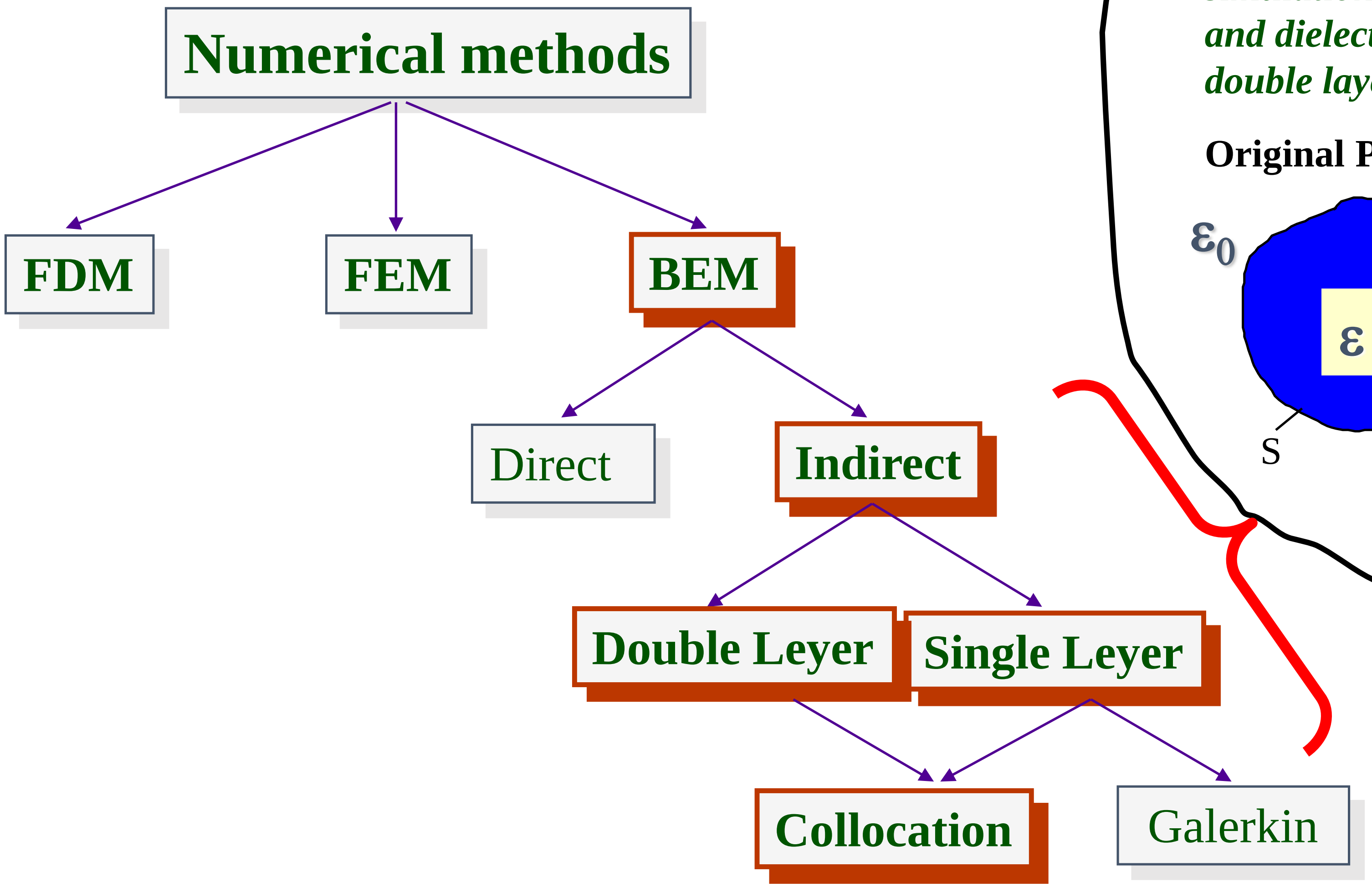
$$\varepsilon_1 \frac{\partial \varphi_1}{\partial n} - \varepsilon_2 \frac{\partial \varphi_2}{\partial n} = \sigma$$

For homogeneous media, where the space charge $\rho = 0$

$$\nabla^2 \varphi = 0$$

Laplace's equation

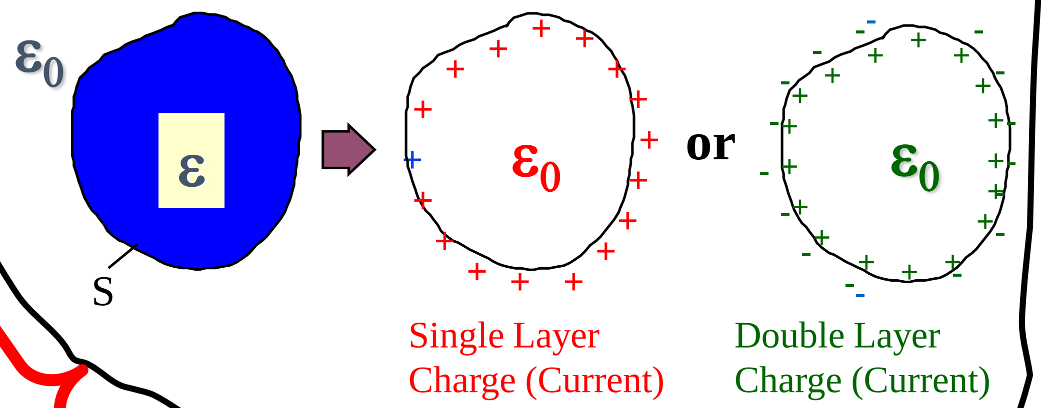
Electrostatics



Basic idea:

simulation of real charges/currents on electrodes and dielectrics by the equivalent sources of single or double layer

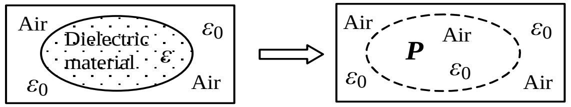
Original Problem **Equivalent Problems**



BEM for Dielectric Problems

Formulation: Single-Layer Ansatz

$$\triangle\varphi = 0 \quad \& \quad \phi_1 = \phi_2 \quad \& \quad \varepsilon_1 \frac{\partial \phi_1}{\partial n} - \varepsilon_2 \frac{\partial \phi_2}{\partial n} = \sigma$$



$$\varphi(I) = \frac{1}{4\pi\varepsilon_0} \int_S \sigma(J) \frac{1}{r_{IJ}} dS_J$$

← I FIE (potential continuity)

Fictive charges

$$\sigma(I) = \frac{\lambda}{2\pi} \int_S \sigma(J) \cdot \frac{\vec{r}_{IJ} \cdot \vec{n}_I^{\,0}}{\vec{r}_{IJ}^{\,3}} dS_J$$

← II FIE (flux continuity)

Implementation:

- *Method*: Collocation / Galerkin
- *Ansatz*: Direct / Indirect
- *Approximations*:
  geometry-quadratic
  sources - linear

BEM for Dielectric Problems

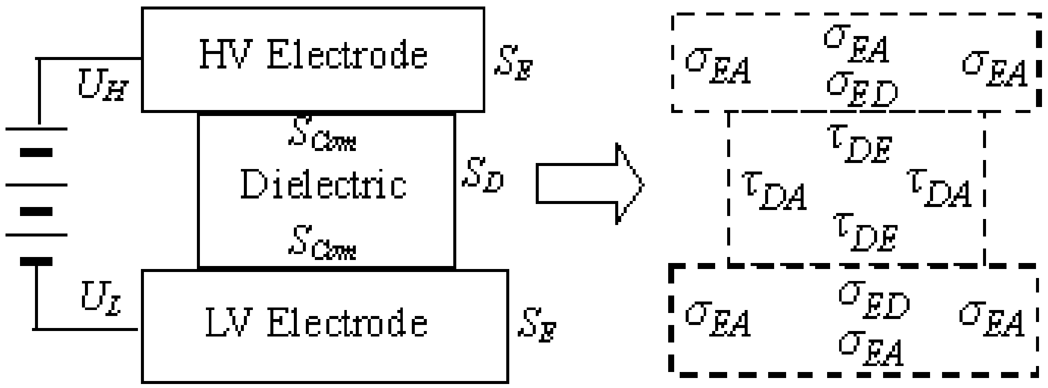
Formulation: Double-Layer Ansatz

$$\triangle\varphi = 0 \quad \& \quad \phi_1 - \phi_2 = \frac{1}{\varepsilon_0}\tau \quad \& \quad (\boldsymbol{E}_1 - \boldsymbol{E}_2)\cdot\boldsymbol{n} = 0$$

$$\varphi(I) = \frac{1}{4\pi\varepsilon_0}\int_S \sigma(J)\frac{1}{r_{IJ}}dS_J$$

Double-Layer charges

$$\frac{\Omega_P(\varepsilon_r - 1) + 4\pi}{4\pi(\varepsilon_r - 1)}\tau_l(P_o) + \int_{S_d}\tau_l\frac{\mathbf{n}_i\cdot\mathbf{r}}{4\pi r^3}dS = -\varepsilon_0\phi_{Ex}(P_o)$$



Flux-density potential:

$$\varphi_J = \varphi_{\sigma J} + \varphi_{\tau J} = \int_{S_E}\sigma_I\frac{1}{4\pi r_{JI}}dS_I + \int_{S_D}\tau_I\frac{\boldsymbol{n}_I\cdot\boldsymbol{r}_{JI}}{4\pi r_{JI}^3}dS_I$$

Flux density:

$$\boldsymbol{D}_J = -\nabla\varphi_J = \int_{S_E}\sigma_I\frac{\boldsymbol{r}_{JI}}{4\pi r_{JI}^3}dS_I + \sum\tau_I\oint_{\Delta L_D}\frac{\boldsymbol{t}_I\times\boldsymbol{r}_{JI}}{4\pi r_{JI}^3}dL_I$$

J. A. Stratton: ***Electromagnetic Theory***
McGraw-Hill, Inc. 1941, ISBN 07-062150-0

Z. Andjelic, K. Ishibashi, P. Di Barba: **Novel Double-Layer BEM for Dielectric Design**, IEEE TDEI 2018 (in print)

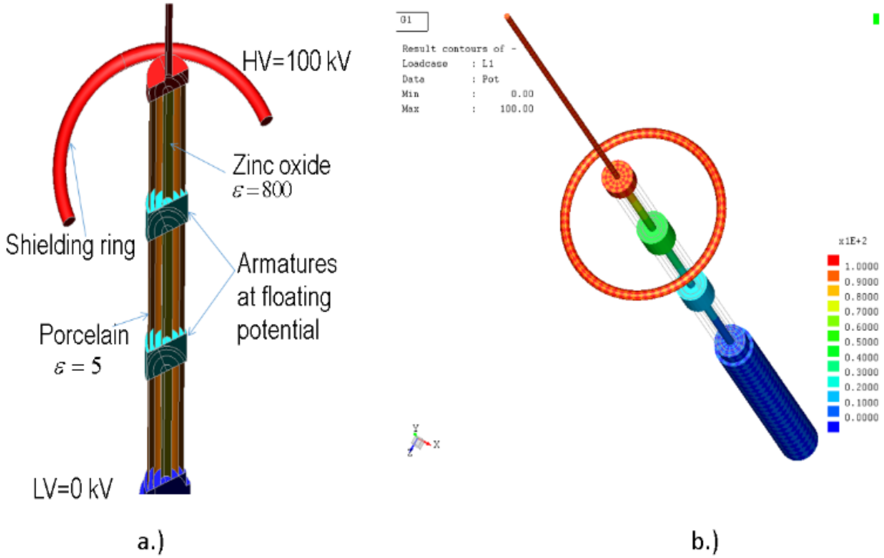
BEM for Dielectric Problems

Formulation: Double-Layer Ansatz

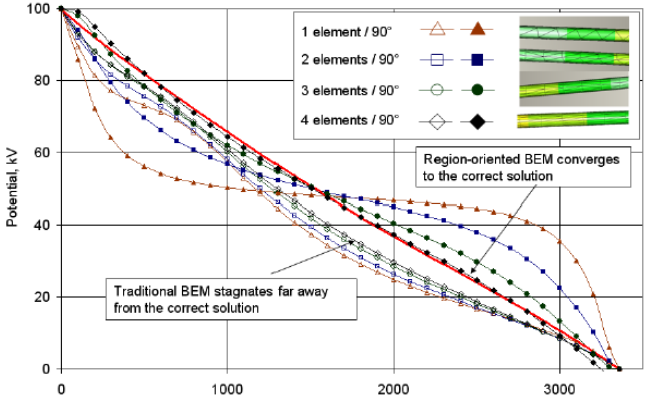
$$\varphi(I)=\frac{1}{4\pi\varepsilon_0}\int_S \sigma(J)\frac{1}{r_{IJ}}dS_J$$

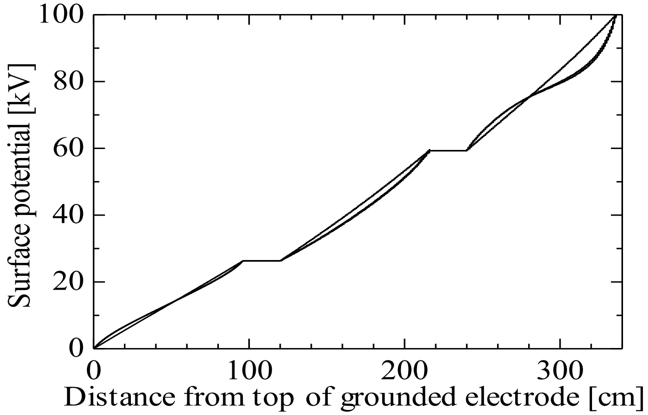
Double-Layer charges

$$\frac{\Omega_P\left(\varepsilon_r-1\right)+4\pi}{4\pi\left(\varepsilon_r-1\right)}\tau_l\left(P_o\right)+\int_{S_d}\tau_l\frac{\mathbf{n}_i\cdot\mathbf{r}}{4\pi r^3}dS=-\varepsilon_0\phi_{Ex}\left(P_o\right)$$



a. IEC surge-arrester model with two floating electrodes and grading ring;
b. b. Potential distribution along the zinc-oxide / HV/ LV components





Potential distribution of IEC surge-arrester model

Indirect Approach: Double-Layer Electrostatic Formulation

$$\varphi(I) = \frac{1}{4\pi\varepsilon_0}\int_S \sigma(J)\frac{1}{r_{IJ}}dS_J$$

$$\frac{\Omega_P(\varepsilon_r - 1) + 4\pi}{4\pi(\varepsilon_r - 1)}\tau_l(P_o) + \int_{S_d}\tau_l\frac{\mathbf{n}_i\cdot\mathbf{r}}{4\pi r^3}dS = -\varepsilon_0\phi_{Ex}(P_o)$$

Sources approximation	Geometry approximation
$\sigma = \sum_{i=1}^{n}\sigma_i \cdot N_i$	$\vec{r} = \sum_{i=1}^{m}\vec{r}_i \cdot N_i$

$$\tilde{\varphi}(I) = k_1 \sum_{All\_domains}\sum_{GP}\tilde{\sigma}(J)\cdot\tilde{K}_1\cdot\Delta S_e$$

$$\tau(I) = k_2 \sum_{All\_domains}\sum_{GP}\tilde{\tau}(J)\cdot\tilde{K}_2\cdot\Delta S_e$$

$$\begin{bmatrix} a_{1,1} & a_{1,2} & a_{1,3} & \dots & a_{1,n} \\ a_{2,1} & a_{2,2} & a_{2,3} & \dots & a_{2,n} \\ \vdots \\ a_{m,1} & a_{m,2} & a_{m,3} & \dots & a_{m,n} \\ a_{m+1,1} & a_{m+1,2} & a_{m+1,3} & \dots & a_{m+1,n} \\ a_{m+2,1} & a_{m+2,2} & a_{m+2,3} & \dots & a_{m+2,n} \\ \vdots \\ a_{n,1} & a_{n,2} & a_{n,3} & \dots & a_{n,n} \end{bmatrix} \begin{bmatrix} \sigma \\ \tau \end{bmatrix} = \begin{bmatrix} \phi \\ 0 \end{bmatrix}$$

$$[A][x] = [V]$$

Static problems

(dielectric design)

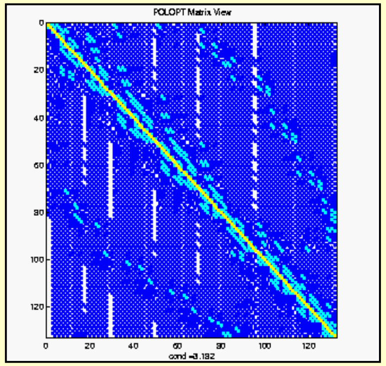
Fredholm integral equations

1 DOF (real scalars)

Typical problem size: 10.000-20.000 unknowns

Typical matrix size: < 200Mb

Matrix: full populated, diagonal dominant



Typical calc. time: ~1 Hours (serial)

Accuracy: mesh insensitive

Steady-stade problems

(eddy-currents)

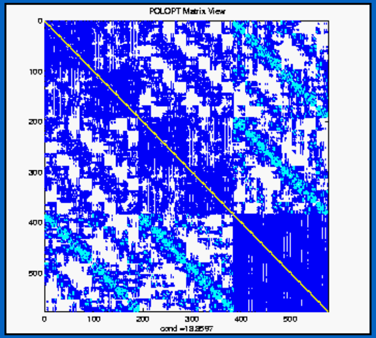
H-ϕ formulation

Min. 3 DOF (complex vectors)

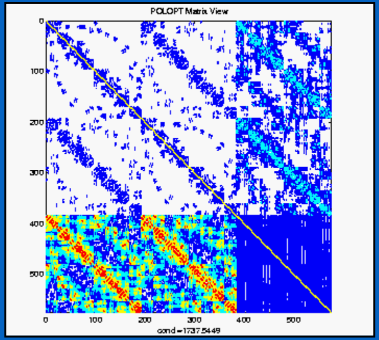
Typical problem size: 10-20.000 unknowns

Typical matrix size: > 4 Gb

Matrix: full populated, diagonal dominance depends on material parameters



Copper (μ=1)



Steel (μ=200)

Typical calc. time: 1-2 days (serial)

Accuracy: highly mesh dependent

BEM: Integration

Major Problems

Matrix generation: | Major Impact:

"Near-field" integration
- singular integration
- nearly-singular integration
- aspect ratio problem

→ **Accuracy, Robustness**

"Far-field" integration → **Speed**

Matrix solution:

Matrix conditioning → **Convergence**

Standard BEM

- **Main bottlenecks**: **Full populated matrices**
  - huge memory size
  - long computational time

MBIT / ACA – Acceleration / Compression Techniques

$$G_{ij} = \int_0^1 \int_0^1 \varphi_i(x)\, g(x,y)\, \varphi_j(y)\, dx\, dy$$

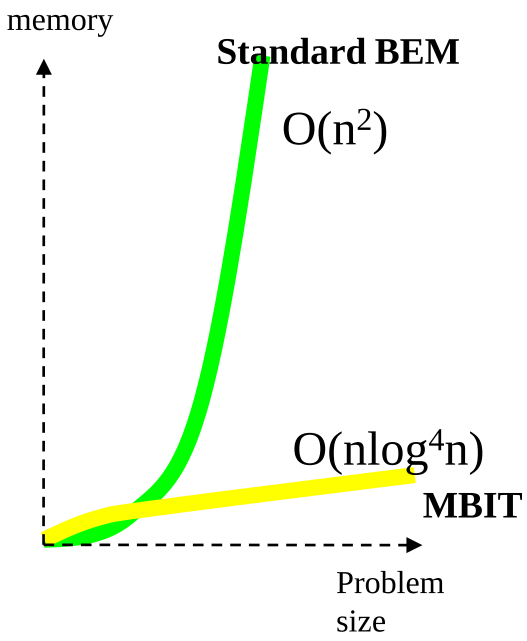
Kernel: Singular for x=y

Smoothly decaying for |x-y|→∝

Key idea: Divide space of interest into near-field and far-field.

Near-field: exact computing of G_{ij}

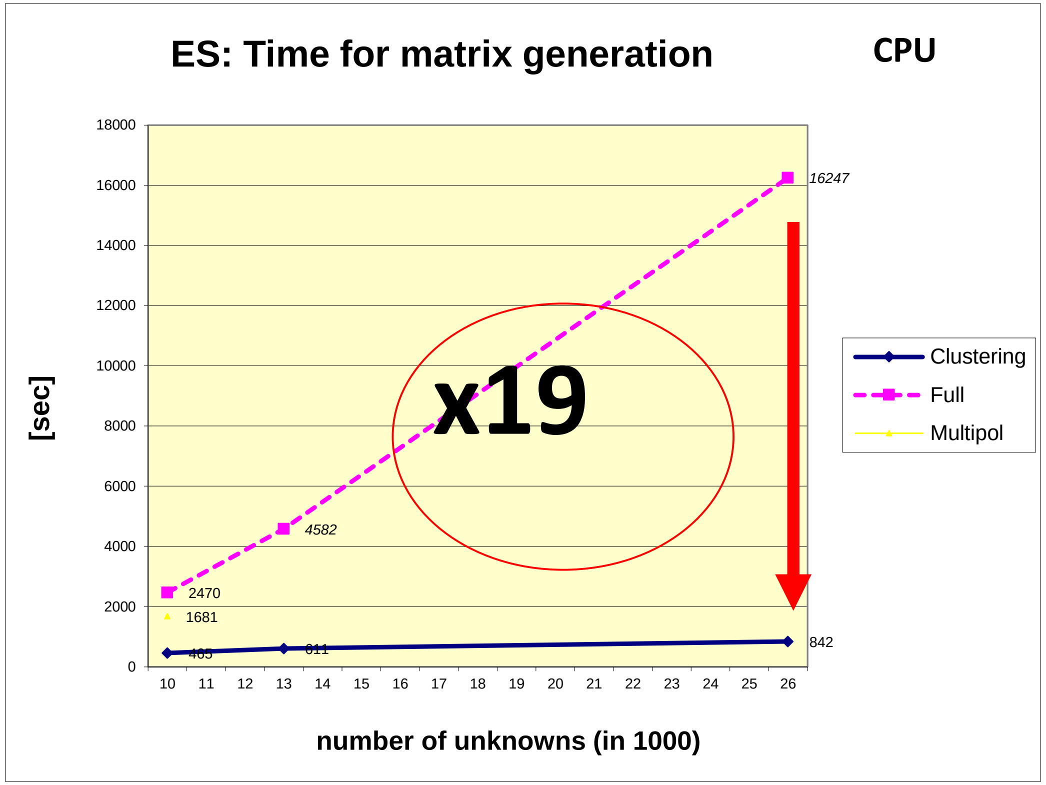
Far-field: only approximations of G_{ij}

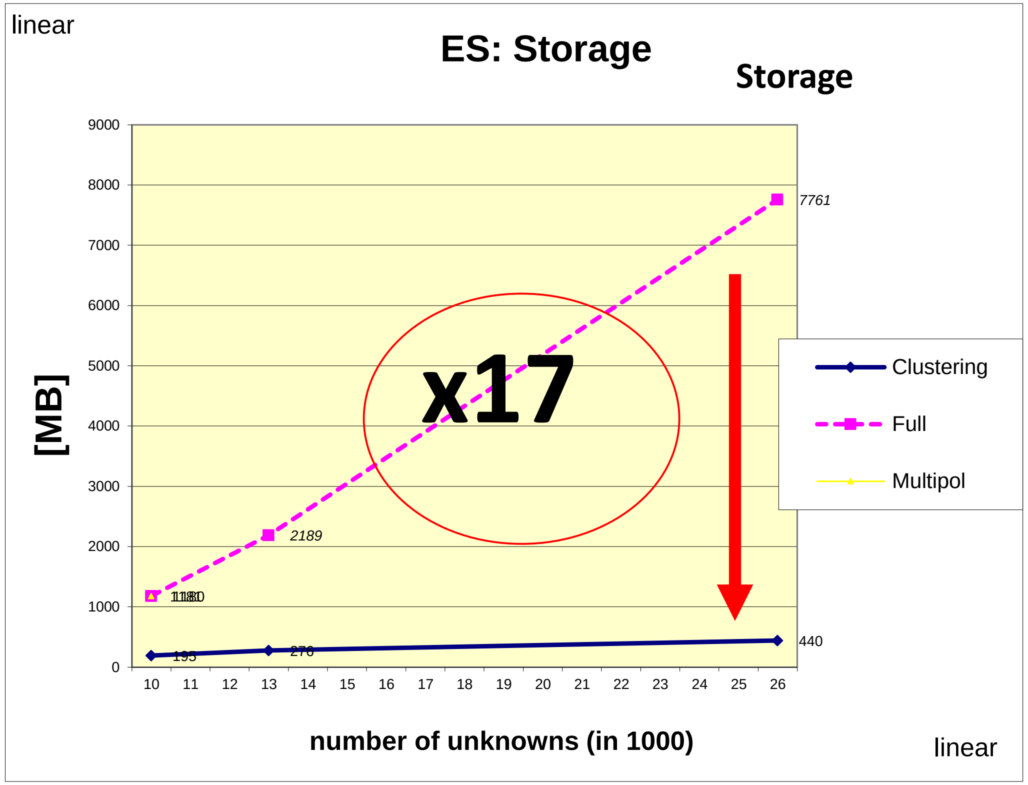


J.Carrier, L.Greengard, V. Rokhlin: **A Fast Adaptive Multipole Algorithm for Particle Simulations** *SIAM Journal of Scientific and Statistical Computing*, 9(4), 1988.

M. Bebendorf, S. Rjasanow: **Adaptive low-rank approximation of collocation matrices** Computing, 70 (2003), 1-24

Difference between techniques: Far-Field treatment!


ES: Time for matrix generation
CPU
[sec]
x19
Clustering
Full
Multipol
16247
4582
2470
1681
842
number of unknowns (in 1000)


linear
ES: Storage
Storage
[MB]
x17
Clustering
Full
Multipol
7761
2189
440
number of unknowns (in 1000)
linear

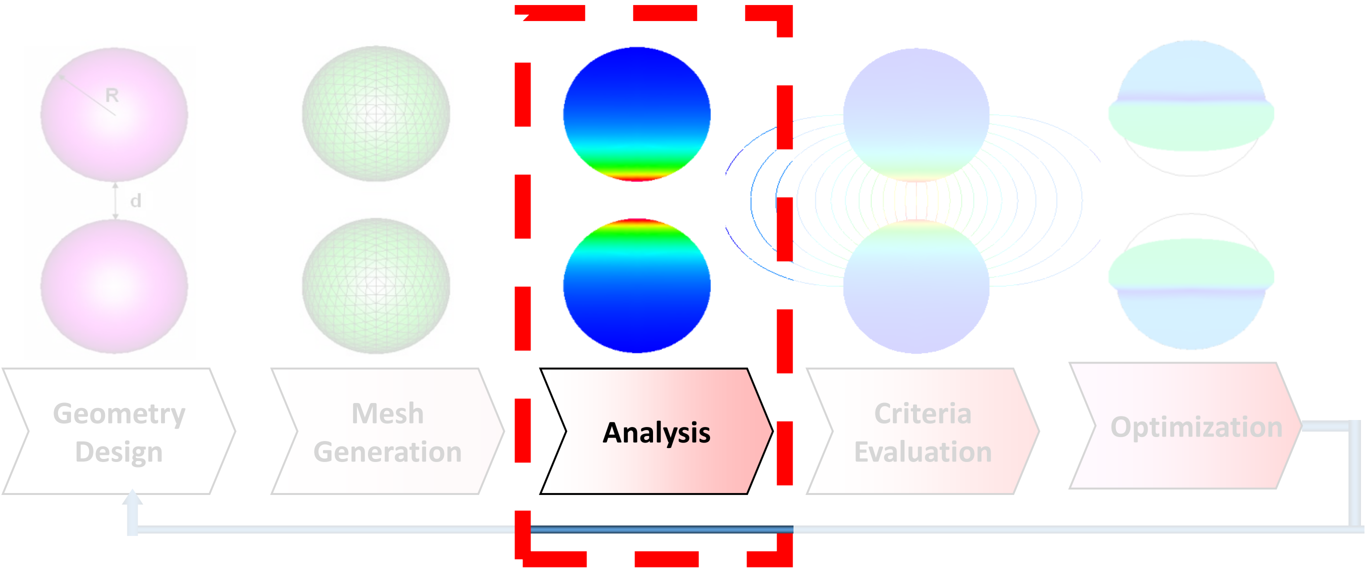
BEM for Dielectric Problems

Formulation: Double-Layer Ansatz

Main features

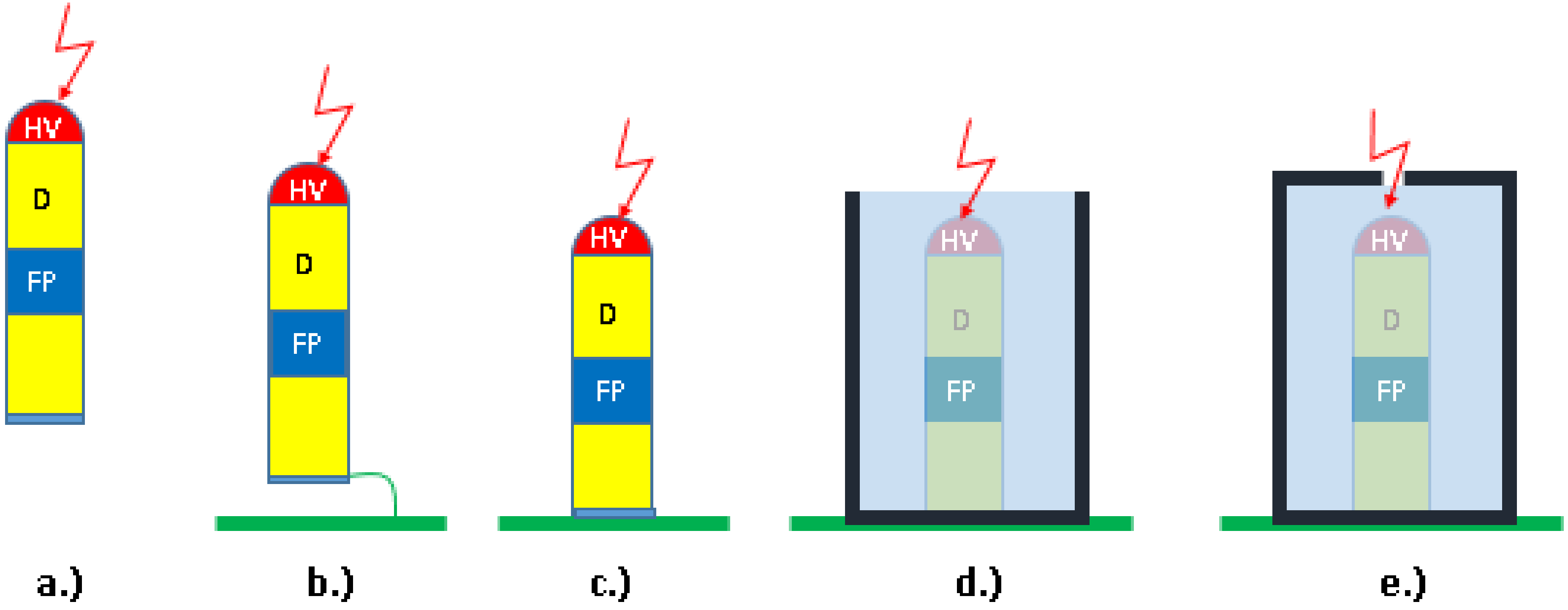
- *Highly accurate treatment of dielectric problems independent of the material features of the dielectric components,*
- *Robust calculation of the problems exhibiting geometrical singularities (edges and corners),*
- *Novel singularity-less calculation of the electrical field / flux,*
- *The calculated charge densities correspond to the real physical quantities (instead of fictitious as in SCM!),*
- *Thanks to 4, capacitances of the analyzed model are inherent output i.e. direct function of the calculated charges (no need for extra capacitance run!)*
- *Easy treatment of the floating–potential problems.*

SBD in ED: Dielectric Design of HV Products



- Mathematical model
- Numerical representation
- **Some examples**

Electrostatic Problems Classification



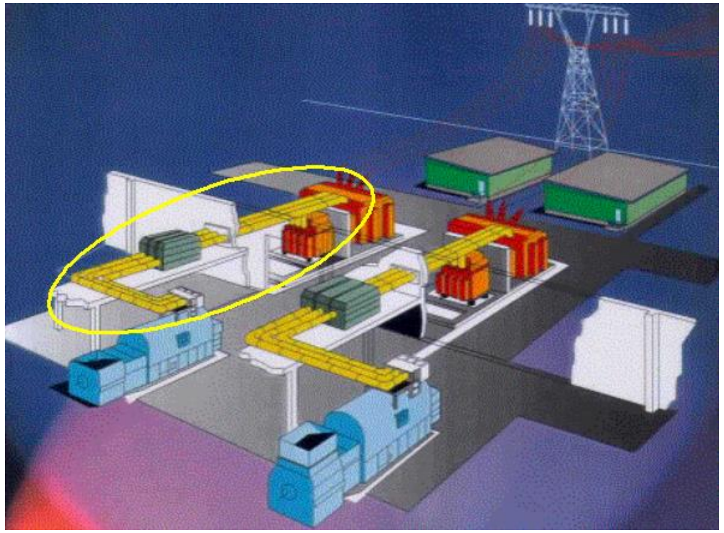
TEC | MIM | MIM | Standard BEM? | Standard BEM

TEC - Total Electrode Charge

MIM - Mirror-Imaging Method

Z. Andjelic, K. Ishibashi, P. Di Barba: **Novel Double-Layer BEM for Dielectric Design**, IEEE TDEI 2018 (in print)

SBD in ED: Dielectric Design of HV Products



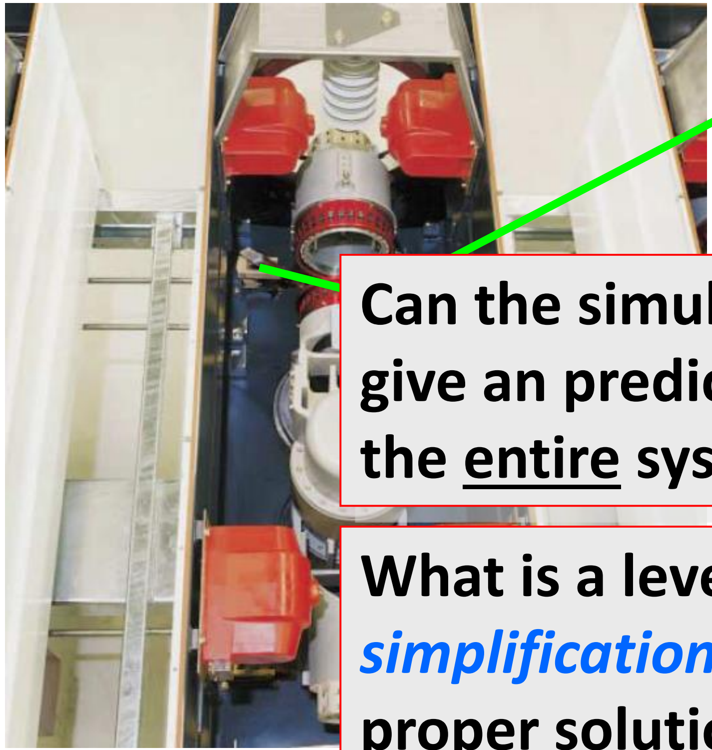
Generator Circuit Breaker Systems

Task:

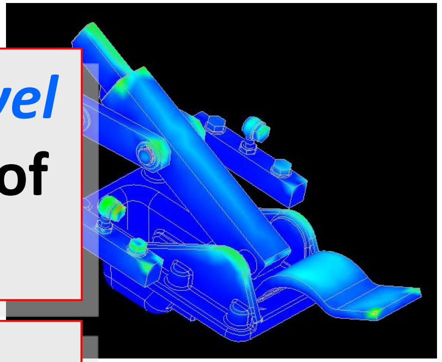
Predict a breakdown voltage (safety margin) for all operating conditions:

Nominal voltages: 17-30 kV
Nominal currents: 6-28 kA
Short-circuit currents: 50-160 kA

SBD in ED: Dielectric Design of HV Products



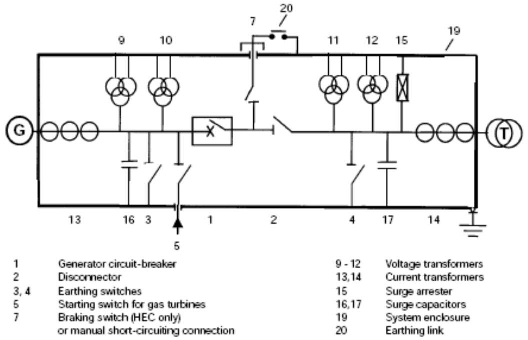
Interrupting chamber

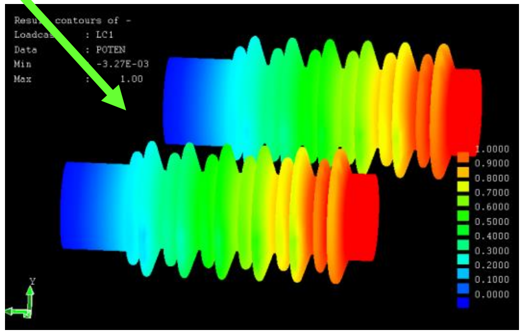


Can the simulation at the *component level* give an prediction on the *safety margin* of the <u>entire</u> system?

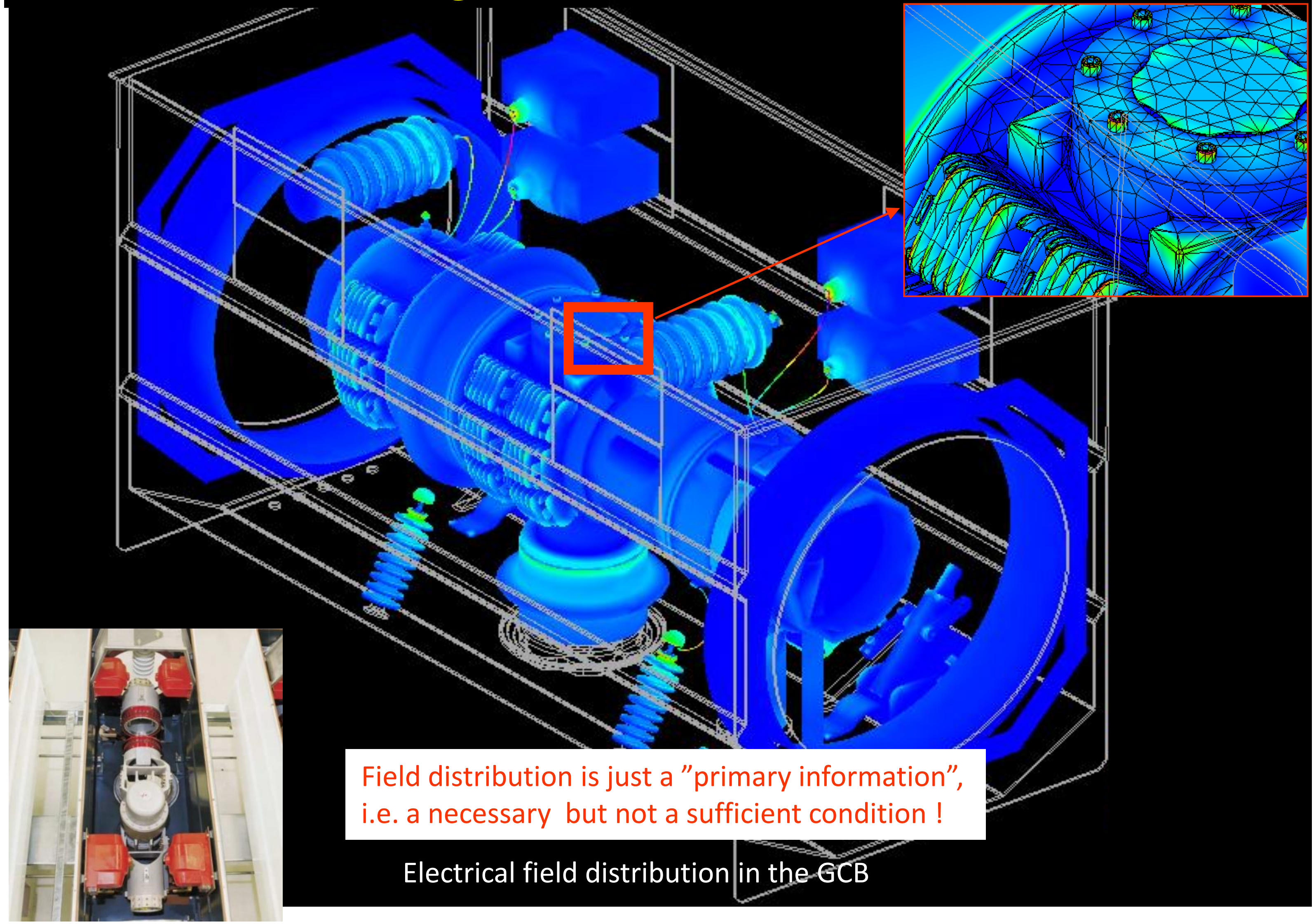
What is a level of the *model simplifications* that still guarantee the proper solution?

Equipment options



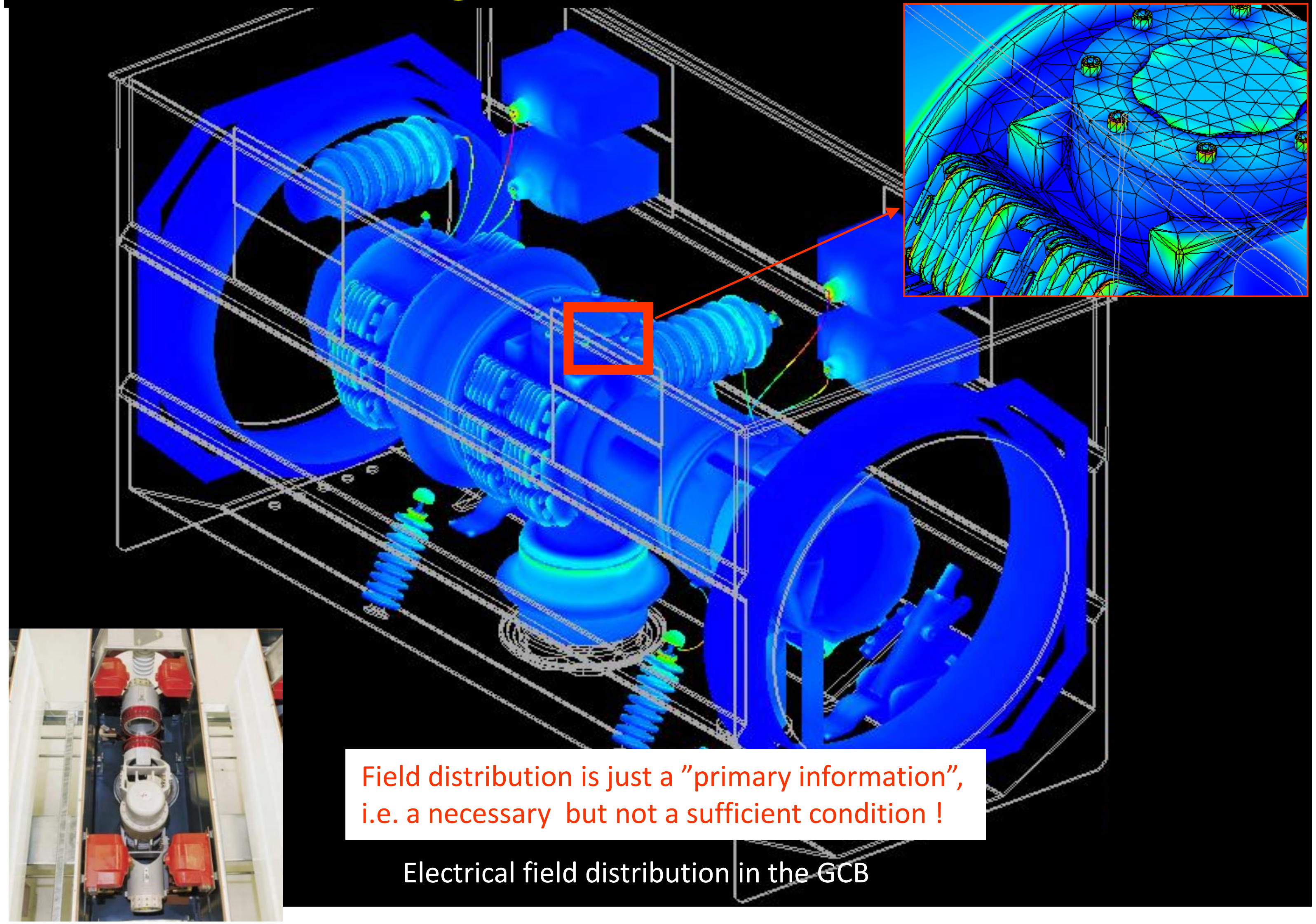


GCBS /Dielectric Design

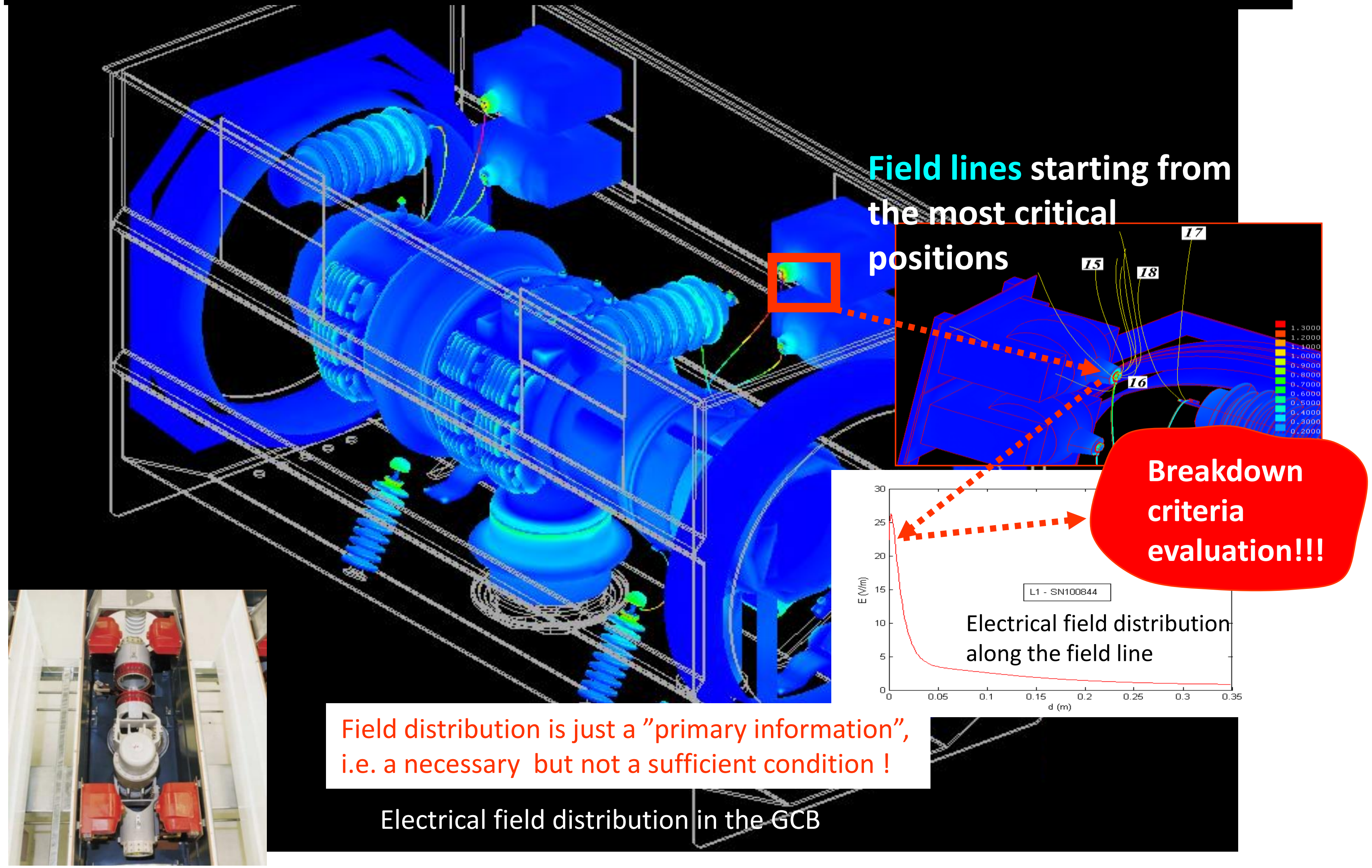


Electrical field distribution in the GCB

GCBS /Dielectric Design

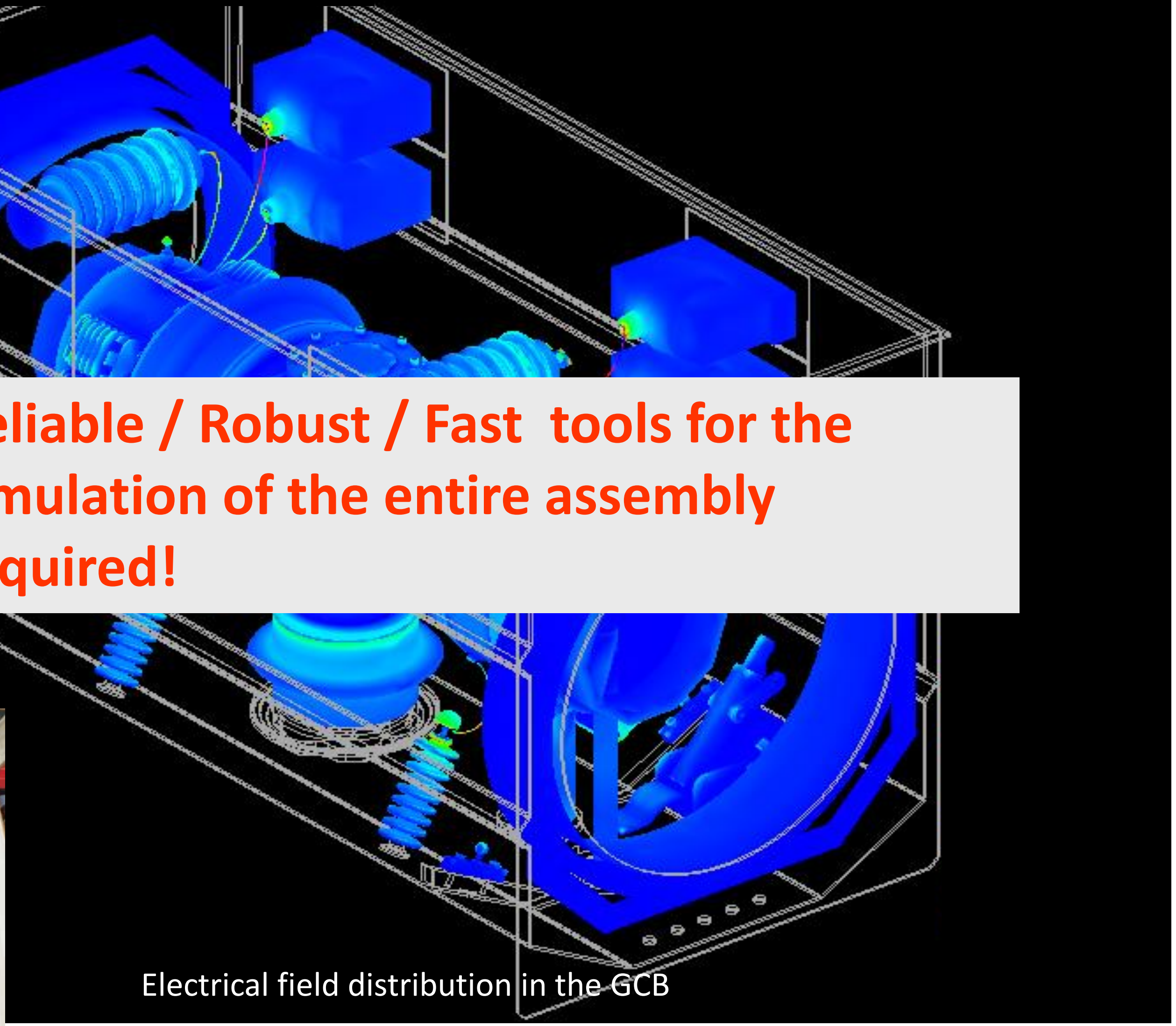


GCBS /Dielectric Design



GCBS /Dielectric Design

POLOPT

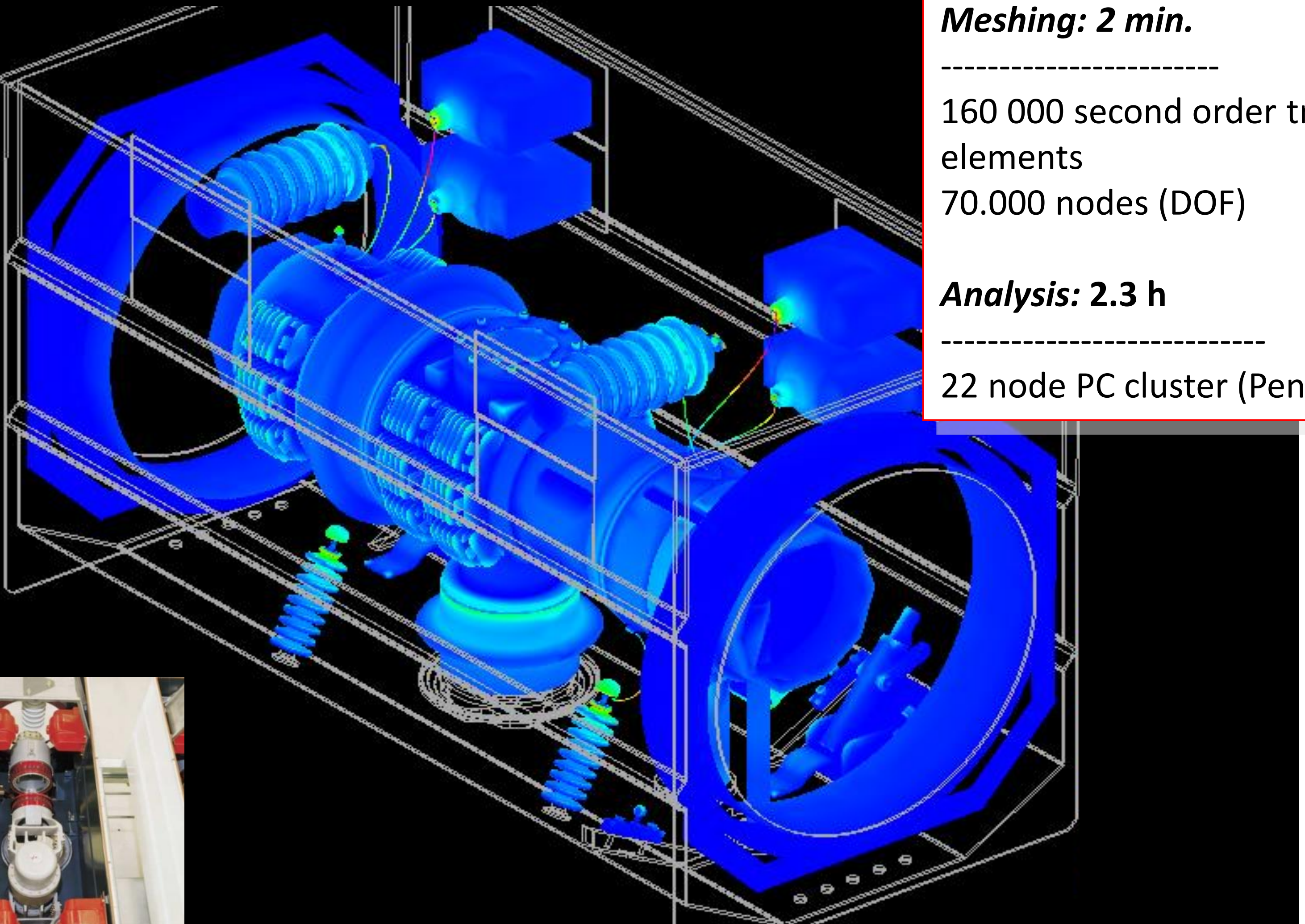


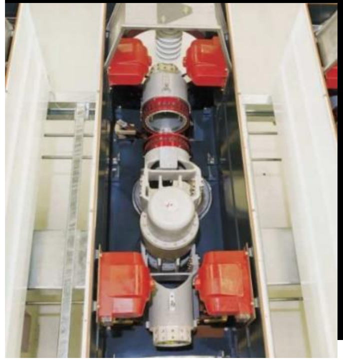
Reliable / Robust / Fast tools for the simulation of the entire assembly required!

Electrical field distribution in the GCB

GCBS /Dielectric Design

POLOPT





Electrical field distribution in the GCB

Meshing:* *2 min.

----

160 000 second order triangle elements

70.000 nodes (DOF)

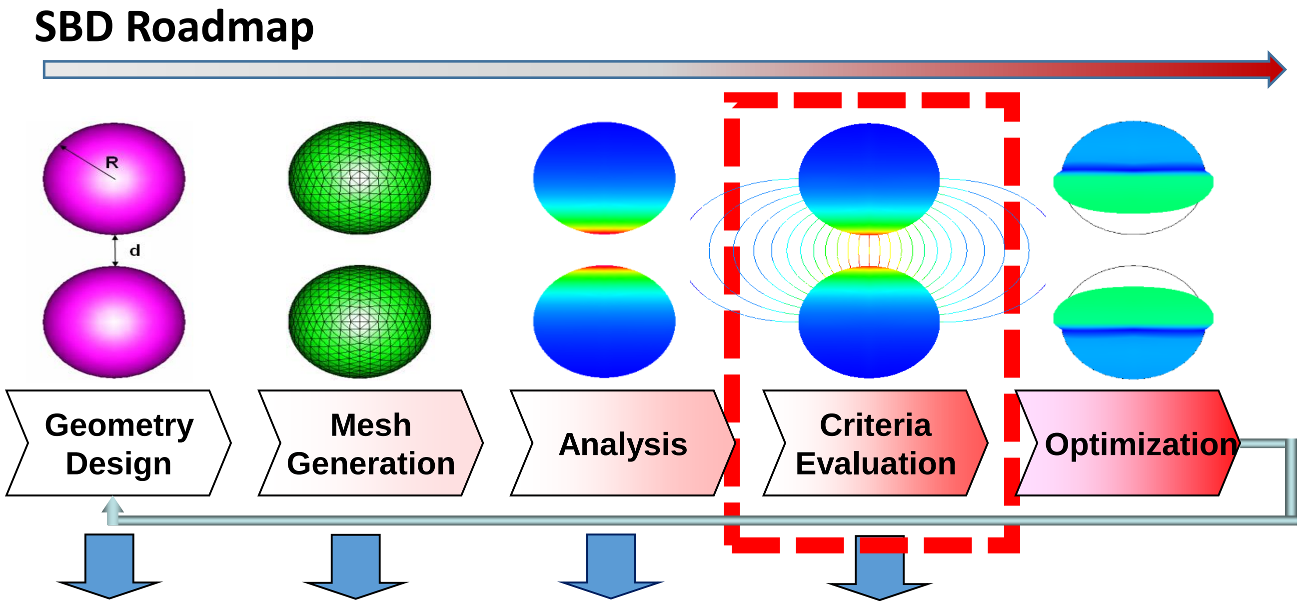
Analysis: **2.3 h**

----

22 node PC cluster (Pentium3)

Dielectric Design Criteria

Dielectric Design Criteria



- Pro/E
- Ideas
- Catia
- SolidWork
- SolidEdge
- …

- CADfix
- ProE
- Patran
- Ideas
- …

FEM
- Ansys
- Maxwell
- Vector Fields
- …
- ***BEM***
- IES
- **Polopt**

POLOPT/Laplace
- FLC
- CVC
- CPC

E. Kuffel, W.S. Zaengl: **High Voltage Engineering**, Pergamon Press, 1984, ISBN 0-08-024213-8

Z. Andjelic, S. Sadovic: **Reduction of the Breakdown Appearance by Automatic Geometry Optimization**, Conf. On El. Insulation and Dielectric Phenomena, 2007, ISBN 978-1-4244-1481-9

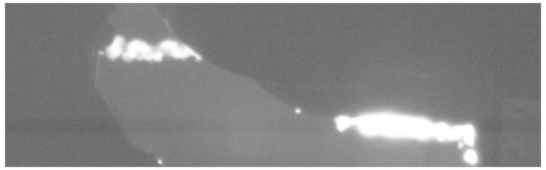
A. Blaszczyk: **Flashover Workshop** 2006, Baden Deattwil

H. Böhme: **Mittelspannung Technik**, 2005, ISBN-10: 3341014950

What is a main purpose of the Design Criteria (DC) ?

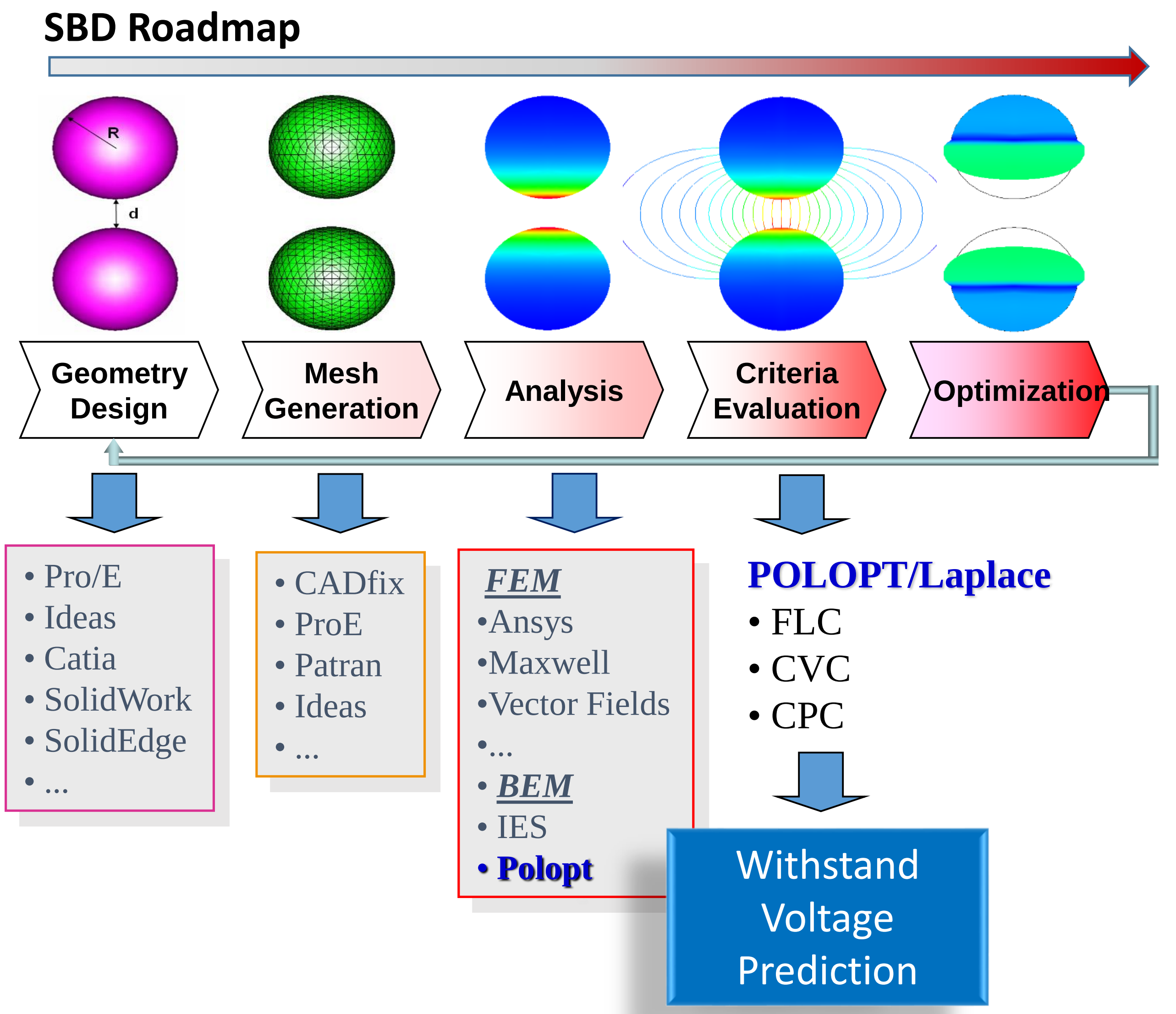
Design Criteria serve to predict weather or not the **Breakdown**/**Flashover** can happened!

What is a flashover ?



- **Flash-over** – is a discharge in a gas along the surface of a solid dielectric [IEC].
- **Spark-over** – is a discharge across a gap between electrodes in a gas.
- **Withstand voltage** - is the highest voltage applied to an arrangement that, with a low probability (<2%), can lead to a discharge.
- **Breakdown voltage** is a voltage that will lead to a discharge.

Prediction of withstand voltage in a design system



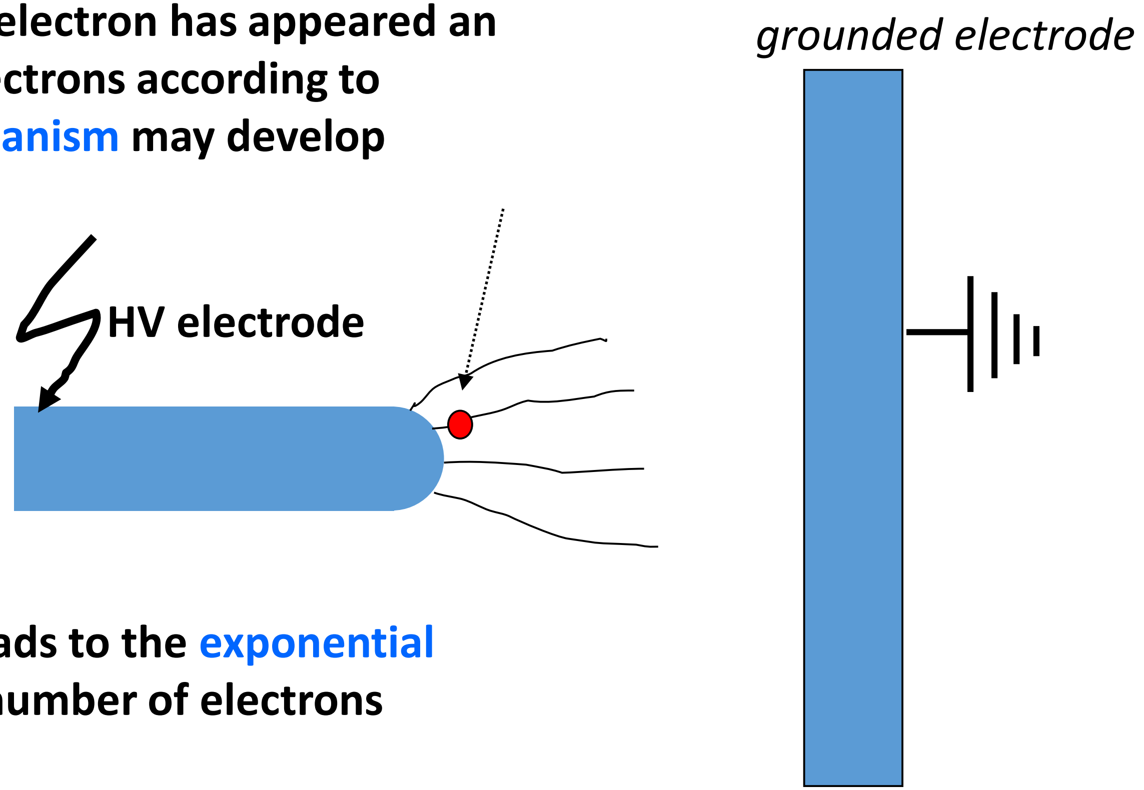
Dielectric Criteria Roadmap

(1) Evaluate **inception** voltage **Udi** based on **streamer criterion** along field lines => numerical field analysis

(2) Calculate **withstand voltage** as a product of **Udi** and empirical coefficients

Discharge mechanism in gases: Inception

- After the initial electron has appeared an avalanche of electrons according to Townsend mechanism may develop



- An avalanche leads to the exponential growths of the number of electrons

- If the number of avalanche electrons exceeds a specific limit a self-propagating streamer discharge will occur

Streamer criterion

Assumption:

(1) The avalanche of electrons will develop along a field line started from the high stress area on an electrode

(2) The critical number of electrons Nσ can be obtained by integrating the effective ionization coefficient along the field line

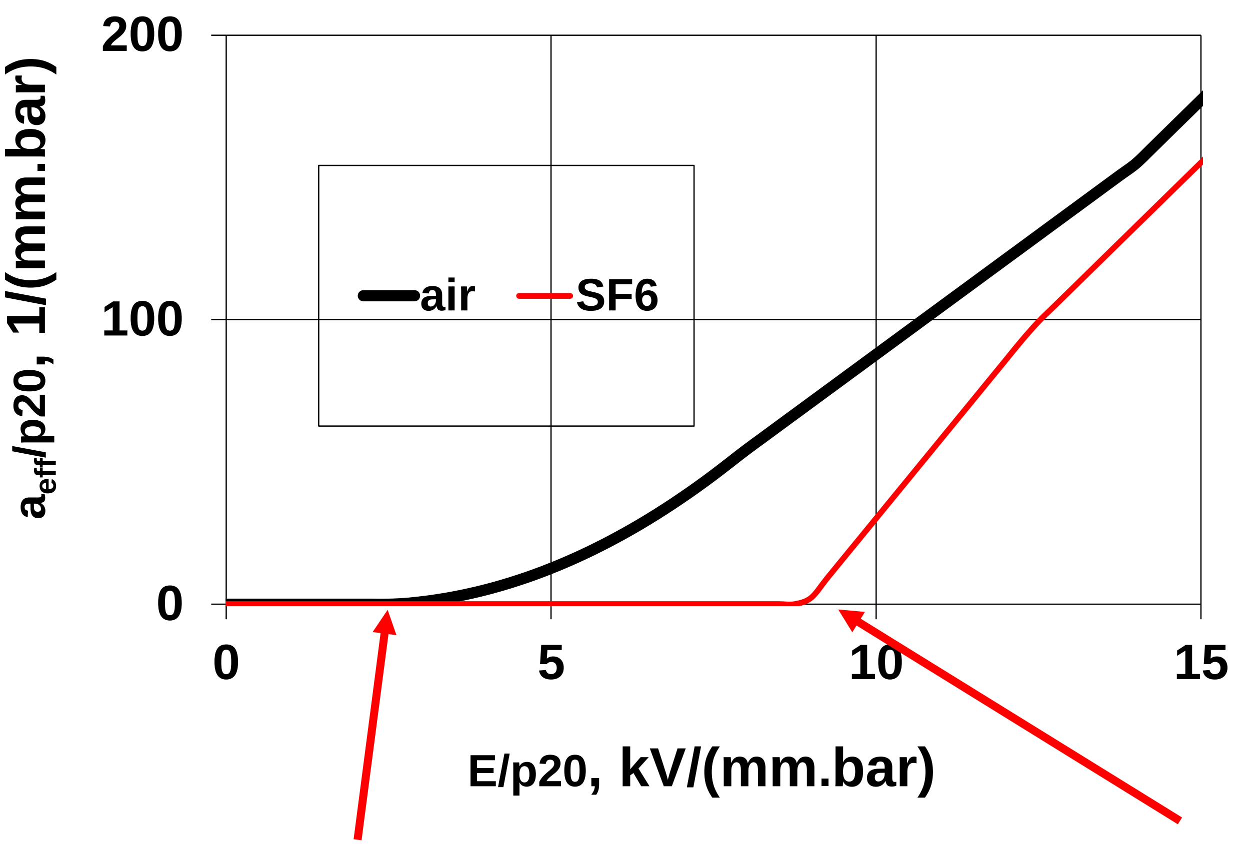
$$\underbrace{\int_0^{x_c} \alpha_{eff}\left[E(x)\right]}_{\text{See next slide}} \cdot dx > \underbrace{\ln(N_\sigma)}_{\text{Streamer constant}}$$

See next slide

Streamer constant:
9.15 for air
10.5 for SF6

Based on latest investigation performed by ETH Zurich (in the past, a value of 18.4 = $\ln(10^8)$ has been commonly assumed)

Ionization coefficient for air and SF6



α = 0 for E < 2.6 kV/mm at 1bar

α = 0 for E < 8.9 kV/mm at 1bar

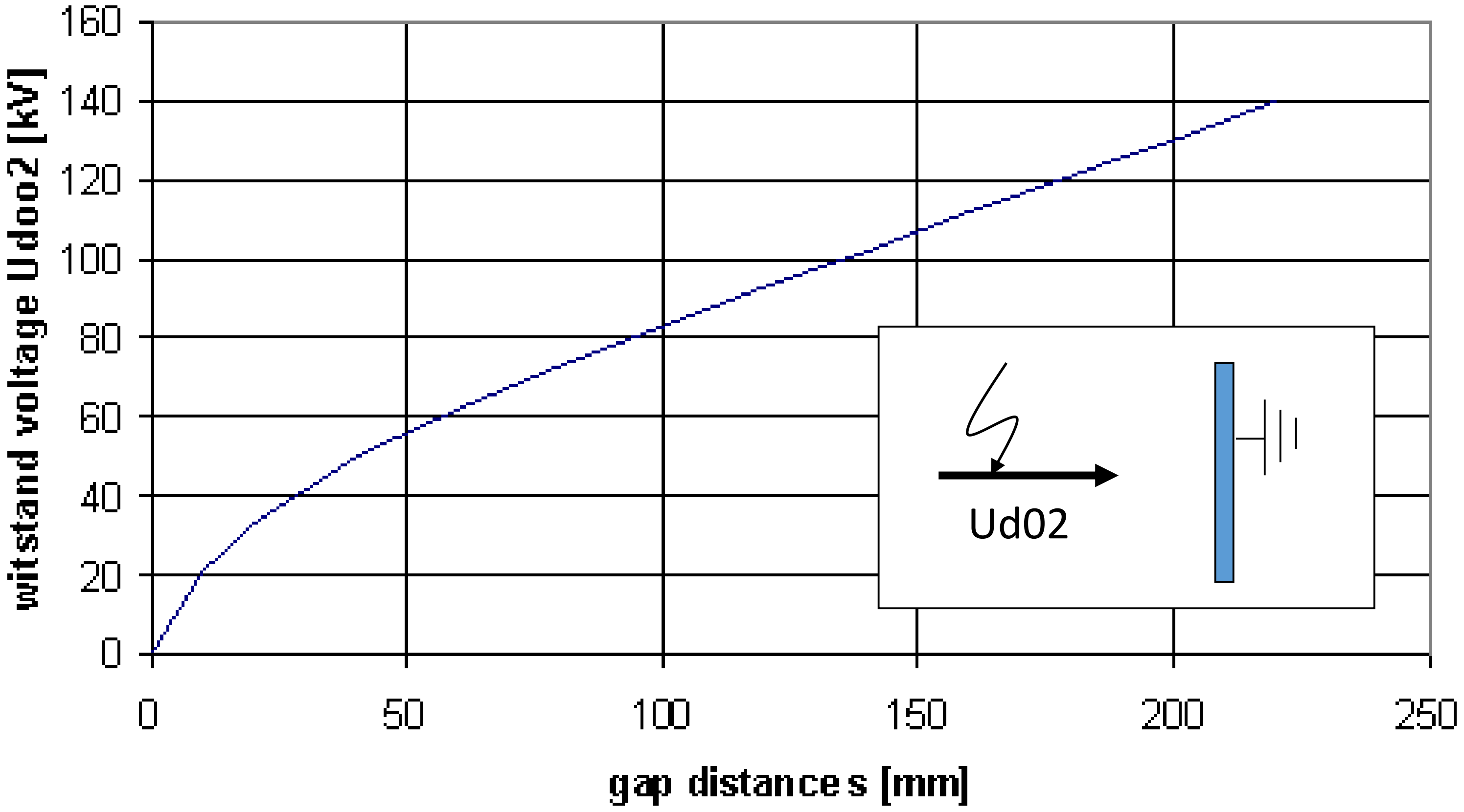
Inception versus breakdown

- Inception voltage *Udi* can be accurately calculated for any arbitrary electrode configuration (in 3D)
  - **Udi determines the partial discharge inception**

- Inception can be influenced by the microscopic field enhancement => **surface roughness**

- Streamer inception not always leads to a breakdown! The following factors can contribute to a breakdown voltage higher than the inception voltage:
  - **Field in-homogeneity**
  - **Short duration of the applied voltage** ("time lag") (this is more important for lightning impulses in SF6)

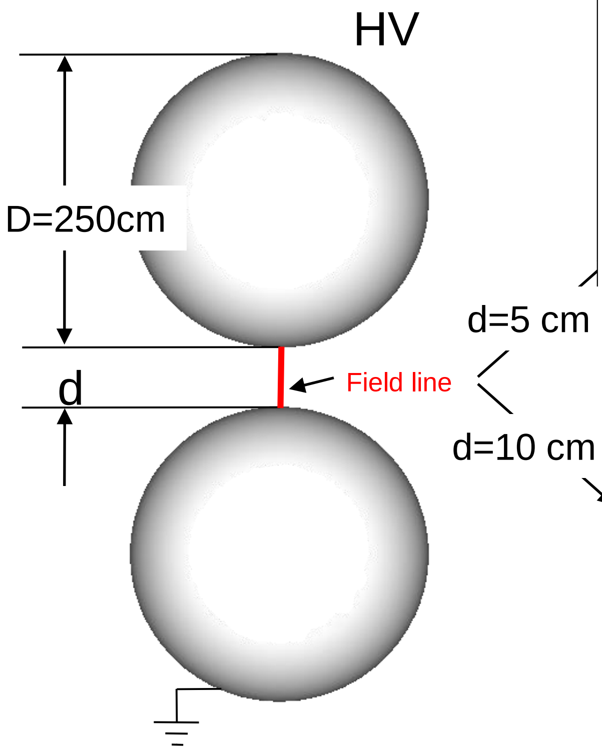
Withstand voltage for needle-plate arrangement in air

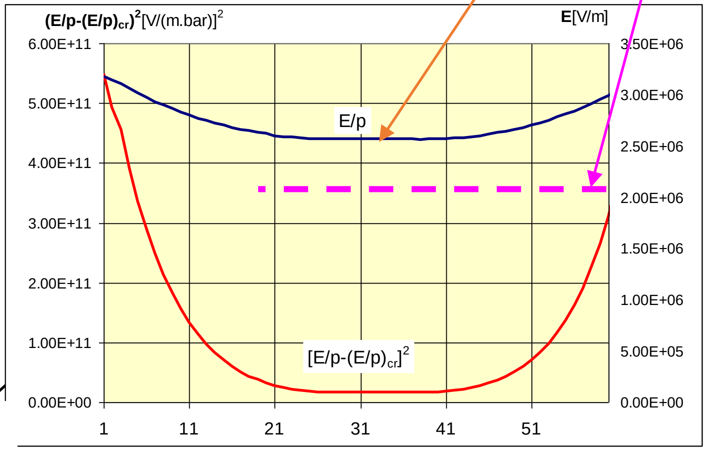


Design Criteria Evaluation

Streamer Criteria

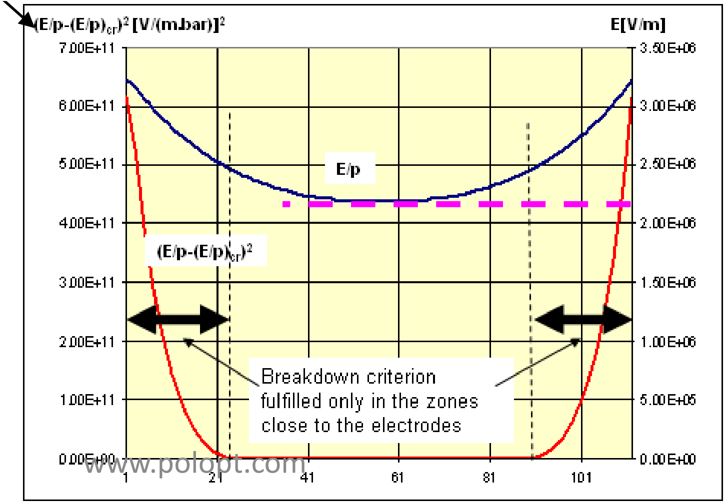
$E_{min}/p >$ $E_{cr/p}=2.16e^6$ V/mbar ⇨ SM I





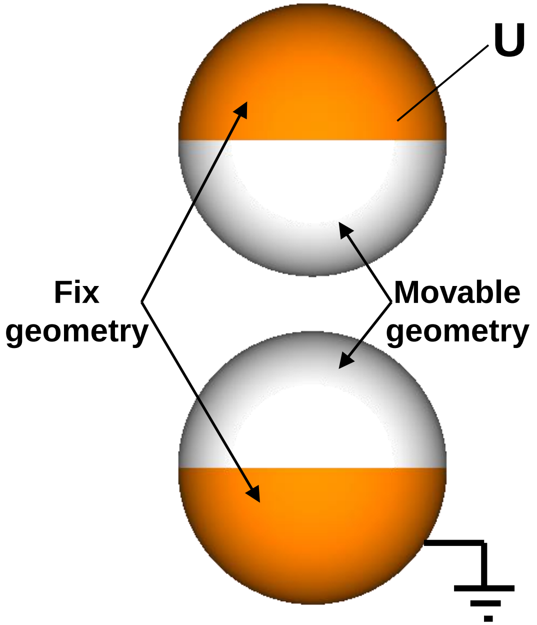
U_{br}=136.8 kV,
(137kV, IEC Pub. 52)

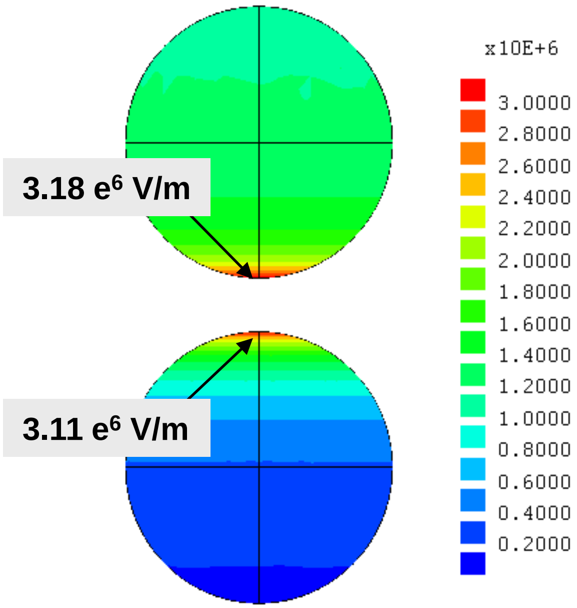
$E_{min}/p <$ $E_c/p=2.16e^6$ V/mbar ⇨ SM II



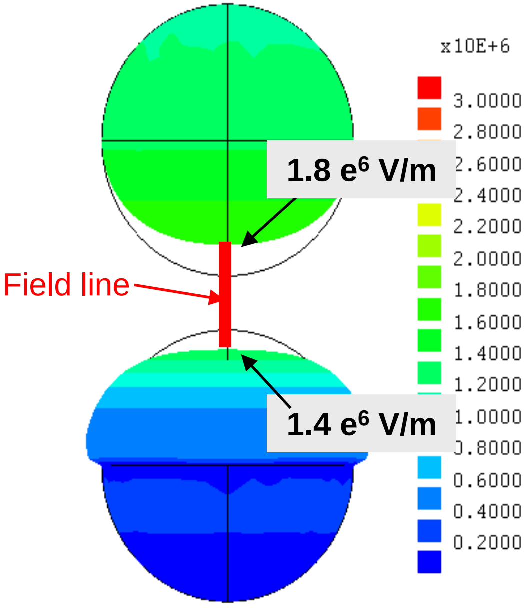
U_{br}=246 kV,
(241kV, IEC Pub. 52)

Example I: Two spheres (single-load opt.)



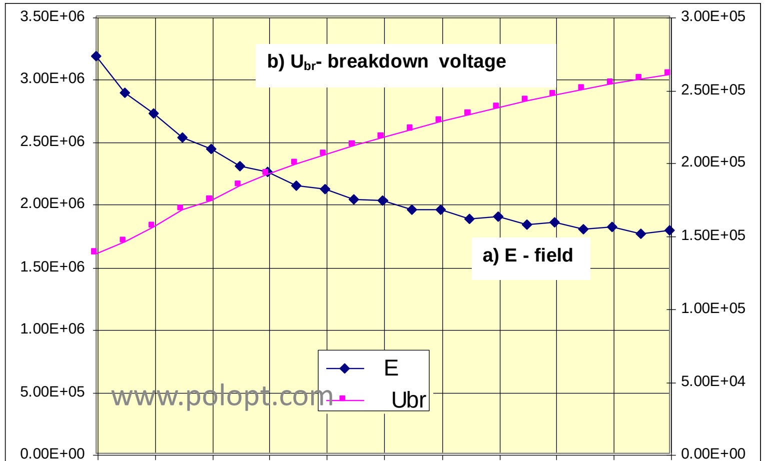


b) Non-optimized spheres



c) Optimized spheres

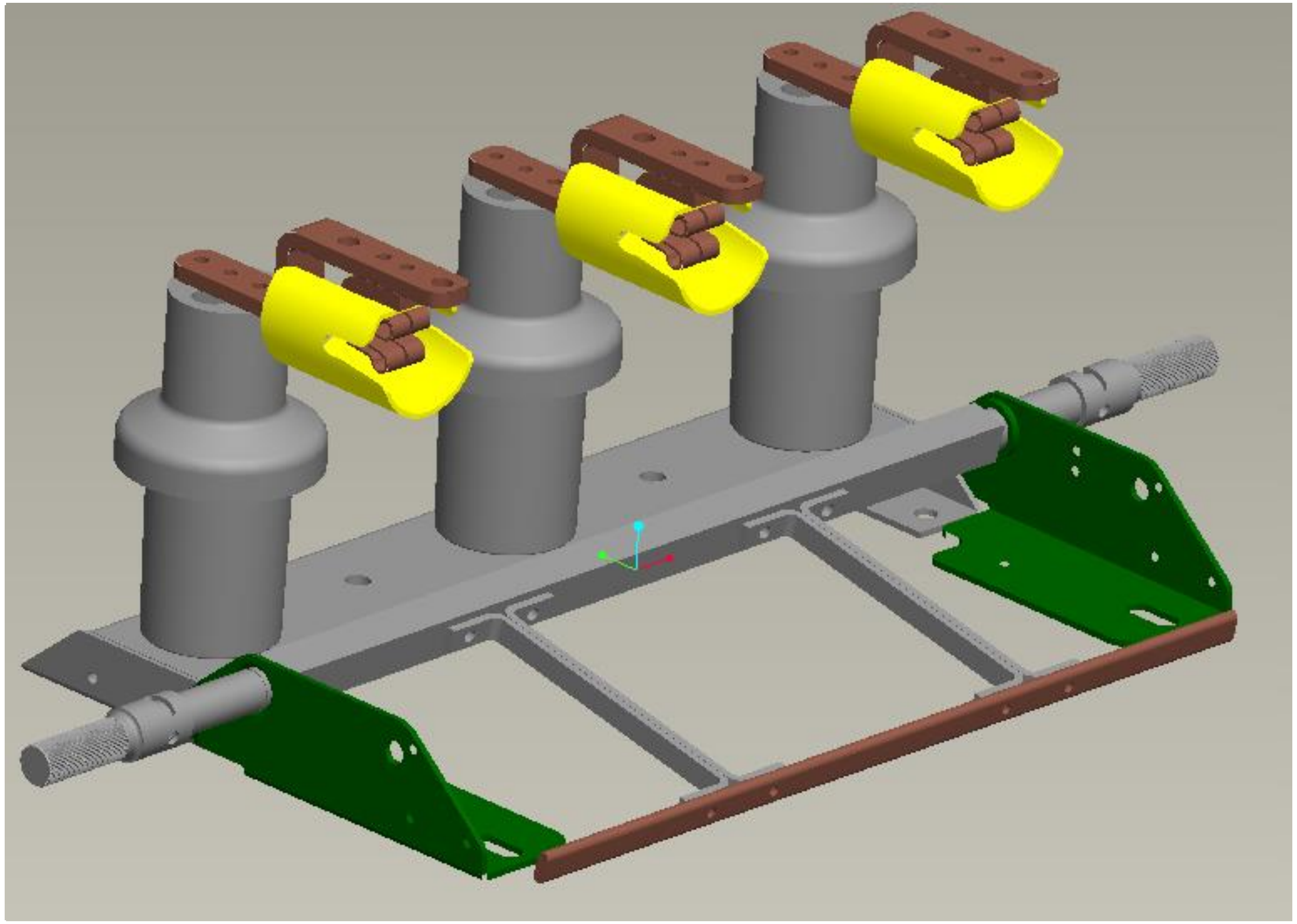
a) Field distribution [V/m] at the starting point of the field line (HV electrode);
b) Breakdown voltages [V] for each of 21 optimization step



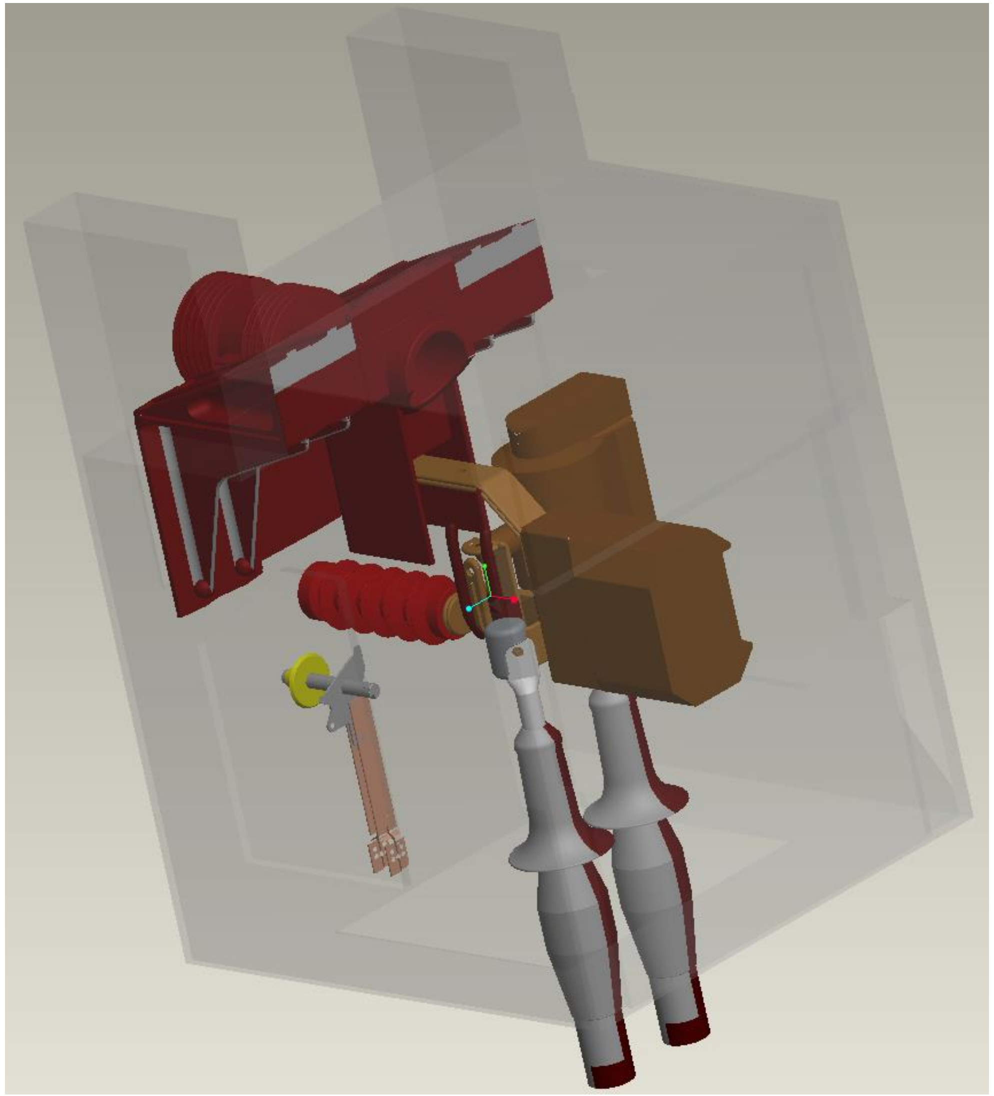
E_{max}: 76% ↓

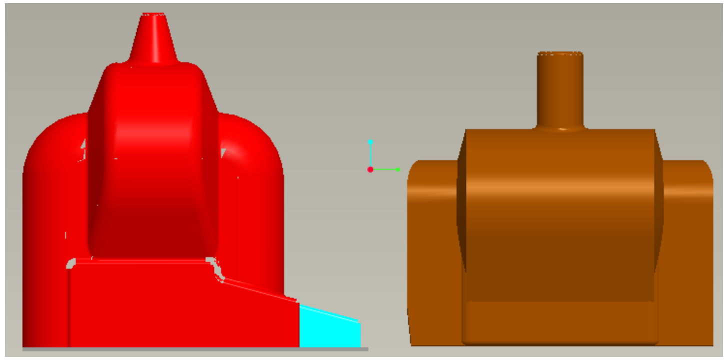
U_{br} : 90% ↑

Improving the withstand of the NAL earth switch

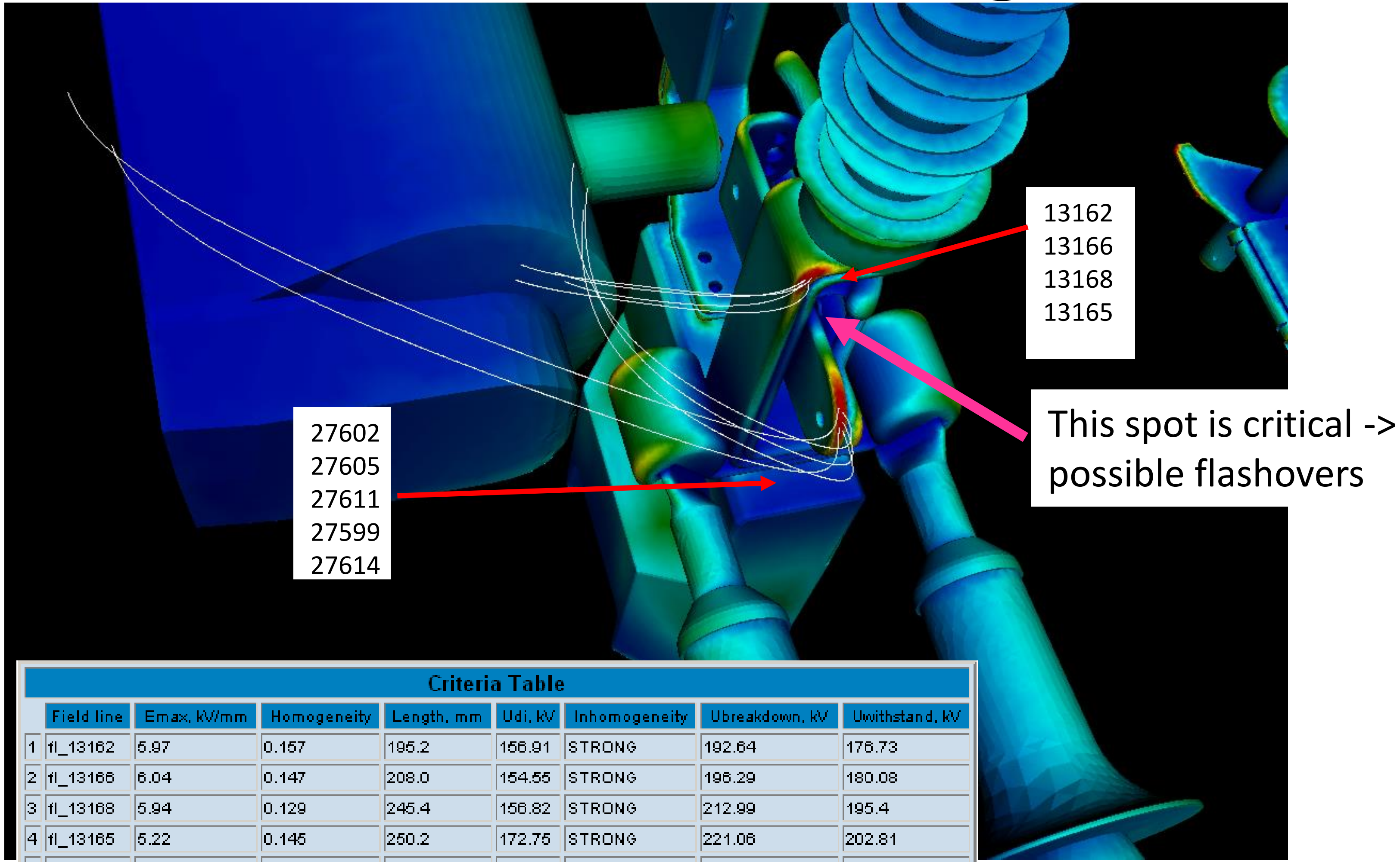


Flashovers in a 40 kV cable compartment (R40, CHSEC)



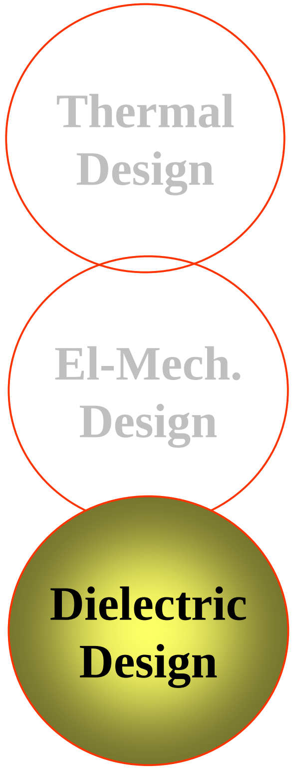


Evaluation of withstand voltage (R40)



Criteria Table

	Field line	Emax, kV/mm	Homogeneity	Length, mm	Udi, kV	Inhomogeneity	Ubreakdown, kV	Uwithstand, kV
1	fl_13162	5.97	0.157	195.2	156.91	STRONG	192.64	176.73
2	fl_13166	6.04	0.147	208.0	154.55	STRONG	196.29	180.08
3	fl_13168	5.94	0.129	245.4	156.82	STRONG	212.99	195.4
4	fl_13165	5.22	0.145	250.2	172.75	STRONG	221.06	202.81
5	fl_27611	5.44	0.068	541.2	168.28	STRONG	327.63	300.58
6	fl_27605	5.37	0.068	547.2	170.37	STRONG	330.91	303.58
7	fl_27599	5.16	0.07	556.8	177.08	STRONG	336.15	308.4
8	fl_27614	5.34	0.06	622.3	170.89	STRONG	371.88	341.17
9	fl_27602	5.31	0.06	626.8	172.31	STRONG	374.32	343.41



Simulation-Based Design in Electrical Engineering

- Simulation-Based Design in Engineering Praxis
- **Dielectric Design of HV Products**
- Magnetic Design in EE
- Coupled Problem
- Optimization 1
- Optimization 2