Measurement of Space Charge Accumulation in Dielectric Materials and Analysis using Quantum Chemical Calculation

Part 1 Q(t) measurement

Part 2 PEA measurement

Part 3 Analysis by Quantum Chemical Calculation

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Part 1  Q(t) measurement
Q(t) Measurement Protocol /Low voltage side

- Over
- High voltage power source
- Specimen
- DCIC-Q(t)
- ZigBee Receiver
- EM wave

Q(t) Measurement Protocol /High voltage side

- I(t)
- PC Q(t)
- DCIC-Q(t)
- Vdc
- Specimen
- Plate Heater
- High voltage power source
- Zigbee Receiver

Q(t) measurement result

\[ Q(t) = Q_0 + \Delta Q(t) \]

Electric field threshold of charge accumulation

\[ \frac{Q(t)}{Q_0} = 1 + \frac{\Delta Q(t)}{Q_0} \]

At 80°C: 80°C

\[ Q(t=300s)/Q_0 = 1 \]

At RT: RT

\[ E = 0.8 \text{ kV/mm} \]

\[ E = 20 \text{ kV/mm} \]
Q(t) measurement results (Difficult for charge accumulation in aromatic polymer)
Q(t) measurement results  (Easy for charge accumulation in olefin polymer)
Q(t) Measurement: Water-tree Deteriorated CV Cable

Q(t) device is set on high voltage side

Evaluation on electric charge accumulation

No charge accumulation → No deterioration

Some charge accumulation → deterioration
Q(t) Measurement: Gamma-ray irradiated cable

Generation of electron/hole pair by gamma-ray irradiation in cable → the electron/hole pair are recombined by the thermal energy and an applied electric field.
Charge Measurement Methods of DC insulating materials

- **I(t) measurement**
- **Q(t) measurement**
- **E(0,t) and E(a,t) measurement**
- **PEA method**

![Graphs and illustrations of charge measurement methods](image-url)
**Q(t) and PEA give same properties results**

**< Q(t) Measurement >**

**< PEA Method >**

**PS (polyethylene):** little charge accumulation.

**LDPE (low density polyethylene):** large amounts of charge accumulation.
Comparison among various methods of DC insulating material properties

Q(t) method: wide range of tested temperature and electric stress

Table: Comparison between measurements for electric charge properties

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<th>Q(t) method</th>
<th>PEA method</th>
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<td>Conductivity ( \kappa ) [S/m]</td>
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Part 2  PEA measurement
A : Research Subjects on HVDC Electrical Insulation

- Internal electric field distortion caused by charge accumulation leads to an electrical breakdown of insulating materials

- Electric charge accumulation is one of significant factor for studying the properties of insulating materials
PEA measurement result of space charge accumulation in Kapton film under a different electric field and an elevated temperature.

**B-1 PEA space charge distribution measurement for sheet sample**

PEA measurement result of space charge accumulation in Kapton film under a different electric field and an elevated temperature.

**High temperature P E A system**

PEA : Pulsed Electro-Acoustic method

PWP: Pressure Wave Propagation method

B-2 PEA measurement for Observing Charge Accumulation in Cross Section \((r, \theta)\) in Cable Geometry

Measurement result of accumulated charge
Part 3 Analysis by Quantum Chemical Calculation
<Quantum Chemical Calculation>
Calculation of fundamental function for dielectric materials
- Energy gap $\phi_g$
- Electrode charge injection barrier $\phi_B$
- Charge trap depth $\phi_t$

Consultant Contents
- Measurement technology of space charge accumulation in dielectric materials
- Evaluation and analysis of HVDC insulating materials in new energy power system.
- Evaluation and its analysis for high field DC insulating materials in a power electronic device.
C: Fundamental Electronic Parameters of Insulating Materials by using Quantum Chemical Calculation

Energy level distribution and related parameters

Molecular orbital of PE

Molecular orbital of PTFE

Electron energy [eV]
-4
-2
-8
-6
-10
-12
+4
+2

PE (C_{24}H_{50})

PTFE (C_{24}F_{50})

HOMO

LUMO

\( \phi_g = 9.99 \text{eV} \)

\( \phi_i = 7.60 \text{eV} \)

\( \chi = -2.39 \text{eV} < 0 \)

\( \phi_g = 7.96 \text{eV} \)

\( \phi_i = 10.46 \text{eV} \)

\( \chi = +2.50 \text{eV} > 0 \)

Electronegativity

Fluorine F

(negatively charged)

Carbon C

(positively charged)

C:  Fundamental Electronic Parameters of Insulating Materials by using Quantum Chemical Calculation
D: Analysis of Electric Charge Accumulation in Dielectrics

- Electron energy level distribution is calculated by Quantum Chemical Calculation. →

- Electron and hole trapping sites are introduced on the main chain which are determined by chemical molecular structure. →

- 3-dimensional electro-static potential distribution for positively and negatively charged chains was calculated by Quantum Chemical Calculation. →

- It is clearly found that the potential distortion is located at the estimated trapping sites on the chemical molecular structure.

Quantum Chemical Calculation is very useful to analyze the charge accumulation properties of insulating materials.
D: Analysis of Electric Charge Accumulation in Dielectrics

- Positive charge injection from anode into polyethylene under high electric field stress is observed by PEA method. →

- Why does the positive charge inject significantly in PE? →

- The barrier high ($\phi_B$) of hole carrier is evaluated by using Quantum Chemical Calculation. →

- It is found that the hole carrier injection barrier from semi-conducting electrode is low, leading to the positive charge accumulation.

Key subjects:
- PEA measurement
- Quantum Chemical Calculation
Key issues for dielectrics investigation:

1. **Classical theory of electro-magnetic and dielectric physics**
2. **Measurement technology and signal processing**
3. **Quantum chemical calculation.**