
Réseau de transport d'électricité

# Aging: what is expected from a Transmission System Operator?

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# Summary

1. Context & RTE projects
2. Physical phenomena
3. Space charge in HVDC cables
4. Models development
5. Conclusions

# 2 different technologies: HVAC links/ HVDC links

## Development of HVDC links at Rte:

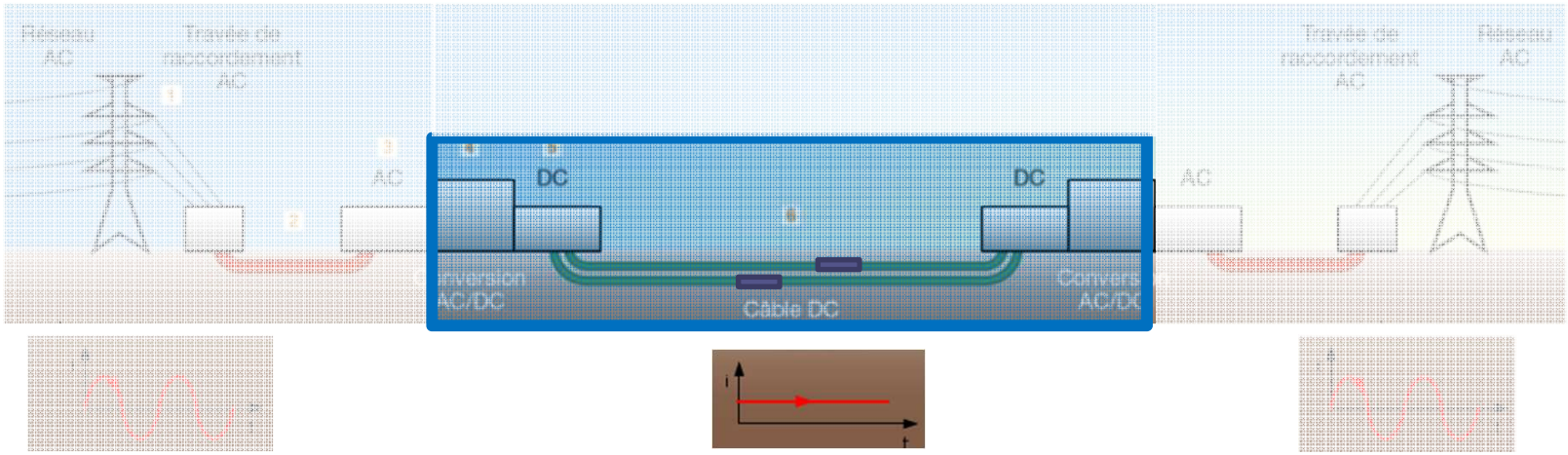
- ✓ Inelfe (France & Spain)
- ✓ IFA 2 (France & England)
- ✓ Savoie-Piémont (France & Italia)
- ✓ Midi-Provence

**➔ Why does Rte select HVDC technology?**

## Advantages of HVDC/ HVAC

- ✓ No reactive power
- ✓ Lower losses in cables
- ✓ No synchronism problem
- ✓ Cheaper in the case of long length

# Composition of a HVDC links




- **Cable;**
- **Joint;**
- **Termination;**
- **Converter station;**

**HVDC system**

# HVDC cable technologies

**Mass impregnated cable**

**Self-Contained Fluid Filled cable**

**Extruded cable**

✓ Different materials association

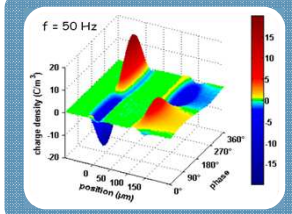
➔ **Different materials**
➔ **Impact on the aging of the system**

# What is expected from XLPE technologies?

- ✓ Reliable
- ✓ Few maintenance
- ✓ Less losses
- ✓ Lifetime of at least 40 years

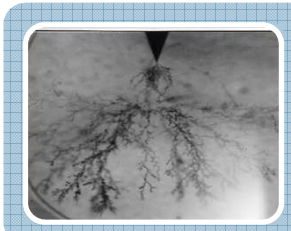
**➔ Need to know and understand physical phenomena linked to aging mechanisms**

# PHYSICAL PHENOMENA




## Space charge

- Definition
- Nature of space charge
- Traps depth



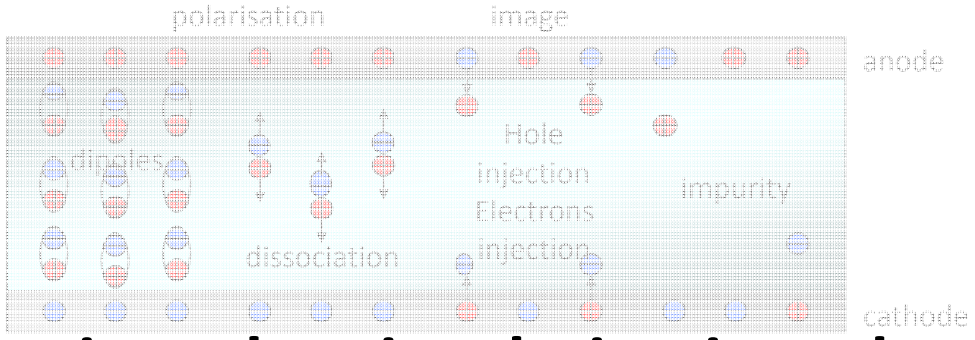
## Consequences of space charge

- Dielectric breakdown
- Premature aging

Physical phenomena

## Space charge

All the charges present on the surface or bulk of an electrical insulator.




# What is happening when insulation is under DC voltage?

**In bulk**

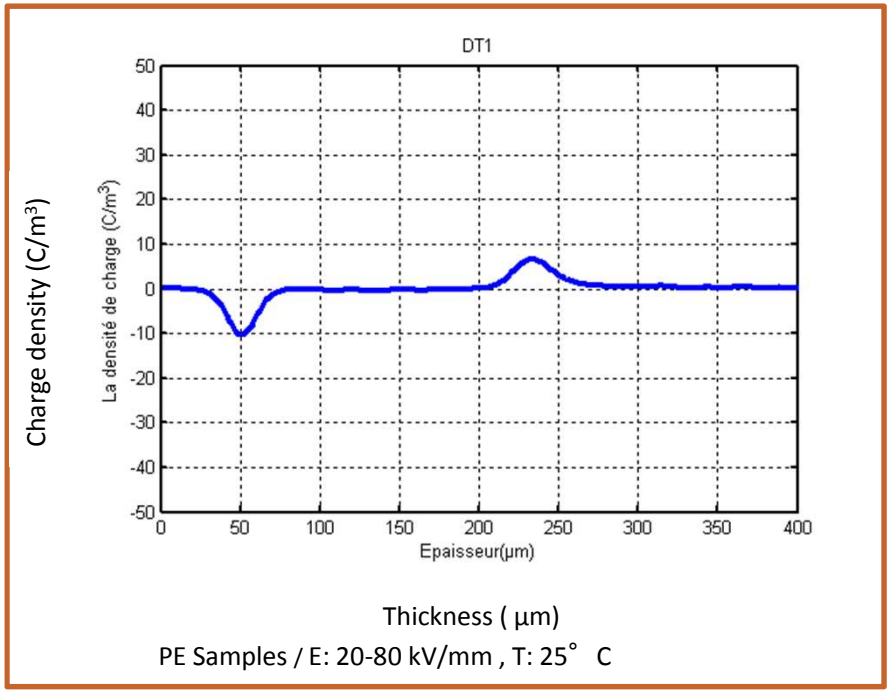
- Polarization of the dipoles
- Ionic carriers
- Electro-dissociation of neutral species

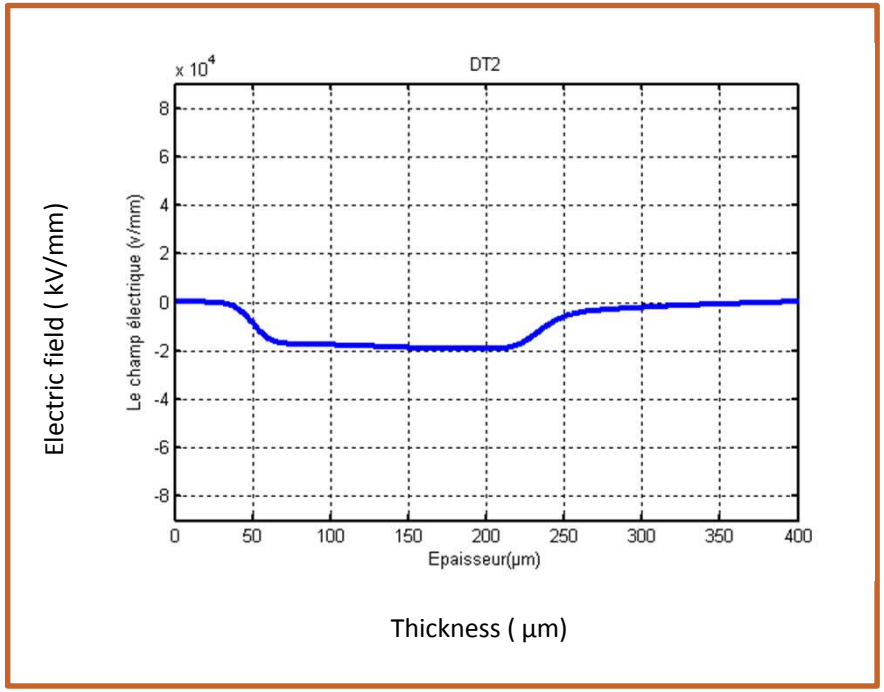
**In the interfaces**

- injection of holes at the anode and electrons at the cathode
- surface states
- chemical reactions

# Consequence of space charge on dielectric properties

RTE2



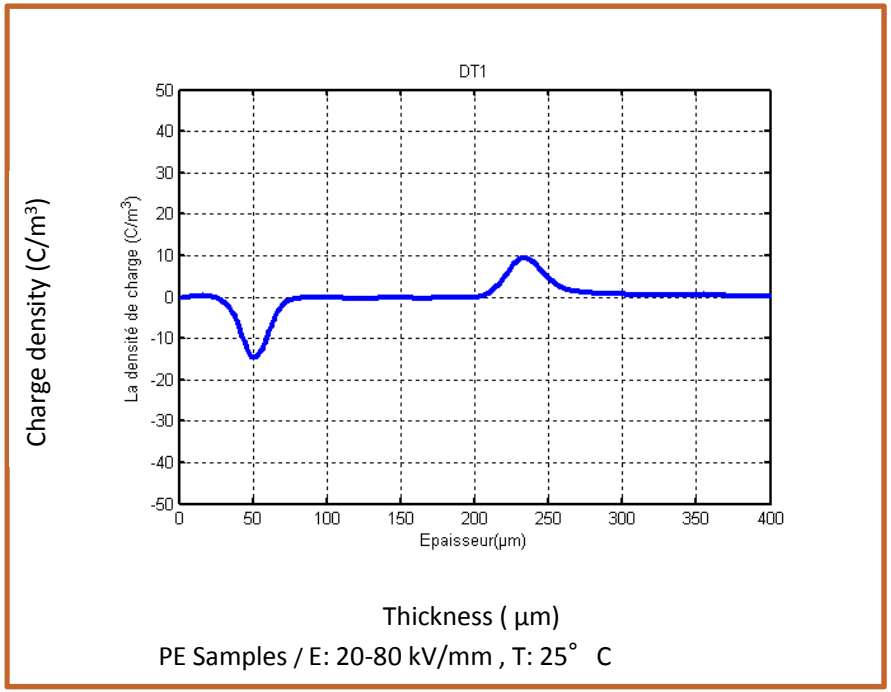

➔ **Short term =>** local intensification of electric field => dielectric breakdown

➔ **Long term =>** physico-chemical changes of the material=> **aging**

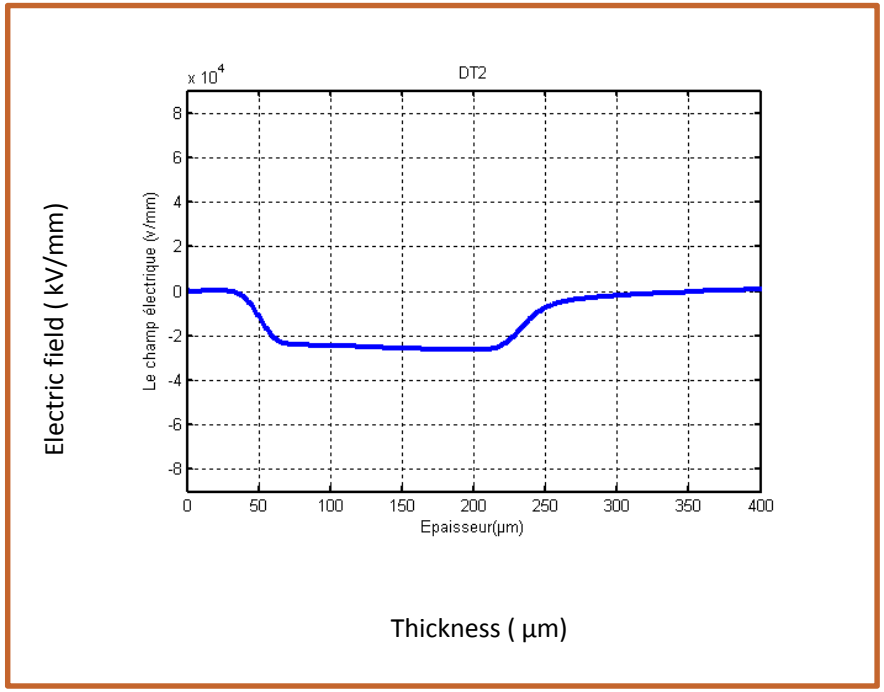
[1] Mandana TALEB , Phénomènes aux interfaces des isolants : mesure et simulation, Ph.D Thesis, Paul Sabatier University,Toulouse, 2011.

# Consequence of space charge on dielectric properties

RTE3




Click on the sketch to see the video

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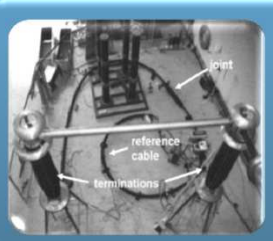
# SPACE CHARGE IN EXTRUDED (XLPE) INSULATION




## Materials

- Antioxydants
- Crosslinking agents

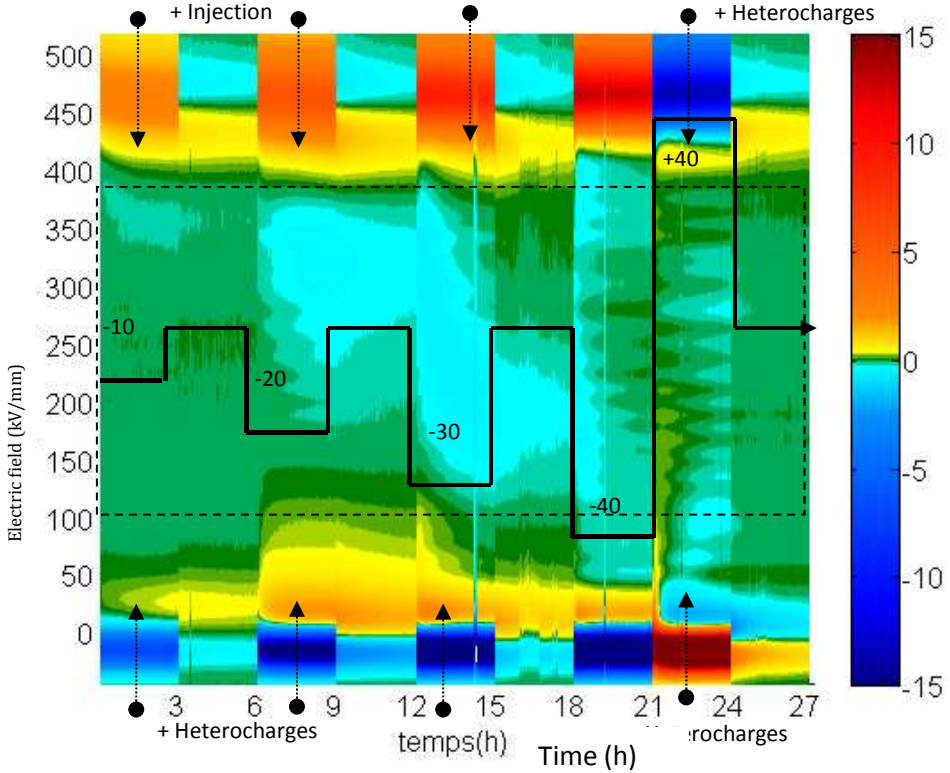
## Interfaces

- SC/insulation
- SC/lubricant/ Insulation
- Insulation/Insulation

## Electrical and thermal stress

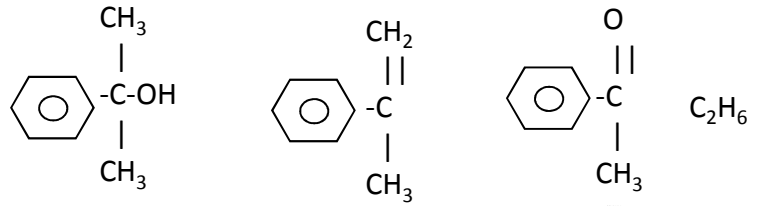
- Temperature gradient

# Influence of additives on space charge formation



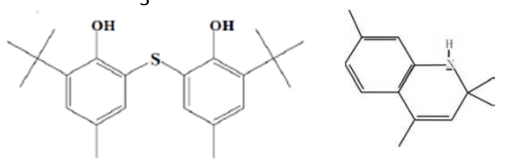

Sample :SC/XLPE (HVDC) /SC/ press-moulded plaques / T: 25° C [1]

*Cumyl alcohol (≈2D)* *α Methyl-styrene* *Acetophenone (≈ 3D)*




Decompostion products of (AO)

$H_2O$ $CH_4$




Phenolic antioxydant



Aromatic amine

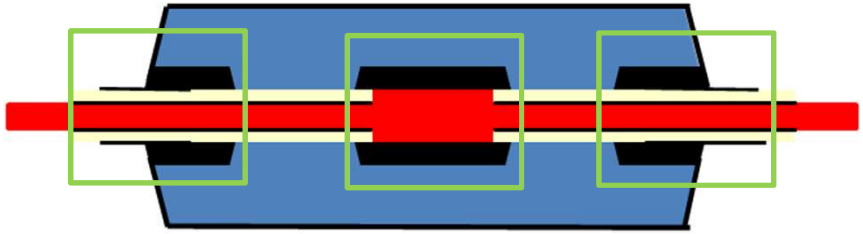
➔ Cross linking residues are known to be a cause of heterocharges accumulation in the insulation.

➔ Additives such as antioxidants are capable to form additional deep traps.

➔ According to the nature of antioxidant, heterocharges or homocharges could be seen in the bulk.

[1] Bertrand VISSOUVANADIN , Matériaux de câbles à isolation synthétique pour des applications au transport d'énergie Haute Tension à Courant Continu (HVDC), Ph.D Thesis, Paul Sabatier University,Toulouse, 2011.

# Influence of interfaces on space charge formation



SC/ Insulation interfaces

➔ nature of conductor and insulation screens are closely related to the charge formation and conduction in the insulation

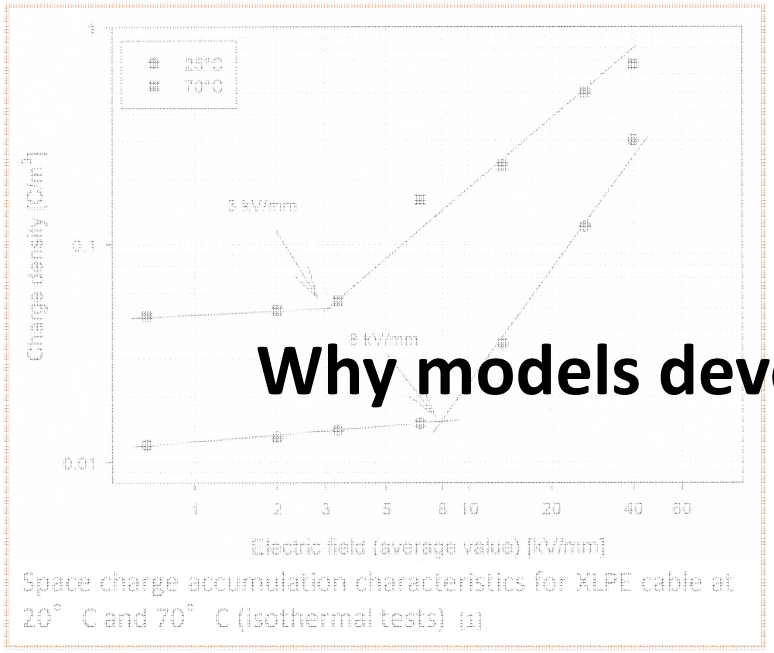
SC/Lubrifiant/Insulation interfaces

➔ Change interface behavior and charge generation mechanism in the insulation.

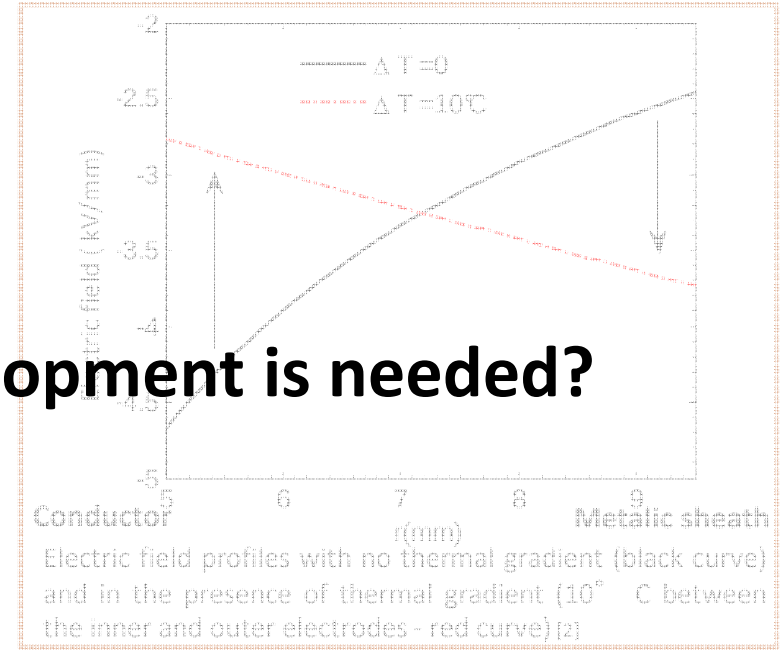
Insulation/ Insulation interfaces

➔ Interfacial charge can be formed in the interface.
➔ Amount and sign of charge depend on the materials permittivity

# Influence of electrical and thermal stress

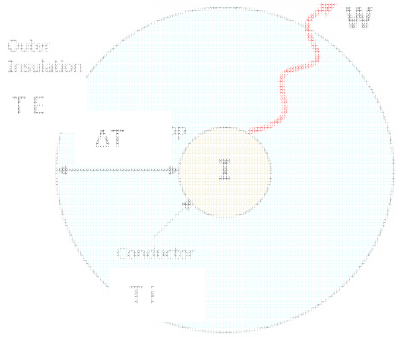



Space charge accumulation characteristics for XLPE cable at 20° C and 70° C (isothermal tests) [1]




Electric field profiles with no thermal gradient (black curve) and in the presence of thermal gradient (10° C between the inner and outer electrodes - red curve) [2]

**Why models development is needed?**




$$E_{at}(r) = \frac{1}{\sigma_c(r)\,r} \cdot \frac{V(r_1) - V(r_2)}{\int_{r_1}^{r_2} \frac{1}{\sigma_c(r)\,r}\,dr}$$

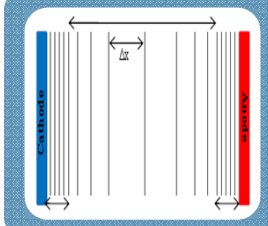
➔The charge injection into the polyethylene is favored by the increase of the electric field and temperature.

➔In the presence of thermal gradient, electrical stress is reversed and becomes maximum at the outer SC electrode.

[1] D. Fabiani et al, 2008 "HVDC Cable Design and Space Charge Accumulation. Part 3: Effect of Temperature Gradient", DEIS, Vol. 14, No. 2.

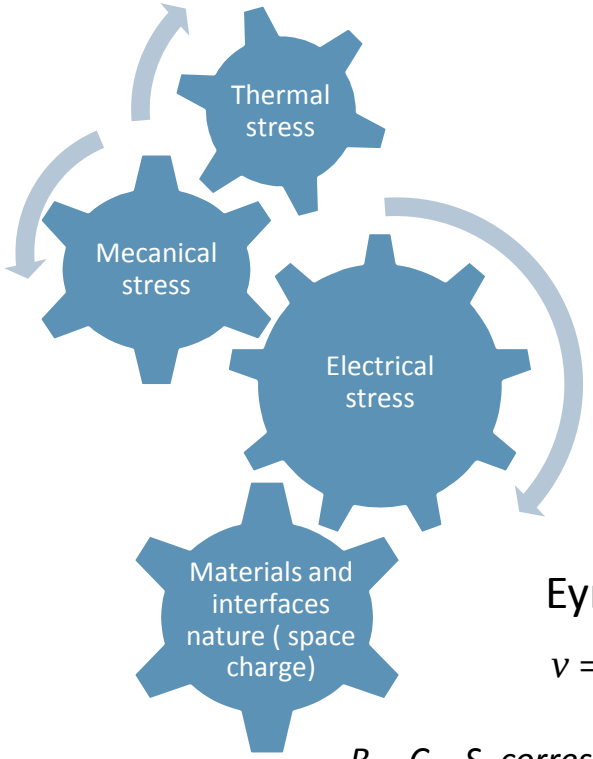
[2] Bertrand VISSOUVANADIN, "Matériaux de câbles à isolation synthétique pour des applications au transport d'énergie Haute Tension à Courant Continu (HVDC)", Ph.D Thesis, Paul Sabatier University Toulouse, 2011.

# MODELS DEVELOPMENT




## Models development

- Physical models
- Aging models




# Aging models

| Parameters | Lewis | DMM | Crine | Zhurkov |
|---|---|---|---|---|
| Mechanical stress | ☑ | | | ☑ |
| Electric stress | ☑ | ☑ | | ☑ |
| Thermal stress | | ☑ | ☑ | |
| DC application | | ☑ | | |
| Space charge | | ☑ | | |

## Eyring Law

$$v = AT^{\alpha} \exp[\frac{E_a}{kT} + \left(B_1 + \frac{C_1}{T}\right)S_1 + \left(B_2 + \frac{C_2}{T}\right)S_2 + \left(B_3 + \frac{C_3}{T}\right)S_3 + \ldots]$$

*$B_n$ , $C_n$, $S_n$ correspond to stress parameters ( Mechanical, Electrical, space charge…) at the temperature T*

➔Understand the mechanism of degradation of XLPE DC cables over the time.
➔ Increase the relevance of the specifications of HVDC cables.
➔Better control of industrial risks with this emerging technology.

# Conclusions

✓ Many projects with HVDC technology

✓ Different HVDC technologies are proposed: XLPE technology is new

✓TSOs and manufacturers need to develop a representative model of cable aging:

- Increase the relevance of the specifications of HVDC cables
- Better control of industrial risk associated with this emerging technology.

✓ Materials, nature of interfaces, mechanical and thermo-electrical stress are particularly critical regarding space charge generation.

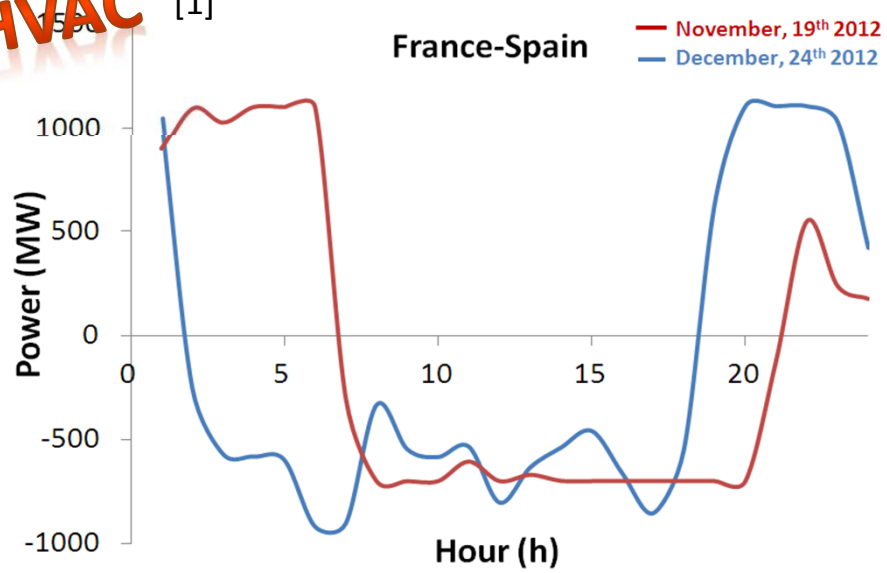
# Perspectives

- Conduct experimental studies to quantify each phenomenon separately.
- Understand impact of each parameter on aging.
- Develop a reliable aging model.

# Thank you for your attention

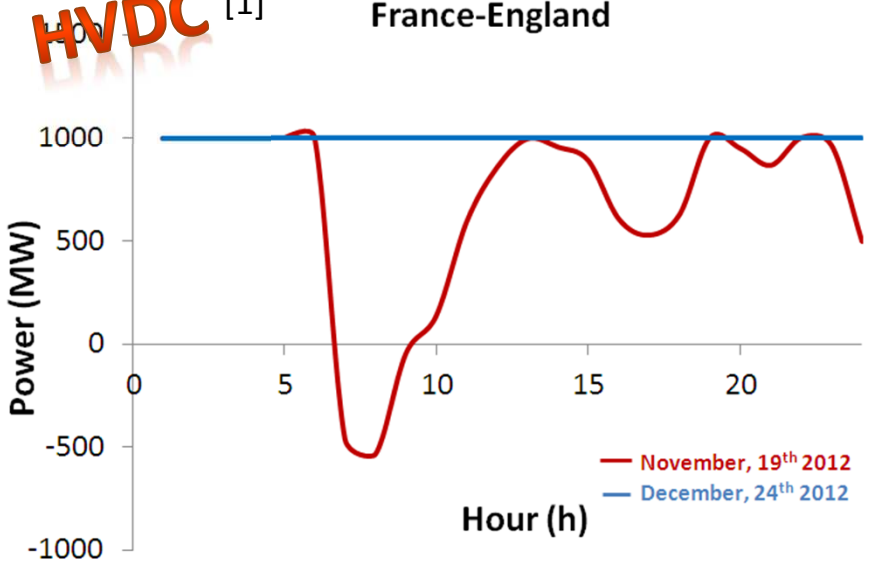
# Operation of HVDC links / HVAC links

HVAC [1]




- ✓ Load curve depends on the day
- ✓ Many variations per day
- ✓ Limit values not so ofen reached
- ✓ Load value not chosen

HVDC [1]



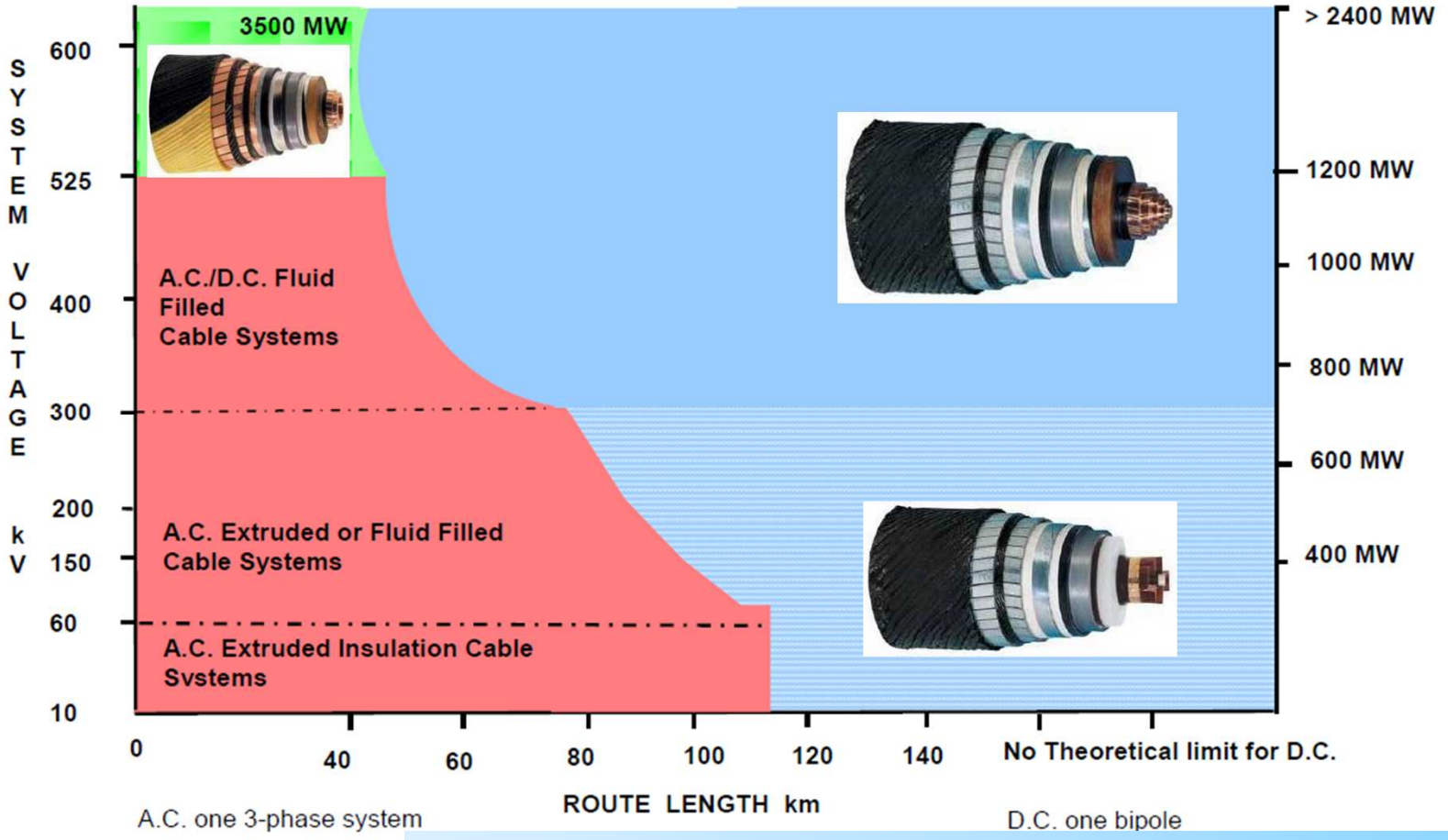

- ✓ Load curve depends on the day
- ✓ Not so many variations per day
- ✓ Limit values ofen reached
- ✓ Load value chosen
- ✓ Function of the electricity market

➔ **Sollicitations are differents between HVAC/HVDC**

➔ **Impact of the aging of the system**

[1] Rte's data, SLTN sofware

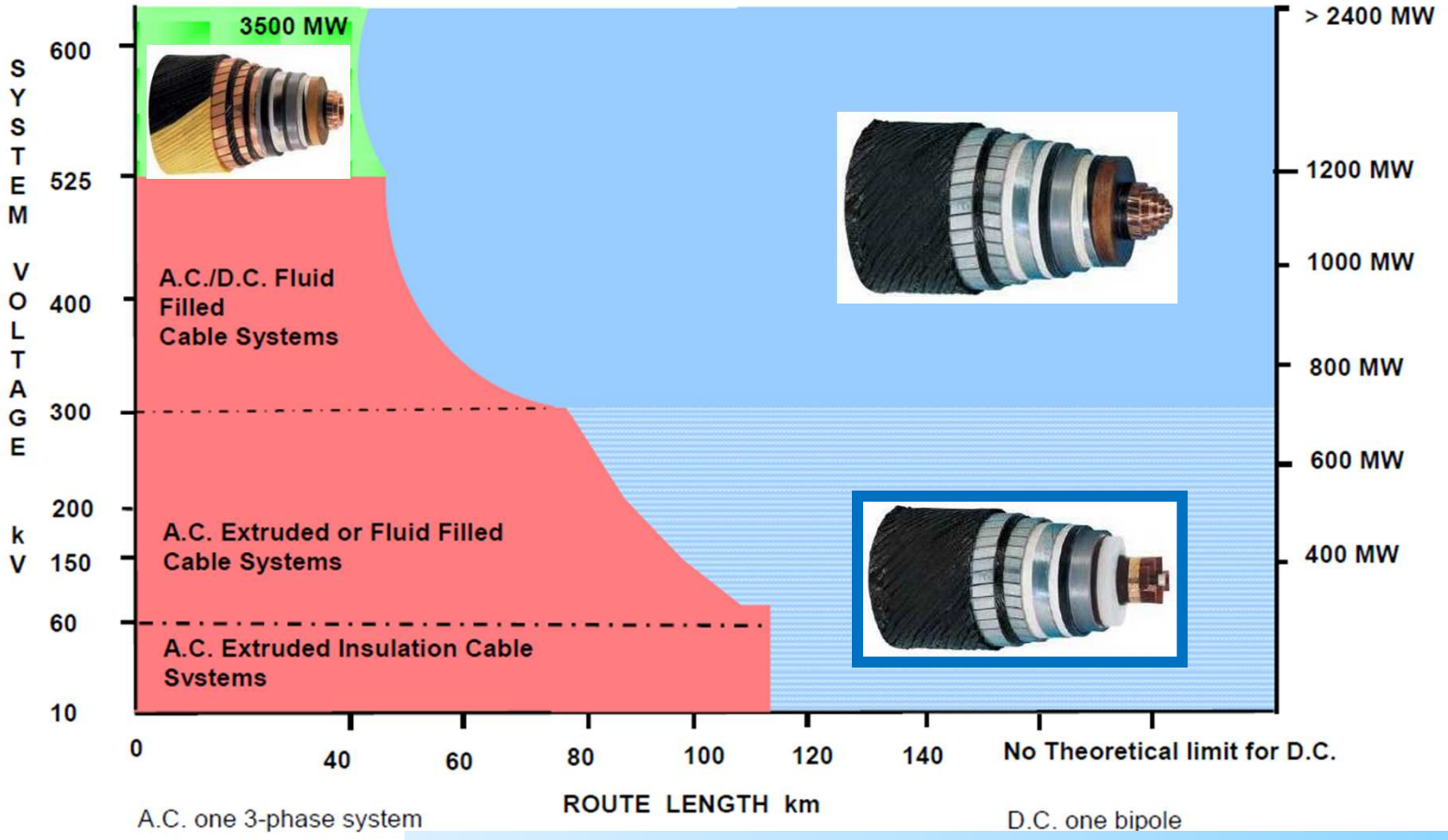
# HVDC cable technologies




➔ **Different materials, different limits of use**

➔ **Impact on the aging of the system**

# HVDC cable technologies

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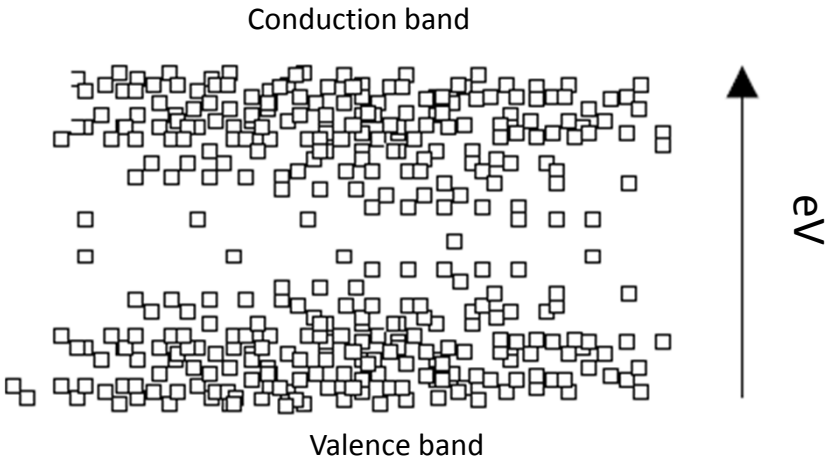
# Distribution of traps




| Nature of especies | $\varepsilon_e$ (eV) | $\varepsilon_h$ (eV) |
|---|---|---|
| Acetophenone | 0.90 | 0.04 |
| Cumyl alcohol | 0.28 | 0.36 |
| α methyl styrene | 1.53 | 0.79 |
| C=C (Conjugated chain) | 0.51 | 0.63 |
| C=C ( In the chain) | 0.16 | 0.57 |
| C=0 ( End of chain) | 0.45 | |

Trap depth ($\varepsilon_e$) for electron and $\varepsilon_h$ ( hole) [1]

Physical defaults (eg: Conformation of the polymer chains) => shallow traps

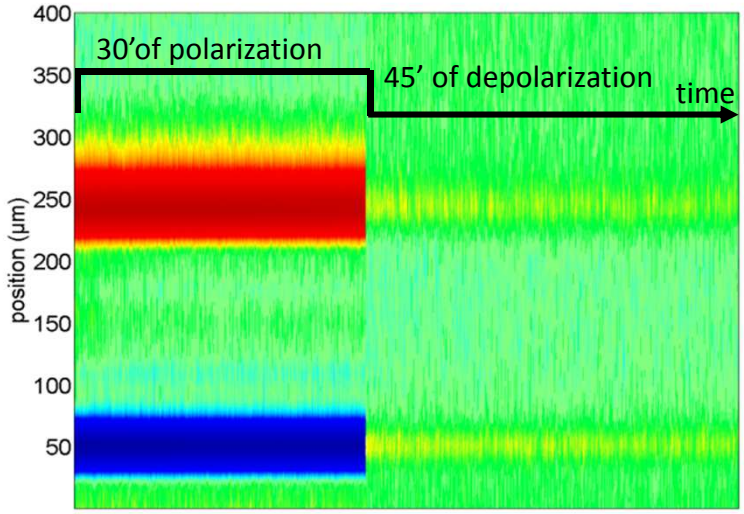
Chemical defaults (eg: residues of additives) => deep traps

Usually located close to interfaces

[1] G. Teyssedre and C. Laurent, "Charge Transport Modelling in Insulating Polymers: From Molecular to Macroscopic Scale", IEEE Trans. Dielectr. Electr. Insul. Vol. 12, pp. 857-875, 2005
G. Teyssedre et al "Deep Trapping Centers in Crosslinked Polyethylene Investigated by Molecular Modeling and Luminescence Techniques " IEEE Trans. Dielectr. Electr. Insul. Vol. 8, pp. 744-752, 2001.

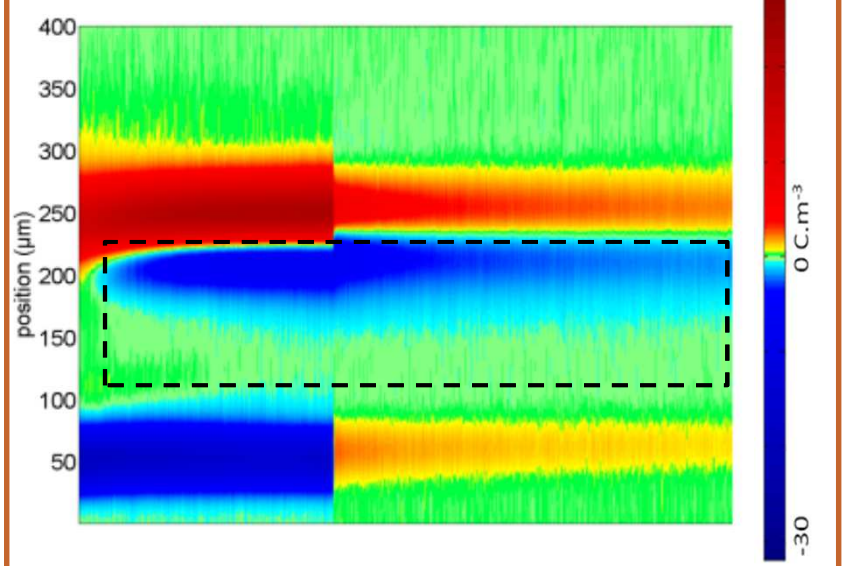
# Influence of antioxidants on space charge formation

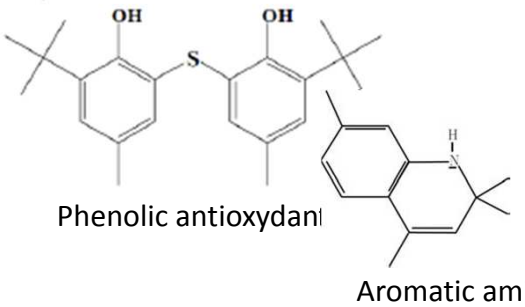
without antioxydant [1]




Samples: Au/PE/Au / press-moulded plaques / E: 50 kV/mm, T: 25° C

with antioxydant [1]

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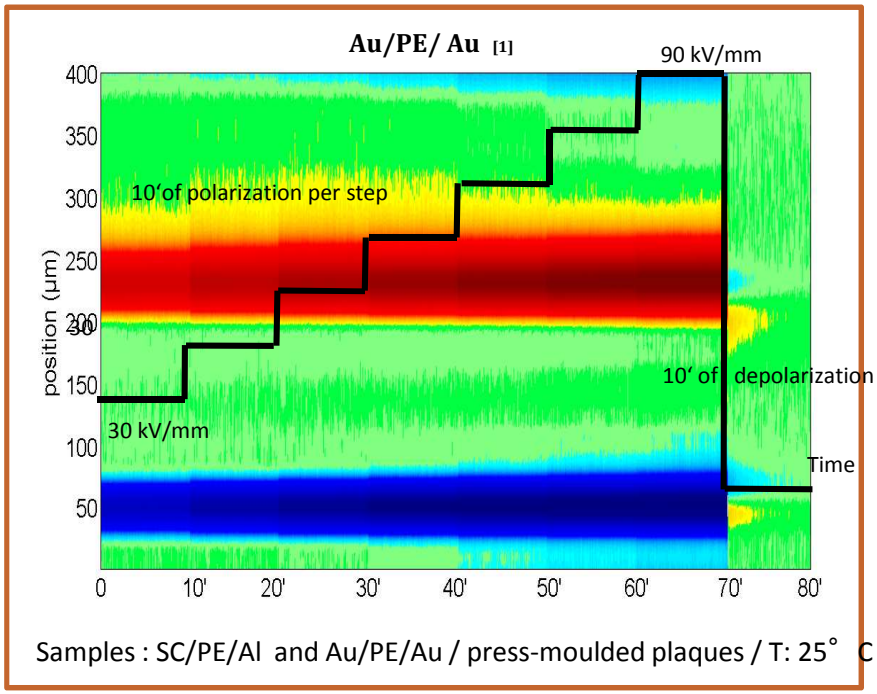
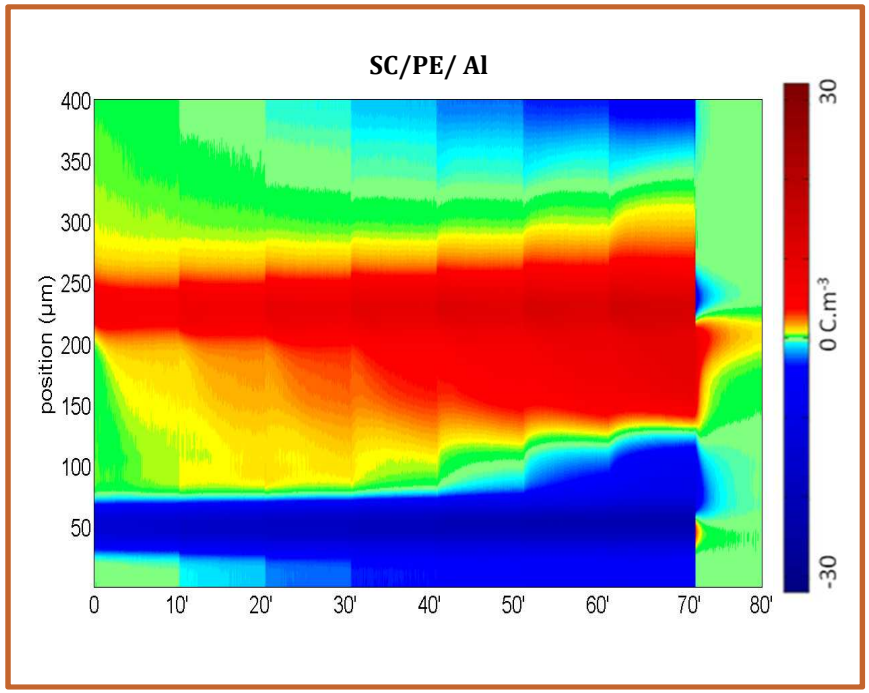



Samples : SC/PE/Al and Au/PE/Au / press-moulded plaques / T: 25° C




Significant impact on the nature of the electrodes on the charge generation

[1]Mandana TALEB , Phénomènes aux interfaces des isolants : mesure et simulation, Ph.D Thesis, Paul Sabatier University,Toulouse, 2011.