ME Project - 2019

Australia's Global University | Faculty of Engineering | School of Electrical Engineering and Telecommunications

Simulation and Analysis of Electric Field Distribution of Insulating material under HVDC with consideration of Space Charge testing

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Thesis background

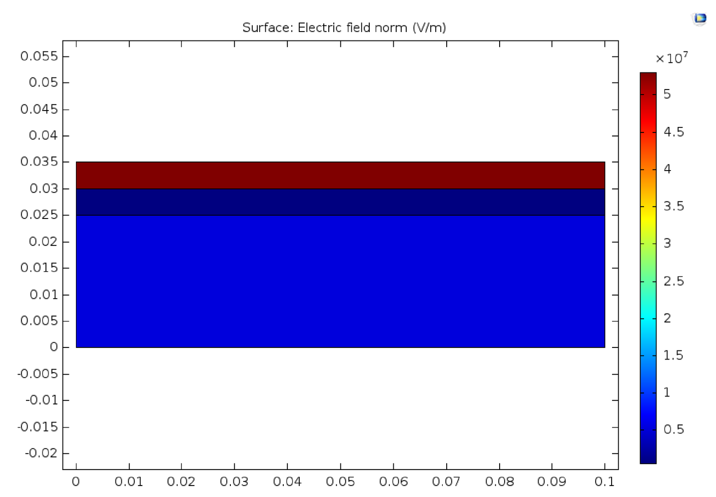
Under HVDC condition, transmission system has the ability to deliver electricity over long distances and the power loss has been reduced greatly. Relevant advantages including asynchronous grid, improved system stability and lower system cost across long distances have made HVDC widely adopted, with a voltage rating up to 1000kV till now. Higher transmission voltage brings advantages together with possibility of insulation breakdown due to excessive electric field. The insulation used in HVDC cable system has evolved from impregnated papers to various extruded polymer like crosslinked polyethylene (XLPE), polypropylene (PP), polypropylene laminated paper (PPLP) and so on. Among all, XLPE has played an important role. In order to figure out the electric field distribution across insulation material under HVDC condition, various simulation based on COMSOL Multiphysics has been carried out including parallel plate model, coaxial cable with single layer insulation, coaxial cable with double layers of insulation. And comparison of electric field distribution under AC and DC condition is also carried out to prove that under DC condition, electric field is dependent on resistivity while under AC condition, electric field is dependent on permittivity. Note that space charge accumulation would also contribute to electric field change, which is the phenomenon describing excessive electric charge distributed at some certain region rather than at some point. The effect of space charge on electric field distortion is researched and relevant space charge testing experiments are done. The testing object including PMMA, single layer XLPE tape, double layer XLPE tape and triple layer XLPE tape. The result of triple layer XLPE needs further research. PEA method is adopted to test space charge distribution.

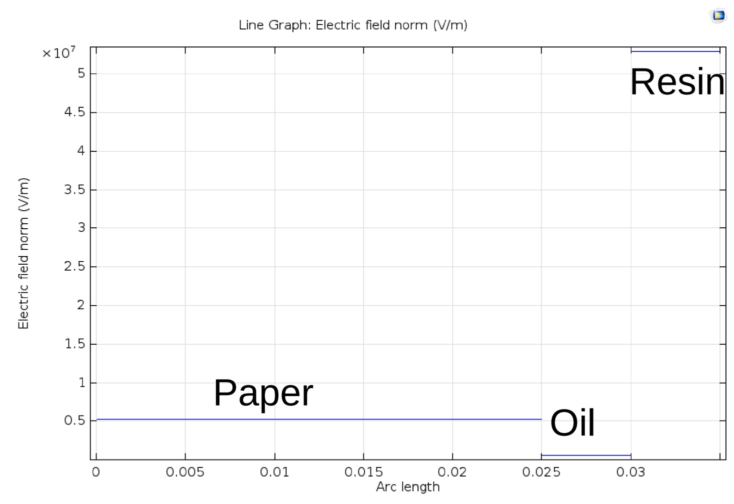
Simulation of electric field distribution

- *Parallel Plate model*

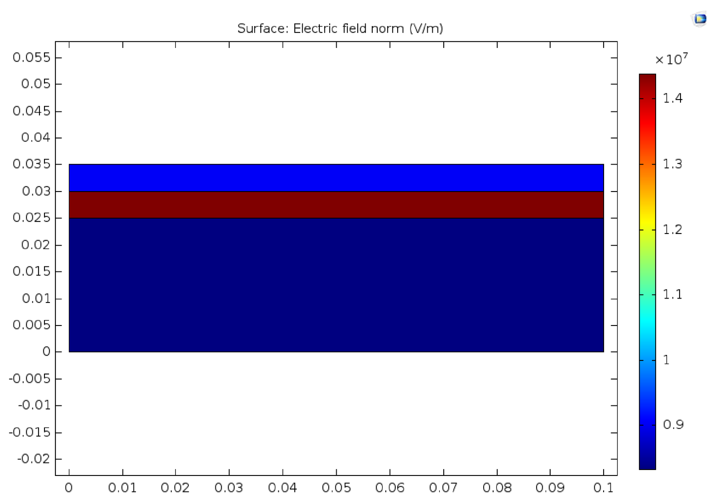
First layer: resin, relative permittivity ε_r=3.5, reference resistivity $\rho = 10^{14}\Omega.\text{m}$, d=5mm;
Second layer: oil, relative permittivity ε_r=2.2, reference resistivity $\rho = 10^{12}\Omega.\text{m}$, d=5mm;
Third layer: paper, relative permittivity ε_r=3.8, reference resistivity $\rho = 10^{13}\Omega.\text{m}$, d=25mm.

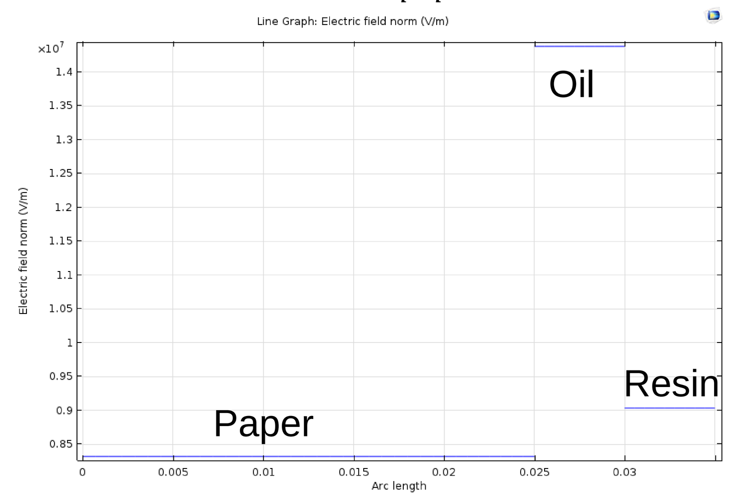
Under DC, the total voltage applied is 400KV. Electric field distribution is dependent on resistivity. $E_{resin} = 52.98kV/mm$, $E_{oil} = 0.53kV/mm$, $E_{paper} = 5.298kV/mm$.





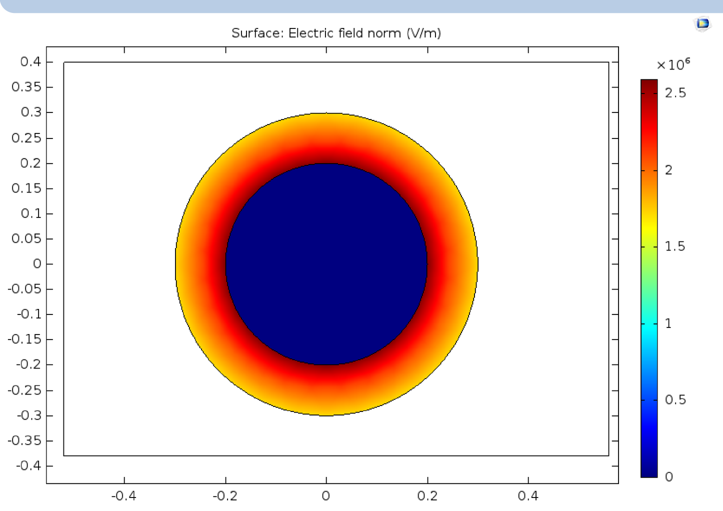
Under AC, the voltage applied is 230kV(rms), 325.27kV(peak). Electric field distribution is dependent on permittivity. $E_{resin} = 9.04kV/mm$, $E_{oil} = 14.38kV/mm$, $E_{paper} = 8.3264kV/mm$.

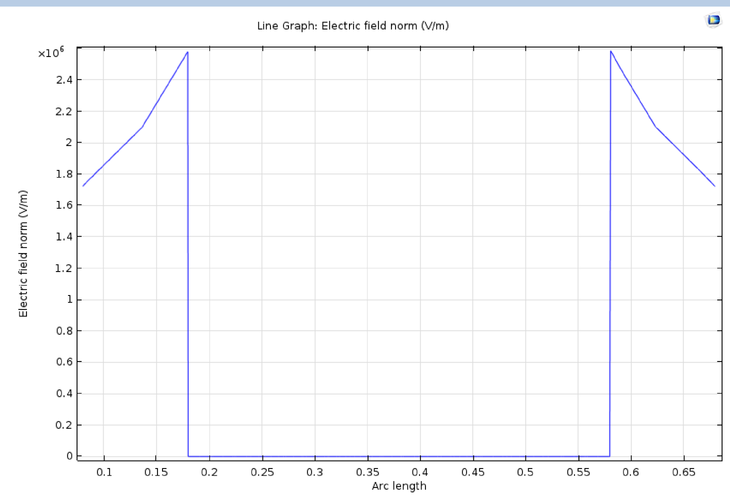




- *Coaxial cable model with single insulation layer*

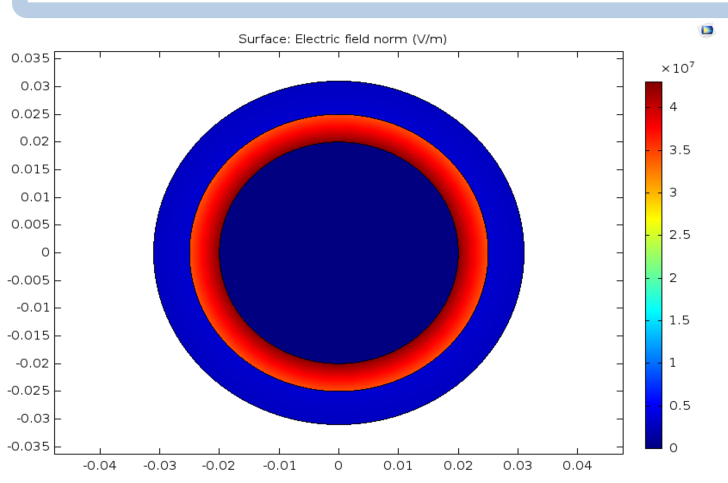
Polyethylene relative permittivity ε_r=2.3, reference resistivity $\rho = 10^{14}\Omega.\text{m}$, reference temperature= 293K. The total DC voltage applied is $V_T = 210kV$. The conductor copper has a radius $r_1 = 0.2m$, insulation thickness is 0.1m. $E_{max} = 2.5896 \times 10^6 V/m$.

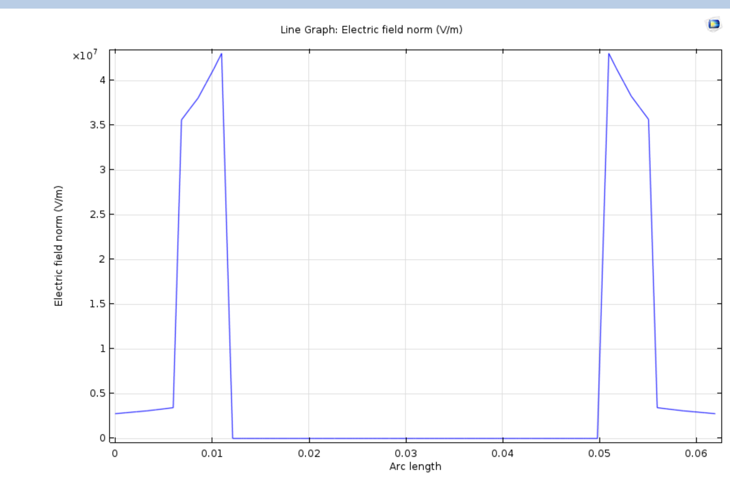




- *Coaxial cable model with double insulation layers*

1st layer: paper, relative permittivity ε_r=3.2, reference resistivity $\rho = 10^{14}\Omega.\text{m}$, T=293K ;
2nd layer: oil, relative permittivity ε_r=2.2, reference resistivity $\rho = 10^{13}\Omega.\text{m}$, T=293K.
Under DC, the voltage applied is 210KV. $E_{1max} = 42.92kV/mm$, $E_{2max} = 3.43kV/mm$.

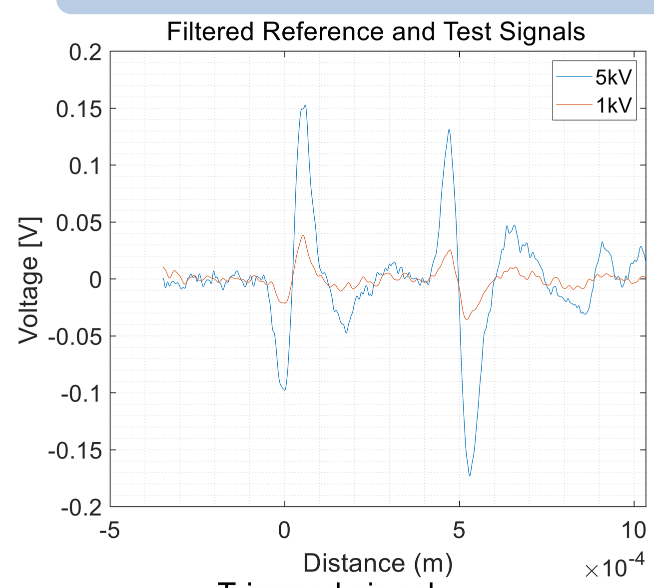


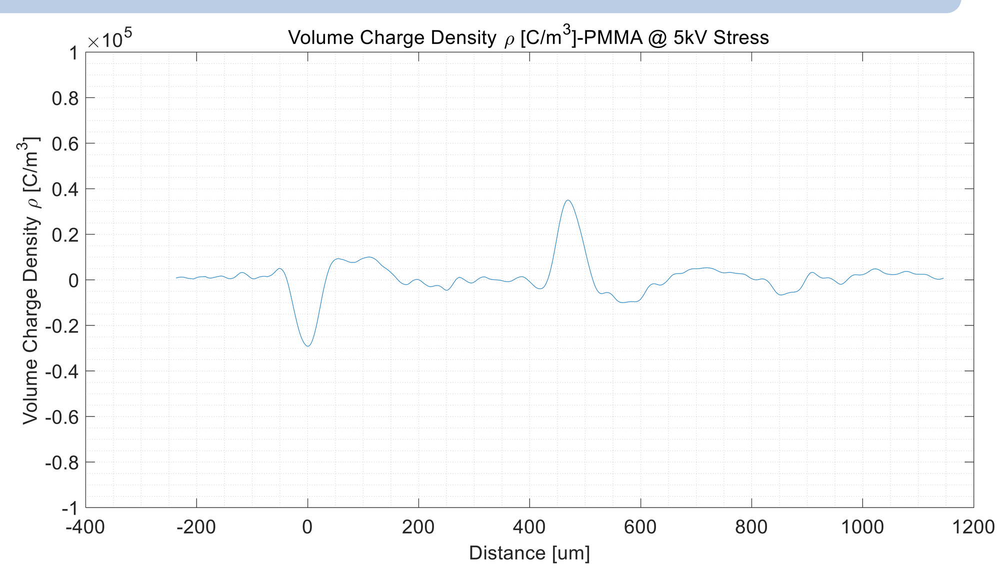


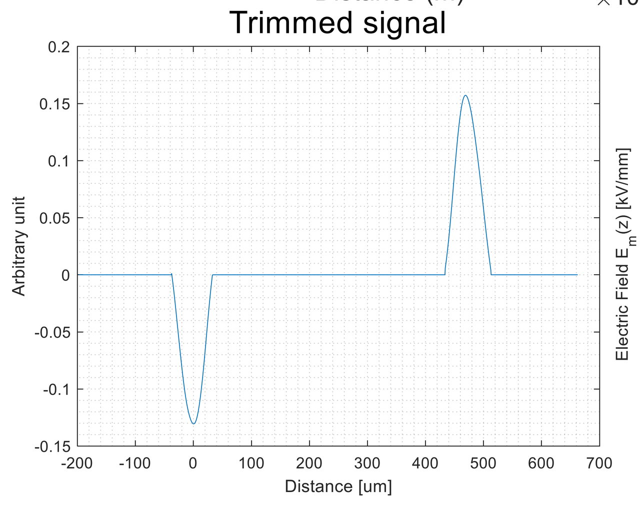
Space charge testing on insulation material

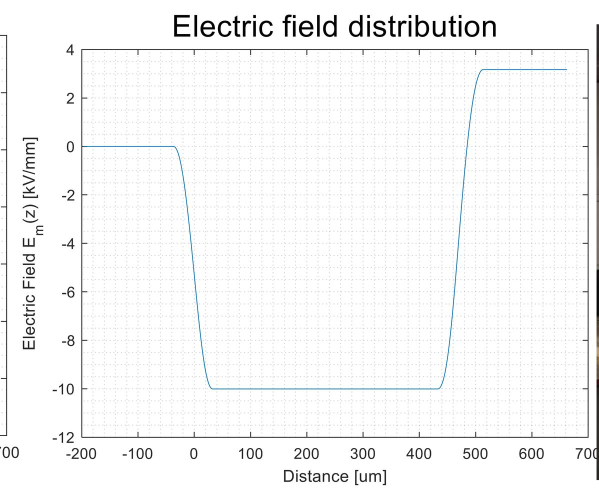
- *Space charge testing on PMMA*

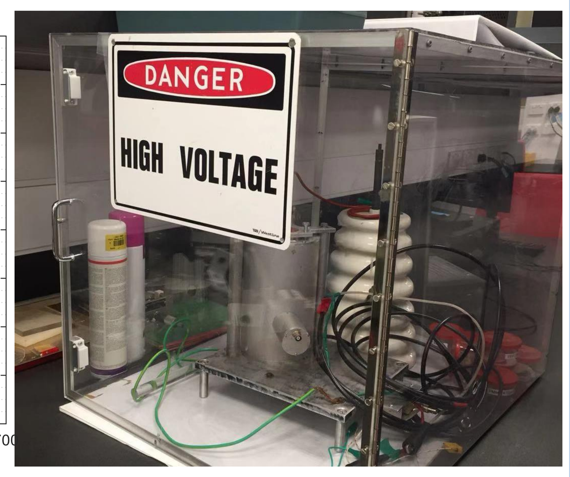
PMMA sample thickness is 470 μm. DC voltage ranges from 1kV to 5kV. Use 1kV as reference signal and 5kV as high voltage result. Averaging time is 100. Voltage for impulse generator is 260V. Sampling frequency 5.8MHz. After trimming, the result is better.





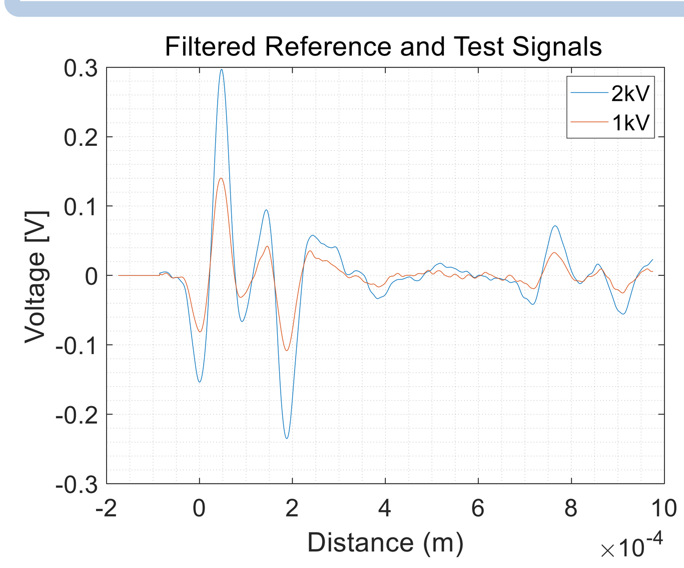


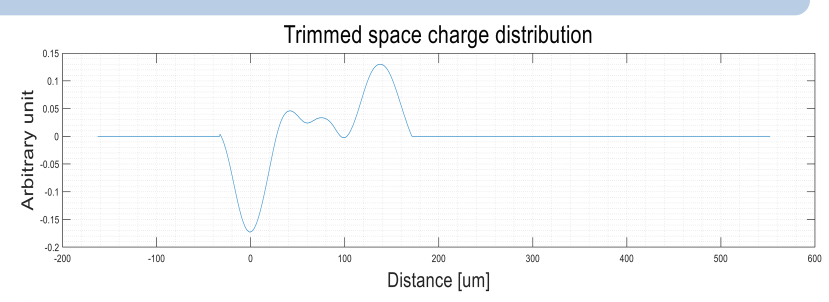


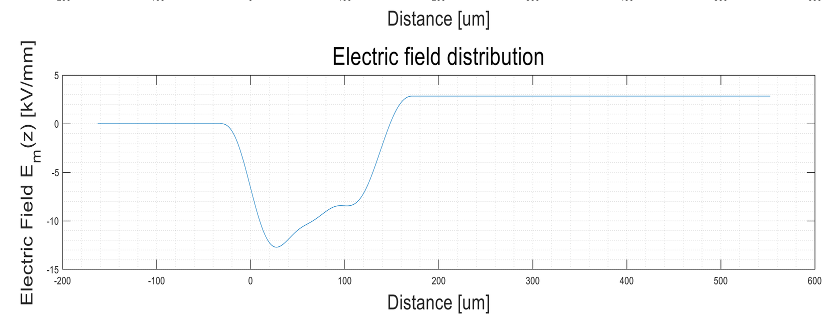


- *Space charge testing on single layer XLPE*

XLPE sample thickness is 120 μm. DC voltage ranges from 1kV to 2.5kV. Use 1kV as reference signal and 2kV as high voltage result. Averaging time is 100. Voltage for impulse generator is 260V. Sampling frequency 5.8MHz. After trimming, the result is better.

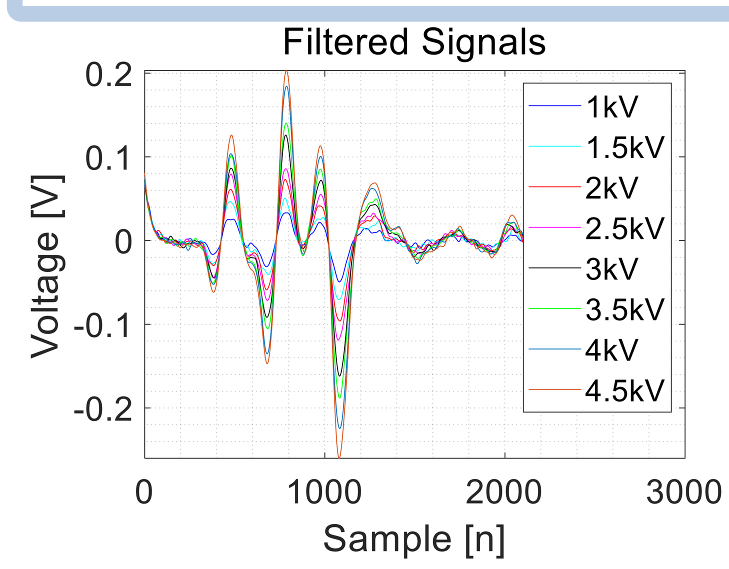


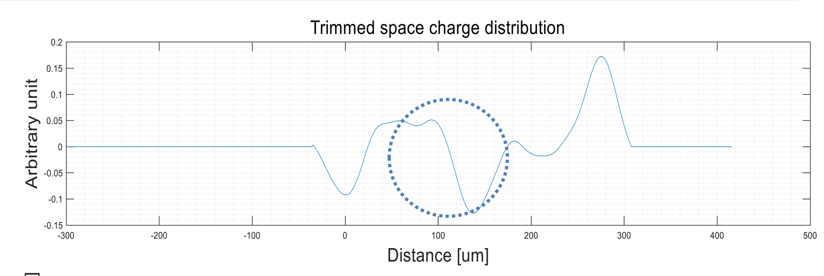


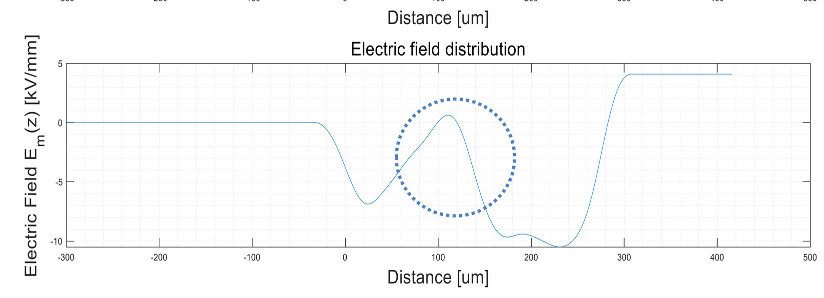


- *Space charge testing on double layer XLPE*

2-layerXLPE sample thickness is 250 μm. DC voltage ranges from 1kV to 4.5kV. Use 1kV as reference signal and 2kV as high voltage result. Sample is not tightly pressed thus air void exists and distorts test result.







Conclusion

To catch up the tendency of higher applied voltage in HVDC system, the selection of insulation material should have the ability to withstand high voltage and work properly. And it seems that compound material or material after some special procedure can have a better performance such as XLPE, PPLP. After all the simulation, it is clear that electric field is important for insulation material and its strength can vary under different condition like AC and DC, in different cable model like parallel plate model and coaxial cable model. Under DC, electric field is dependent on resistivity and under AC, it is dependent on permittivity. Space charge could affect electric field distribution. For PMMA material, space charge is hard to build up across sample thus PMMA is usually used for space charge testing calibration. For XLPE, positive charge could build up near ground electrode and affect the electric field distribution. For double layer XLPE in 2 pieces, air void between sample layers brings negative charge and affect field distribution. The result of triple layer XLPE needs further research.