High voltage engineering general and partial discharge basics

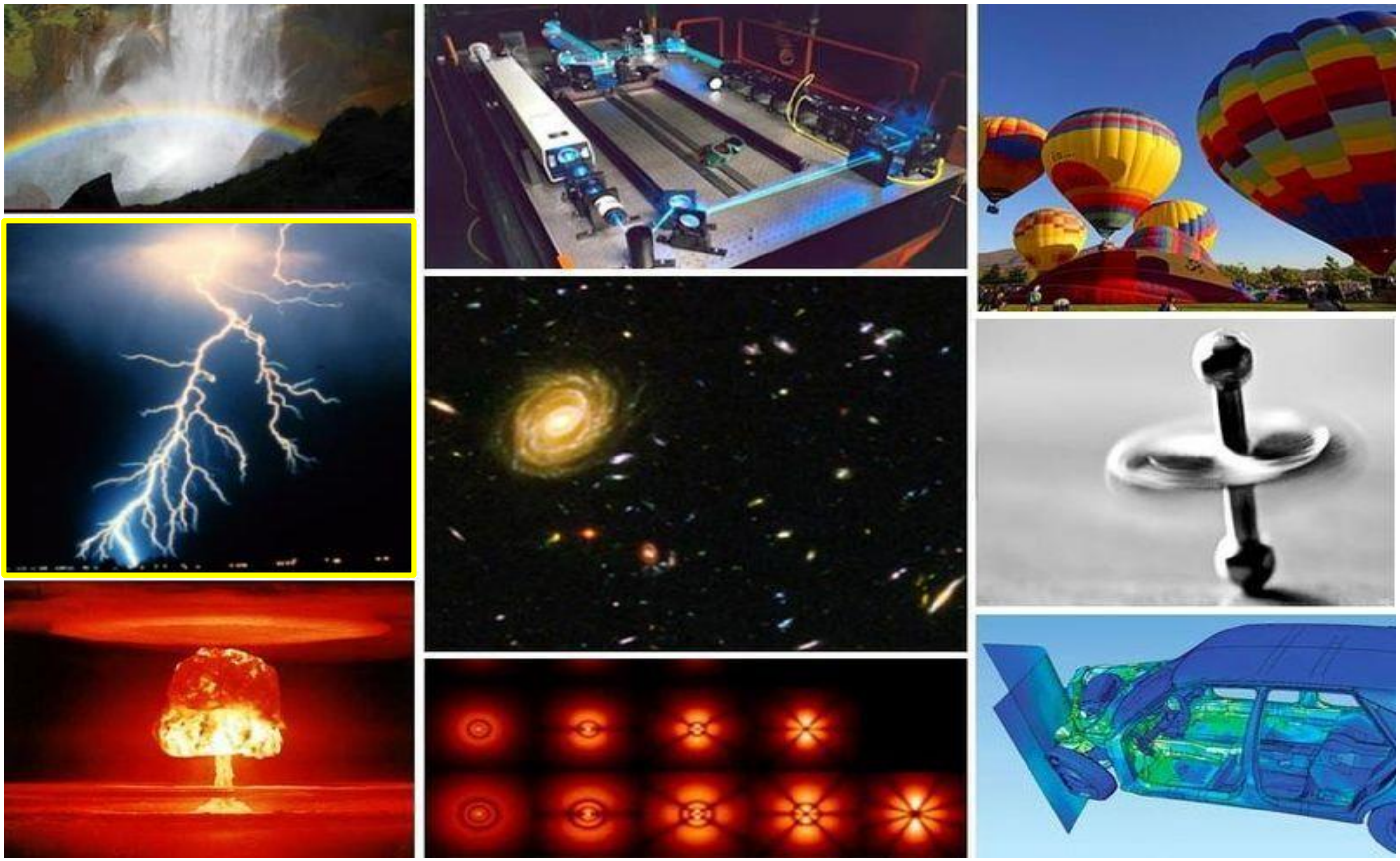
Korea Electric Power Research Institute Next Generation Transmission and Substation Research Institute

Lee Jong-geon

Contents

Introduction

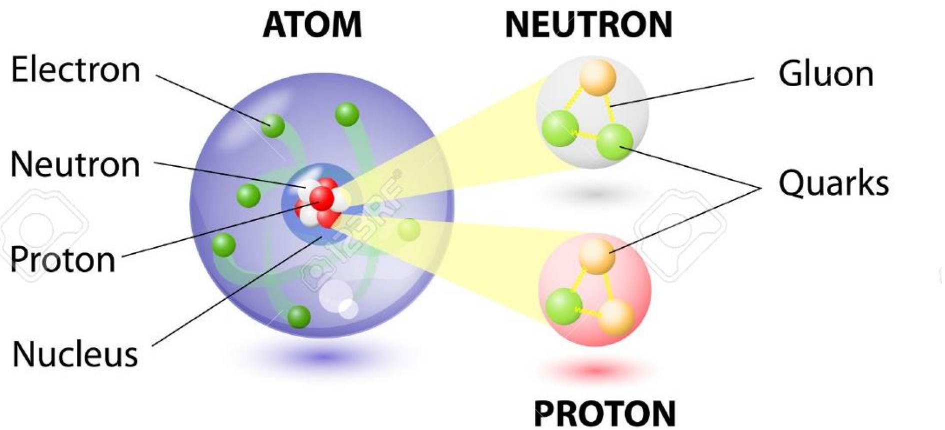
- **Physical phenomenon (Physical Phenomenon)**

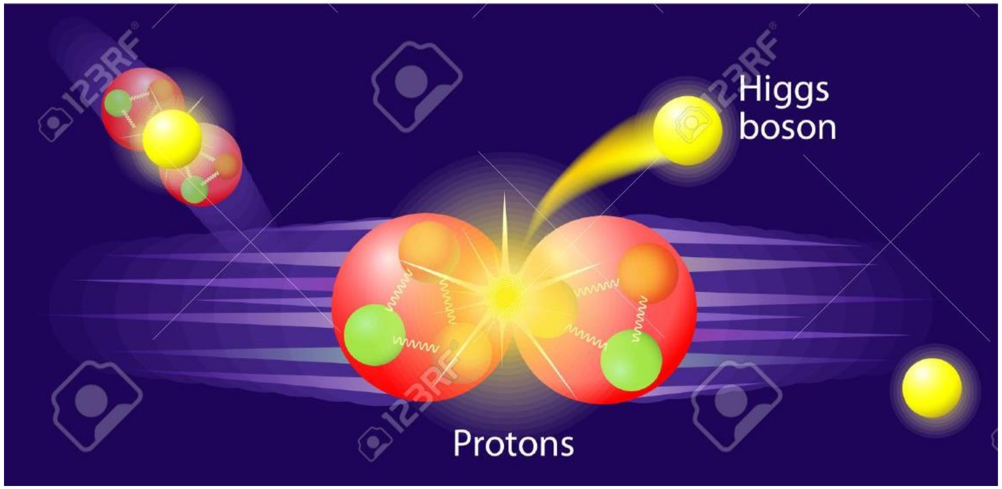


energygomediumPhenomenon transmitted through

Introduction

- **medium((Medium)**





Introduction

- Classification of physical phenomena according to particle type

Classical mechanics ((Newton's Law)

- Physical phenomena at the atomic and molecular level

Electromagnetism (Electromagnetics)

optics(Optics)

- Atomic nucleus, electron unit physical phenomenon

Quantum mechanics (Quantum Physics)

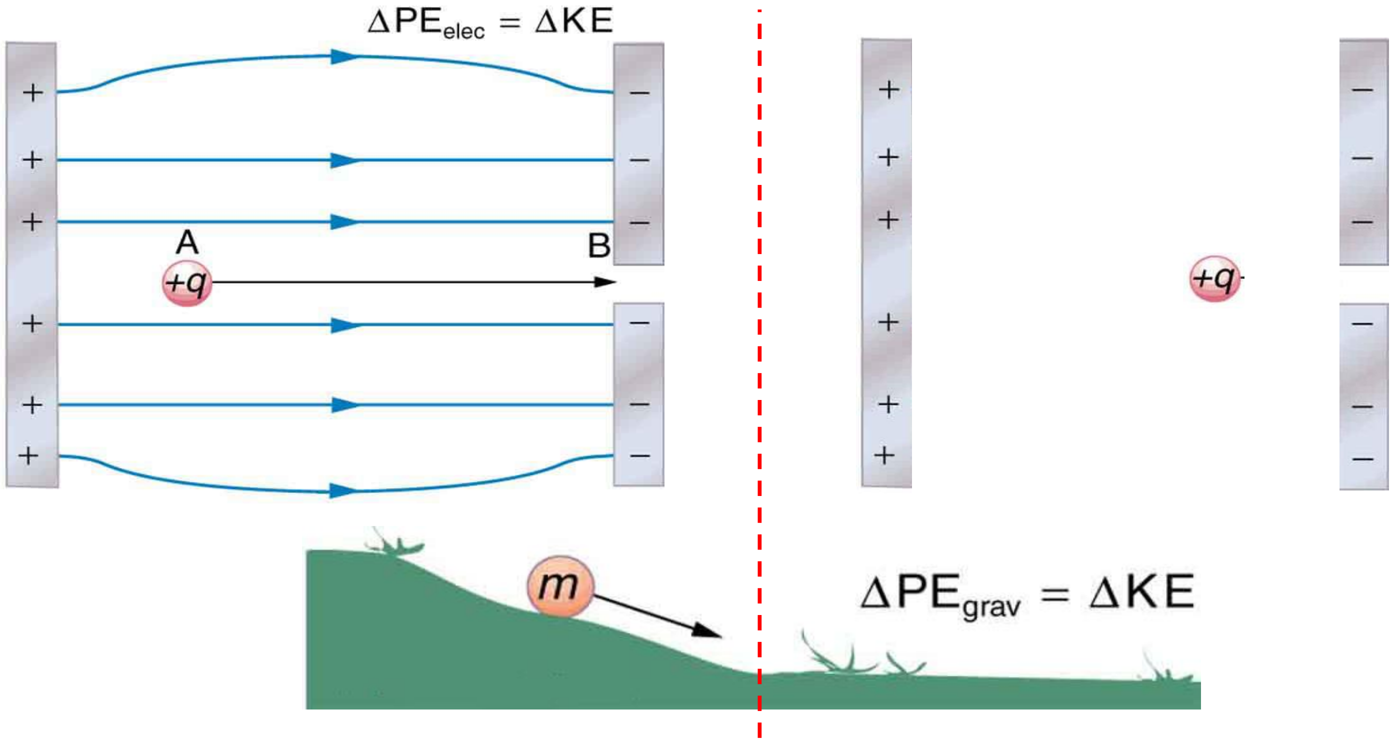
- Physical phenomenon in units below electrons

The electrical phenomenon isNucleusandElectronIt can be explained just by

Voltage, Current

- transfer of energy

Energy: The ability of matter to do physical work.

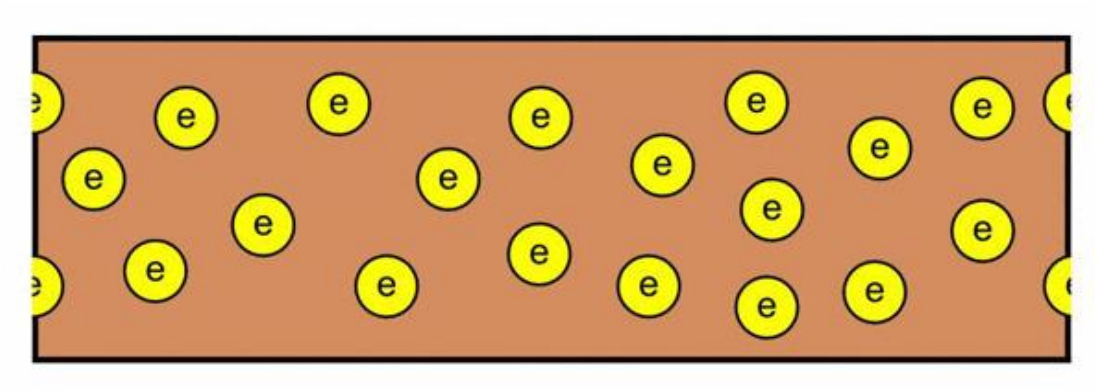


Voltage: Electrical potential energy, forms a field,

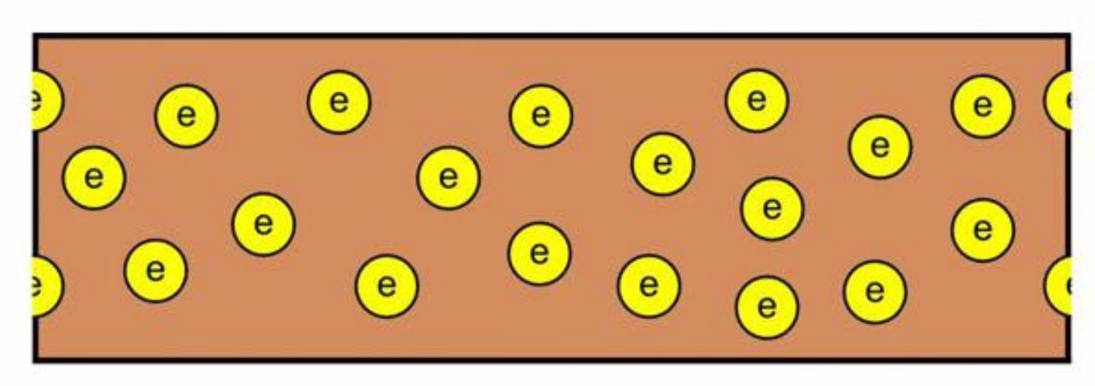
Move electrons (Current) doing the job

electric field type

- **AC/DCclassification**



Alternating Current (AC)



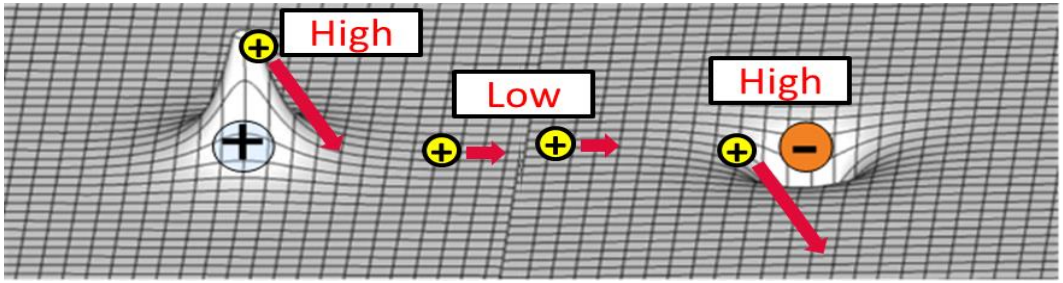
Direct Current (DC)

The energy transfer method of electrons varies depending on the type of applied voltage.

Electric Field

- **formation of an electric field**

  - Electric Field:A charge with electric forceThe degree to which force is applied to the surrounding space[V/m]
  - Columb Force:Force acting between charged objects with electrical properties



Formation of electric field by positive and negative charges

- **Electric field utilization rate**

  - Based on the uniform electric field formed between infinite platesDegree of inequality in target electric fieldcast

  index that represents

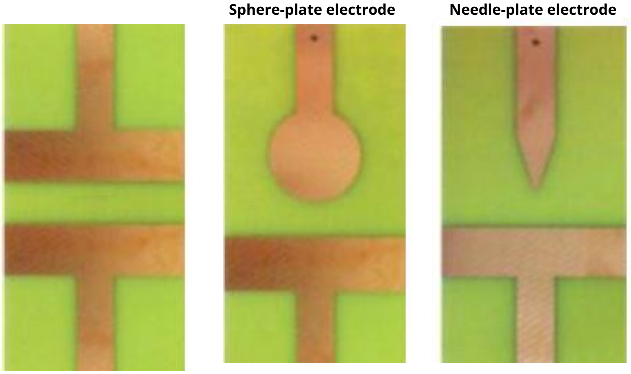
$$- \frac{E_{Mean}}{E_{Max}} - \frac{V One}{d\, E_{Max}} \quad (0 \text{ --–One})$$

Electric Field

- **Classification of electric field types based on electric field utilization rate**
  - Electric field utilization rate (η) changes depending on the shape and arrangement of the electrode.
  - ηThe smaller the value, the more unequal electric field is formed.→Localized charge concentration (electric field concentration)
  - The probability of discharge initiation is high in locations with high electric field concentration.

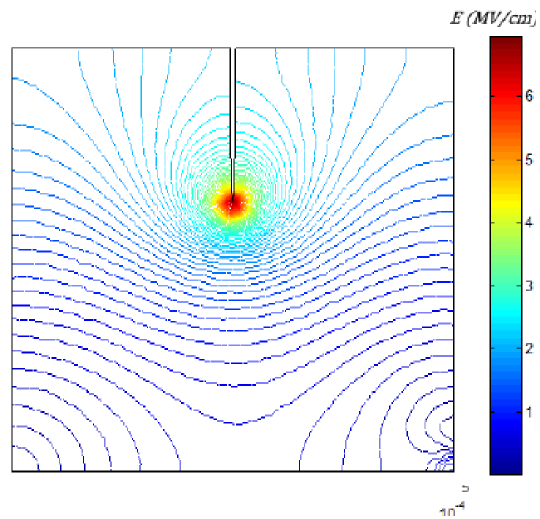
  → Requires electric field mitigation through insulation design

Sphere-plate electrode Needle-plate electrode

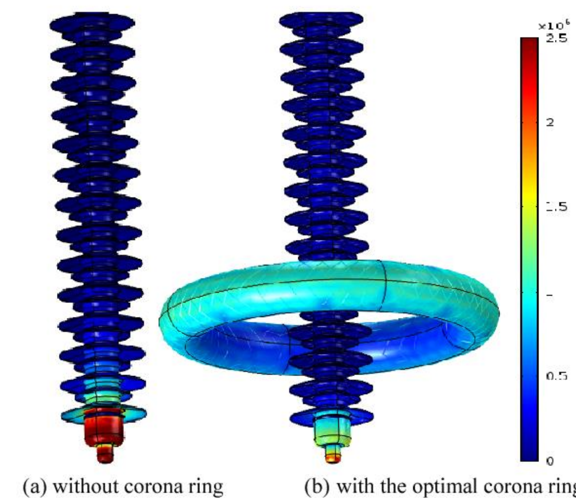


Unequal field

(η <0.5)



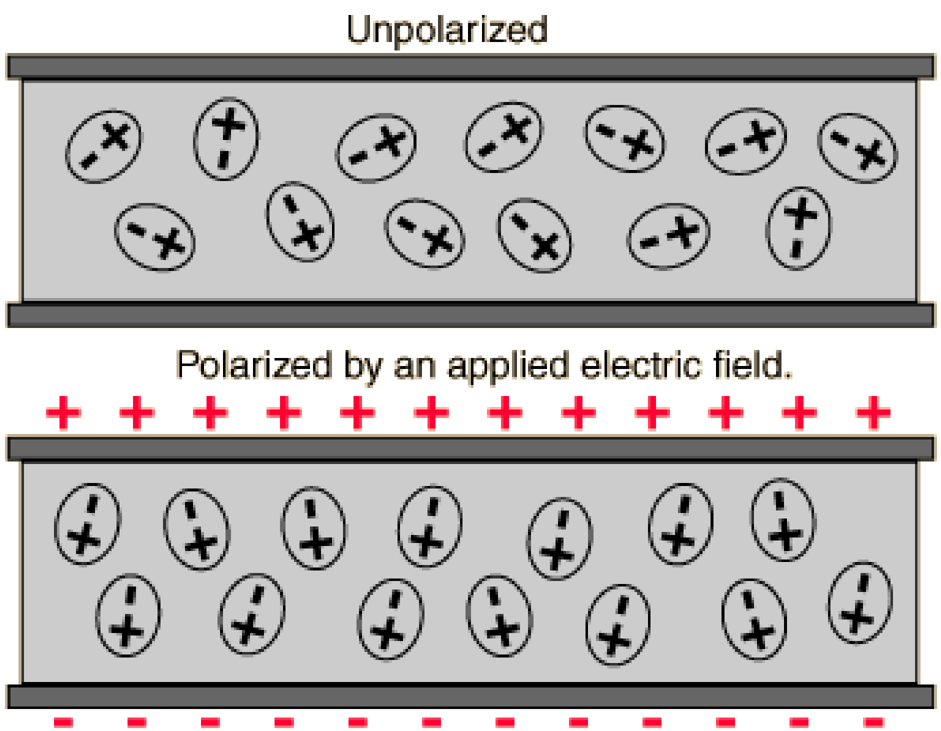
Electric field concentration at electrodes



Electric field mitigation through insulation design

Polarization

- **Dielectric polarization (Polarization)phenomenon**



- When electric field is appliedPolar molecules are alignedA phenomenon that causes electrical polarity to appear on the surface of a material
- The degree of polarization is determined by the relative permittivity (ε) of the material.

Dielectric

- **dielectric(Dielectric)definition of**
  - in an electric fieldDielectric polarization (Polarization)Insulators have polarity due to
  - Within the range permitted by relative permittivityNo direct charge transfer

- **Dielectrics and Insulators**
  - The dielectric is between the plate electrodes.capable of storing electric chargematter

    → Relative dielectric constant (permission)depend on
  - Insulator is between conductors.blocking the flow of electric chargerefers to a substance

    → Resistance (Resistivity)depend on
  - Are dielectrics insulators?

    → For charge accumulation between plate electrodes, constant current ((DC Current)need to block

Permittivity

- First of all, if you look at the English word permit, it means to allow. What does this have to do with the dielectric constant we know?

  I need to see if there is

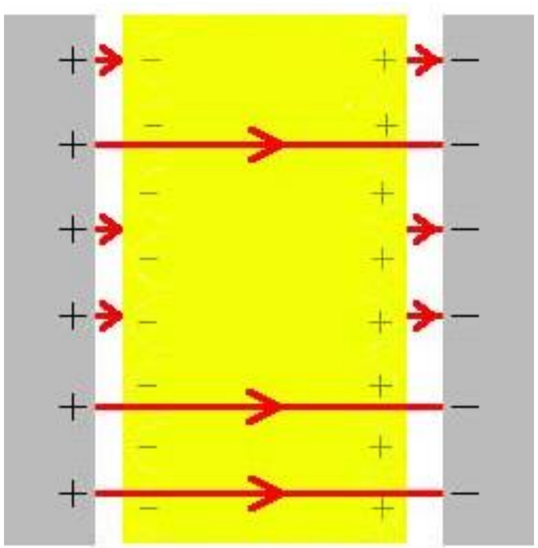
  - When dielectrics are placed in an electric field, they affect each other.

    ① Dielectric is polarized under the influence of electric field.

    ② Electric field decreases as the dielectric polarizes.

- Then why 'permit'?This means that the permittivity of the dielectric is an electric fieldcast

  This is because it is a physical quantity related to how much 'permission' is given.



- The electric field is intact, but if a dielectric enters, the electric field

  It can be seen that it does not pass through the dielectric and shows the appearance of E becoming smaller.

- If the dielectric constant of the dielectric is large, the dielectric produces a larger amount of electric field.

  Gives "permission" to pass through the dielectric.The dielectric

  E on the outside becomes smaller

Polarization

- **Relative permittivity (ε,permission)**

  - 'Permit'tivity:How much electric field does a dielectric have?'Accept'It means the degree to which
  - Materials with high relative dielectric constant: Polarization occurs well→Electric field lines are well filled

ex)Permittivity:1 > 2 > 3,Degree of polarization:1 > 2 > 3,Degree of electric field concentration:3 > 2 > 1

→ Dielectric performance for insulating applications:1 > 2 > 3

(One) (2) (3)

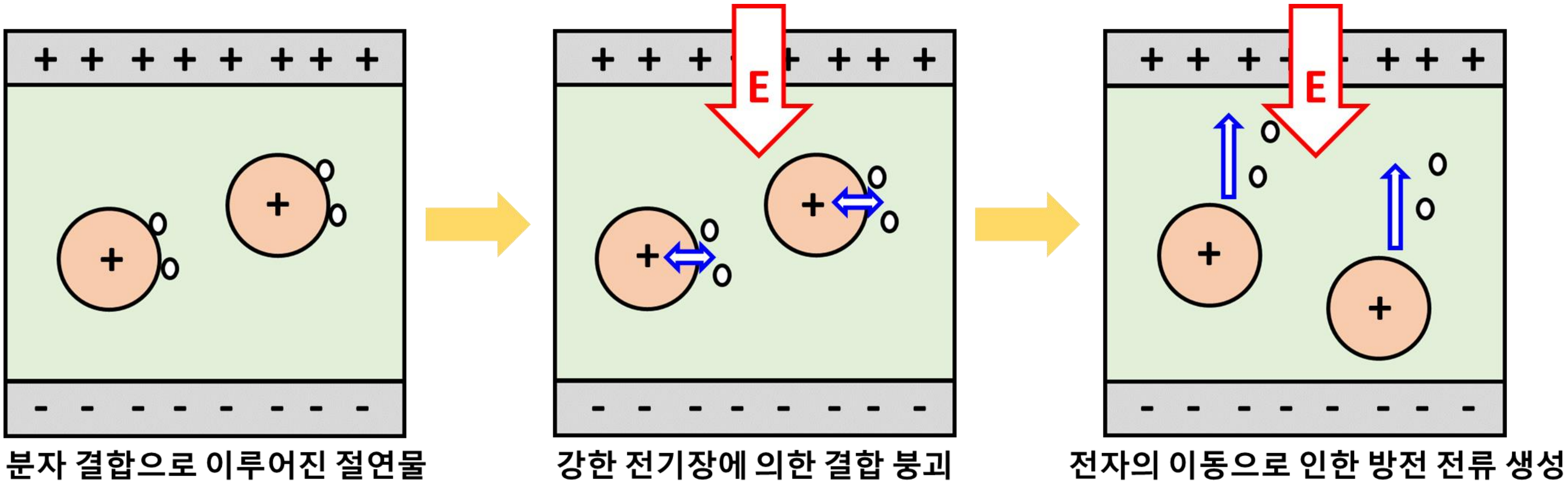
- insulatingCapacitanceWhy must be big

→ To have a large permittivity value→Improves insulation performance and prevents insulation deterioration

Discharge phenomenon

- **Definition of discharge phenomenon**

- Discharge(electric power , discharge):The process by which a charged body with electrons loses its charge
- Applying a voltage that exceeds the insulation performance of the material→Electron movement and discharge current formation
  - Insulation performance: Degree to which electron movement is suppressed in response to applied voltage

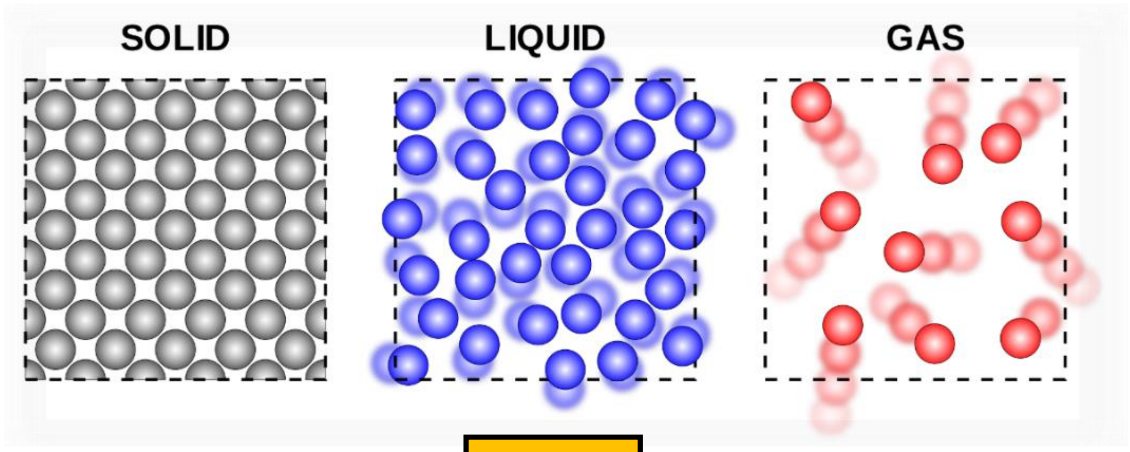


2. Breakdown of insulators

Properties of Insulators

- **Classification of insulating material types according to insulation method**

  - Air insulation, gas insulation, vacuum insulation, solid insulation, liquid insulation, composite insulation



Cable

Transformer

GIS

2. Breakdown of insulators

Properties of Insulators

- **Requirements for Insulators**
  - Capacitancevalue must be large→No high intensity electric field is formed
  - Insulation characteristics must be secured for the target voltage.
  - Mechanical properties such as tensile strength, bending, and elasticity must be guaranteed.
  - Securing thermal characteristics caused by loss due to conductive current, dielectric loss, etc.
  - Must be stable from chemical reactions resulting from discharge

절연물 특성	기체 (SF_6)	액체 (절연유)	고체 (에폭시)	진공
절연특성	O	O	⊙	O
기계적특성	Δ	Δ	⊙	Δ
열적특성	X	⊙	X	X
소호특성	⊙	O	X	⊙

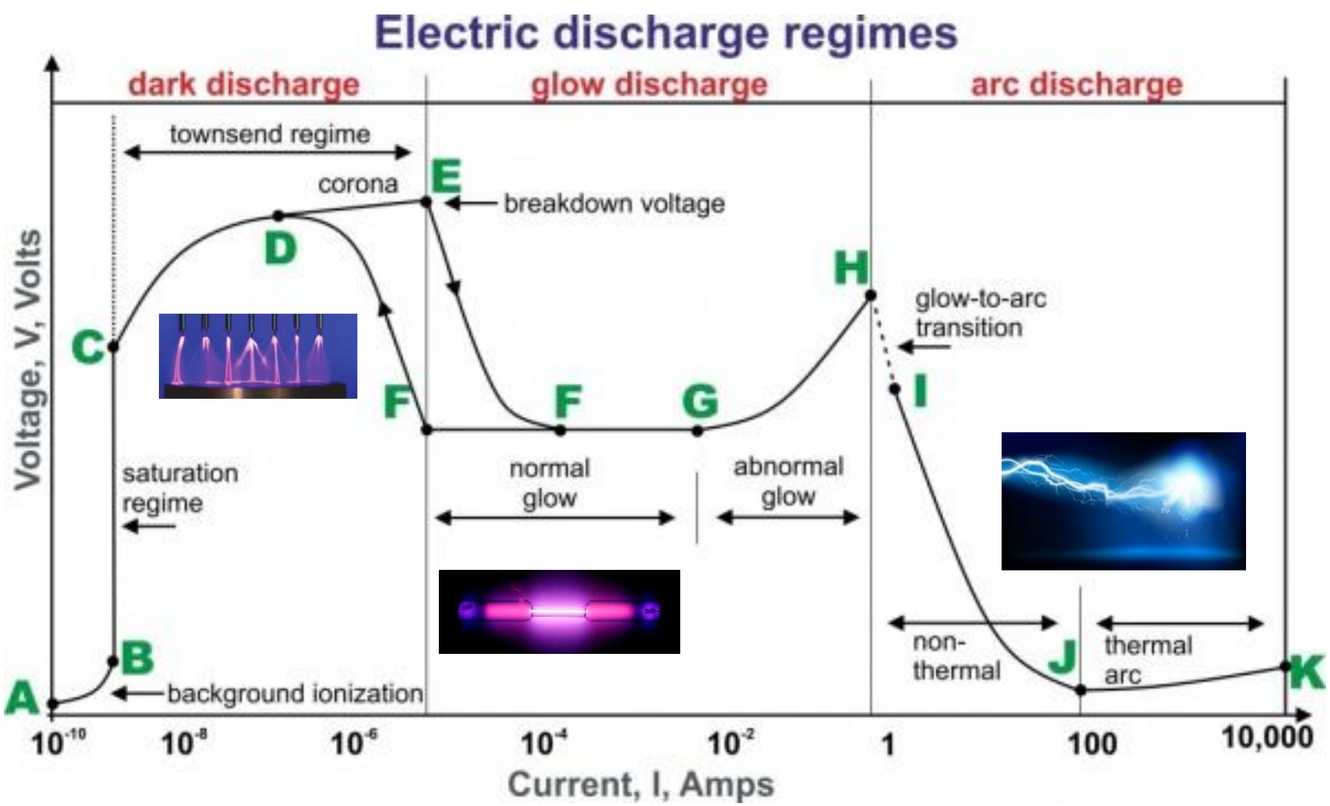
⊙:아주양호, O:양호, Δ:고체의 지지물에 의존, X:불량

2. Breakdown of insulators

Gas insulation breakdown

- **VIClassification of discharge types according to characteristics**

  - Depending on the degree of energy generated during discharge,3Classified by type
  - Dark discharge(Undercurrent) <Glow discharge(glow discharge) <Arc discharge(arc discharge)



2. Breakdown of insulators

Gas insulation breakdown

- **Electronic avalanche (Avalanche)**

  - Electric field application→electronic acceleration→neutron collision→ (+)ionized with (-)→Additional Loot

  - Electronic avalanche aloneCurrent rapidly increases during insulation breakdowncannot explain

- **Townsend discharge**

  - J. S. TownsendDischarge theory considering secondary electron emission factors, advocated by

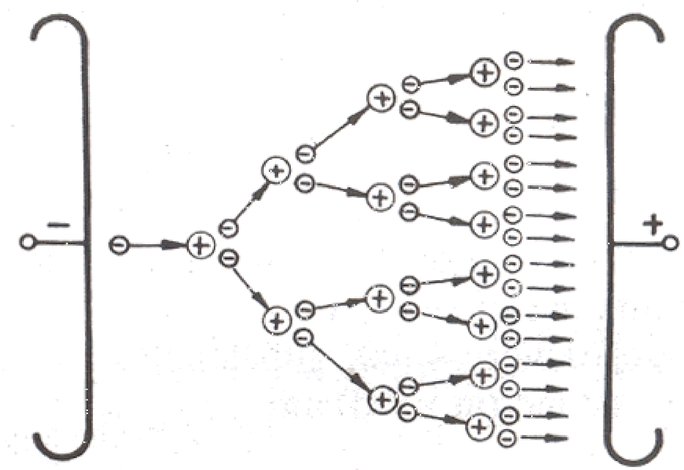
  - 3It consists of three processes, each of which is as follows:

    -αProcess: Collision ionization due to electronic avalanche

    - βProcess: impact ionization by positive ions

    - γProcess: impact ionization at electrodes

  - Accuracy decreases as interpole distance increases or gas pressure increases.

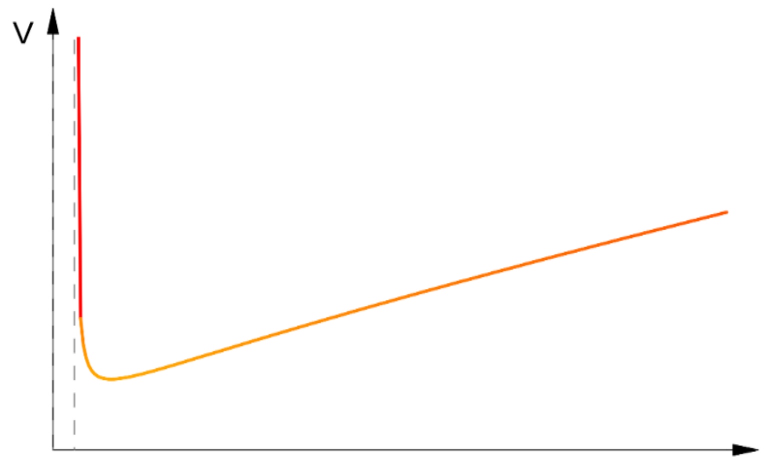


2. Breakdown of insulators

Gas insulation breakdown

- Paschen's Law

- Derivation of pressure-distance and breakdown voltage correlation through Townsend discharge theory
  - Assume that electric field and temperature are constant
  - Discharge start voltage: product of pressure and distancep.d.determined by



Paschen's Curve

- p.d.valueapproximately67 kPa-cmIf it exceedsTownsend discharge theory and

It is derived that the discrepancy between the experimental formulas increases

Gas insulation breakdown

- **Paschen's LawVerification test**

1. 배 경

□ 진공 작업 중 발생하는 저진공(0.1~0.5 Torr) 영역에서 345kV 가공선로로부터 GIB로 유기되는 유도전압에 의한 내부 방전 개시 가능성 검토

2. 문헌자료 분석

□ Paschen curve 분석을 통한 저진공 영역에서의 1kV 이하 전압 환경에서의 방전 개시 가능성 분석

□ 저진공 영역에서 고장이 발생한 345kV GIB의 도체와 외함 간 절연거리를 적용하여 Paschen curve의 변수인 pd(압력×거리)값 산출

<table>
<tr><th></th><th>진공도</th><th>절연거리</th><th colspan="2">pd 값</th></tr>
<tr><td rowspan="2">1</td><td rowspan="2">0.1 ~ 0.5 Torr</td><td rowspan="2">10.3 cm</td><td rowspan="2">1.03 ~ 5.15 Torr-cm</td><td>0.14 ~ 0.69 kPa-cm</td></tr>
<tr><td>13.7 ~ 68.7 mbar-mm</td></tr>
</table>

2. Breakdown of insulators

Gas insulation breakdown

- **Paschen's LawVerification test**

☐ GIB 내에서 공기(Air)가 잔류할 경우와 SF_6 가스가 잔류할 경우에 따른 산출된 pd 범위 내에서의 방전개시전압 도출

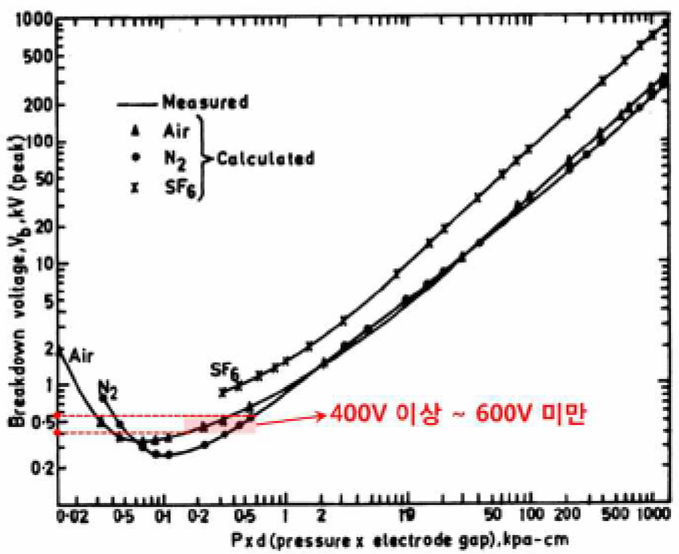


Fig. 1: Measured and calculated Paschen curves for air, N_2 and SF_6

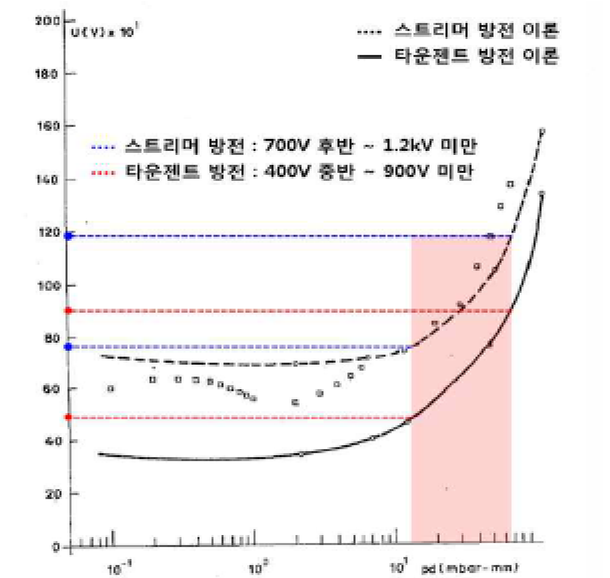


Fig. 2 Experimentally obtained points by static voltage and numerically calculated curves /criteria (1) curve (——) and (2) curve (---) ($\gamma=10^{-8}$)/

공기	400V ~ 600V	SF_6	스트리머 이론	700V~1.2kV
			타운젠트 이론	400V~900V

※ E. Husain et al., "Analysis of Paschen Curves for Air, N2 and SF6 using the Townsend Breakdown Equation", IEEE Trans. Electrical Insulation, AUG.1982

※ P. Osmokrovic, "Electrical Breakdown of SF6 at Small Values of the Product pd", IEEE Trans. Power Delivery, OCT.1989

2. Breakdown of insulators

Gas insulation breakdown

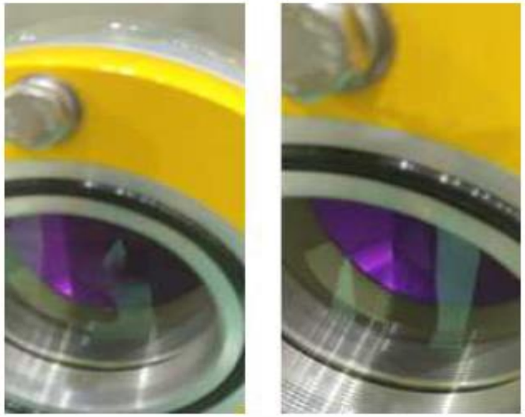
- **Paschen's LawVerification test**

3. 실증시험 결과

- ❏ GIB 내 공기(Air)가 잔류할 경우를 상정, 저진공 영역에서 전압을 인가하여 방전 개시전압을 측정함
- ❏ 문헌 자료 분석 결과와 동일하게 공기 중 저진공(0.25~0.5 Torr) 영역에서 448~500V 전압에서 방전이 개시됨을 확인함

	GIB 조건	시험 조건	결 과
1	0.5 Torr	0V 에서 1kV까지 가압	448V 방전 개시
2	0.25 Torr	0V 에서 1kV까지 가압	500V 방전 개시
3	475V 고정	대기압에서 진공작업 실시	1.0 Torr에서 방전 개시

시험 구성


저전압 방전 확인

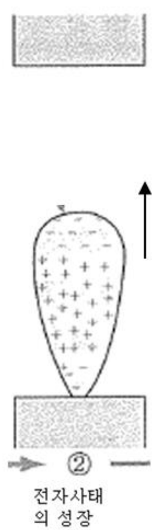
2. Breakdown of insulators

Gas insulation breakdown

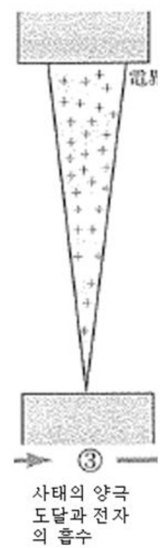
- Streamer Discharge

- Paschen's Lawderived byTownsendComplement the shortcomings of the theoryto do
- Considering the effect of space charge→Highp.d.Discharge phenomenon can be explained in value

인가전압이 커지면 전극간의 전자가 전계에 따라 가속되어 전리가 발생하고, 전자 사태가 일어난다.



이동속도가 큰 전자는 흐름의 선단에 많고, 양이온은 이동속도가 느리므로 고립되고 후방에는 많아진 전자사태가 진전된다.



전자사태가 양극에 도착하면 선단의 전자는 양극에 흡수되고, 양이온만이 공간에 고립된다.

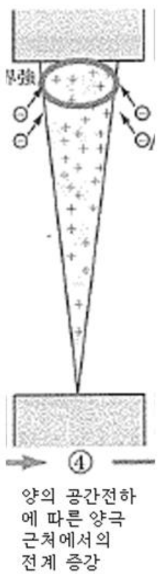
※Space charge effect

:The effect of limiting the flow of current in an object due to the potential of electric charges existing in the space surrounding the object.

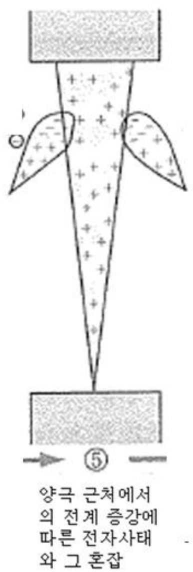
2. Breakdown of insulators

Gas insulation breakdown

- **Streamer Discharge**

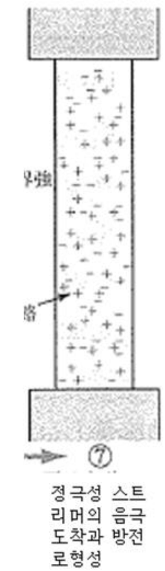


양극부근에서의 양이온 밀도는 극히 커지므로, 그 양이온에 의한 공간전하의 효과로 전계는 그 근방에서 상당히 강해진다.



이 강한 전계에 의해 가까운 전자를 끌어당긴다.

전자는 충돌전리를 반복하고, 새로운 전자사태를 일으키면서 양이온의 밀도가 커지는 공간의 가운데에 들어가고, 양이온과 전자가 혼재한 도전성이 높은 부분(스트리머)이 생김



스트리머가 음극에 도달하면, 방전로가 완성되고, 전극간에 단락되어 불꽃방전이 일어난다.

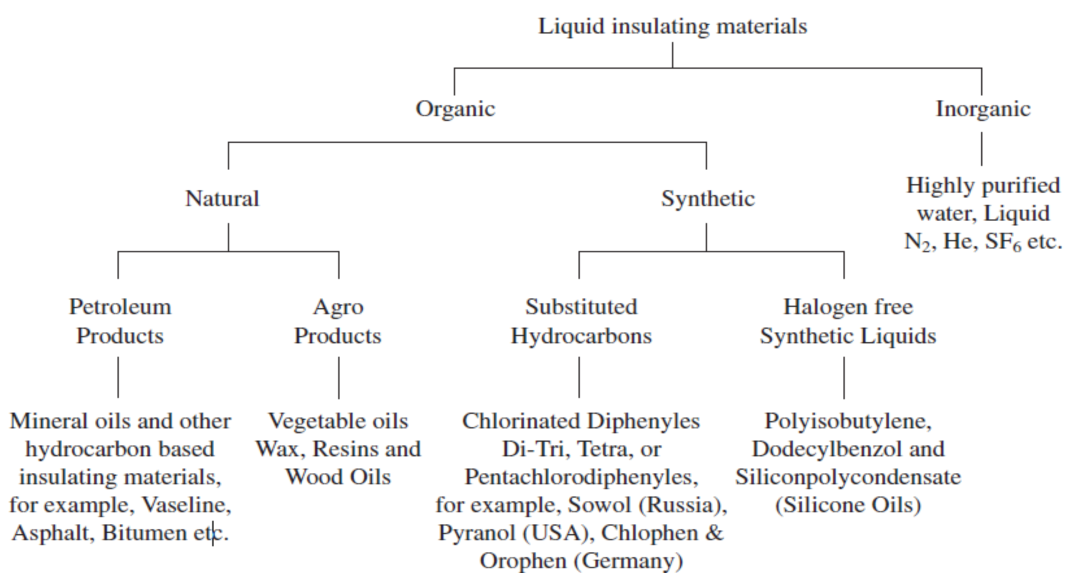
2. Breakdown of insulators

Liquid insulation breakdown

- **Properties of liquid insulators**

  - The exact breakdown mechanism of the liquid is not defined.
  - Liquid insulation breakdown factors → gap spacing, temperature, viscosity, density, molecular structure
  - Liquids with a hydrocarbon-based molecular structure have excellent dielectric strength.

  → Insulating oil (Transformer oil)is mainly used



Classification of liquid insulators

2. Breakdown of insulators

Liquid insulation breakdown

- **Properties of liquid insulators**

  - Insulation breakdown pattern different from gas→The distance between molecules is short and the density is high.

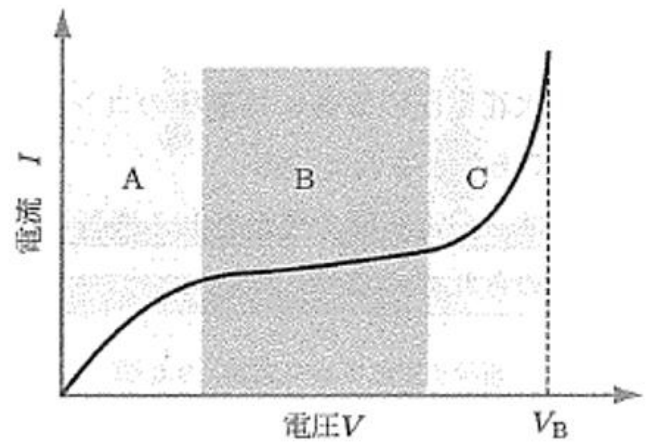


그림 3.10 평등전계하 에서의 액체의 전류-전압특성

  - A:According to Ohm's lawV, Icharacteristic
  - B:A section that appears only in liquids,Ibecomes saturated or rises gently (recombination)
  - C:Insulation breakdown after current surge

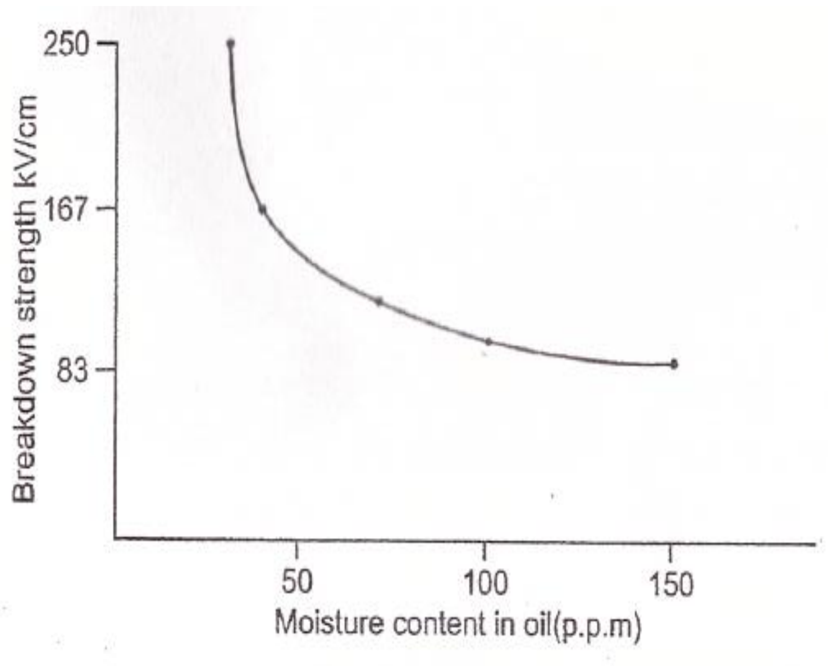
2.

liquid

- **Characteristics of insulating oil**

  - Insulating oil is generally not pure:Contains air bubbles and impurities

    → Reduced dielectric strength,Different breakdown mechanisms



Dielectric strength according to moisture in insulating oil

Formation of insulating oil impurities during insulation breakdown

2. Breakdown of insulators

Liquid insulation breakdown

- **Insulation breakdown caused by foreign substances**
  - The larger the foreign matter, the lower the dielectric strength.
  - If the local electric field is higher than the breakdown electric field of the insulating oil, partial discharge and bubbles occur.
  - If there is a lot of foreign matter, the particles are arranged to form an insulation breakdown path between electrodes.

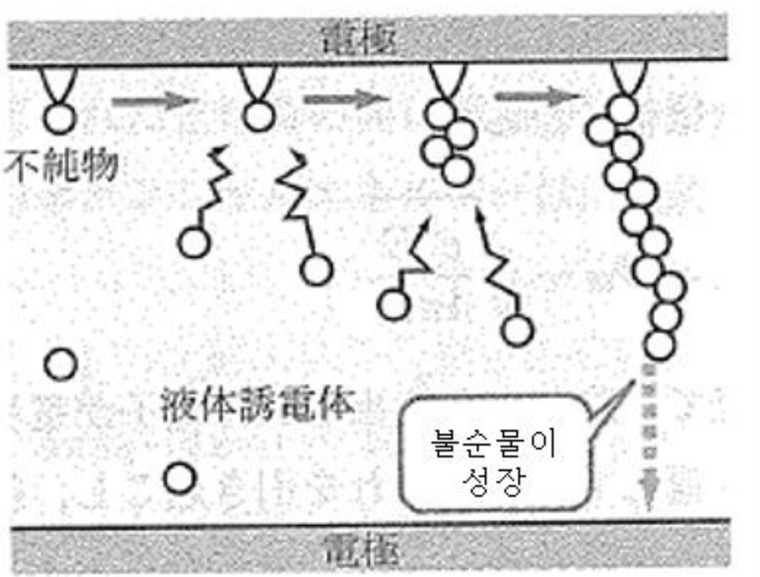
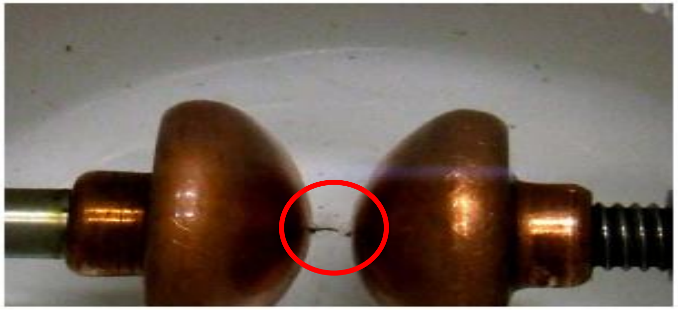


그림 3.12 불순물에 의한 액체의 절연파괴



Converter formation by foreign substances

2. Breakdown of insulators

Liquid insulation breakdown

- **Insulation breakdown caused by air bubbles**

- Cause of bubbles

  - electrode surfacegas pocket
  - Repulsion between space charges inside a liquid
  - Liquid molecules broken down by collision
  - Bubble generation due to partial discharge

- Insulation breakdown caused by bubbles is determined by the initial size of the bubbles.

$$_0 = \frac{\text{One}}{\text{One} - \ 2}\left\{\frac{2\ (2\ + 2)\ \text{One}}{}\left[\frac{}{4}\sqrt{\left(\frac{}{2\ \ 0}\right)} - 1\right]\right\}^{1/2}$$

(�1:dielectric constant of liquid, 2:permittivity of the bubble, :surface tension of liquid, :The initial radius of the bubble, :voltage drop in the bubble)

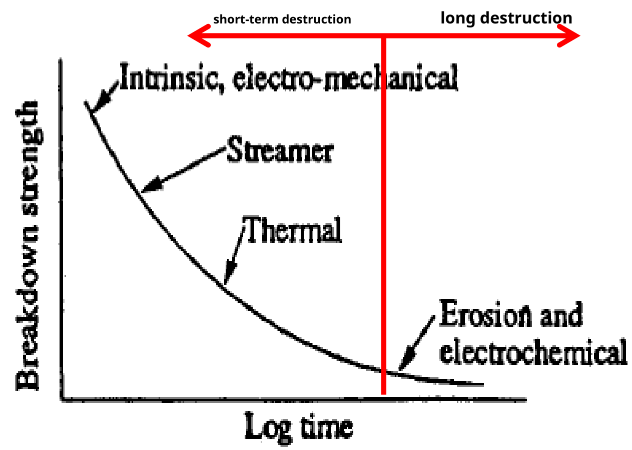
Air bubbles inside insulating oil

2. Breakdown of insulators

solid insulation breakdown

- **Dielectric breakdown characteristics of solid insulators**

  - short-term destruction
    - True destruction (Intrinsic breakdown)
    - Electrical destruction (Electrical breakdown)
    - Electronic avalanche or streamer (Avalanche or Streamer)
    - thermal destruction (Thermal breakdown)
    - Electrodynamic destruction (Electromechanical breakdown)
  - long destruction
    - Deterioration due to corrosion or electrical stress
    - Internal discharge (Internal breakdown)Deterioration caused by
    - Tracking or electric tree (Tracking or Treeing)Deterioration caused by



Classification of destruction characteristics over time

2. Breakdown of insulators

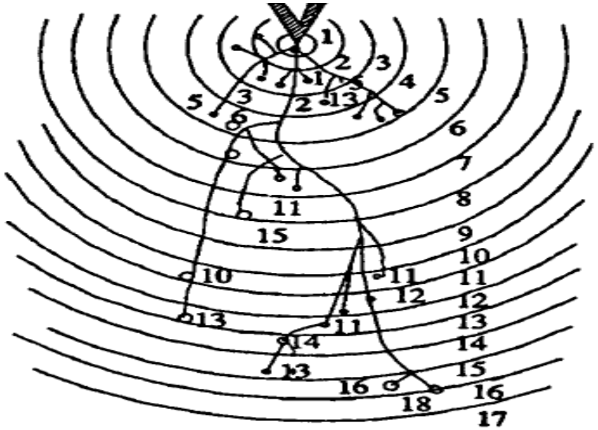
solid insulation breakdown

- **destruction of true nature**
  - A very short time (10^{-8}s)Insulation breakdown phenomenon that occurs within
  - Solid lattice defects cause electrons totrap,Above a certain electric field

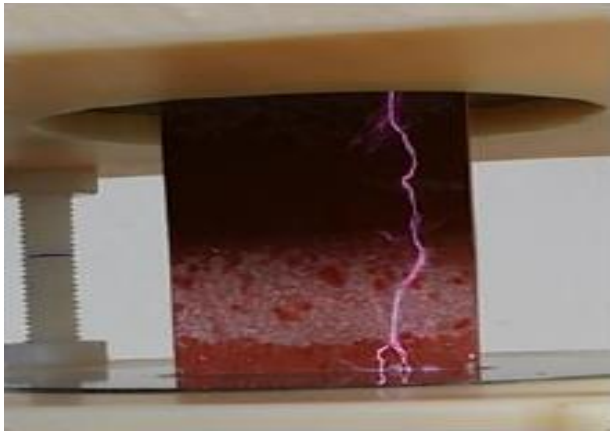
    electron trappedConduction electrons are released and destroy the lattice.

Lattice defects in solid insulators

- **Avalanche or Streamer**



Ionization channel formation



Insulation breakdown due to ionization

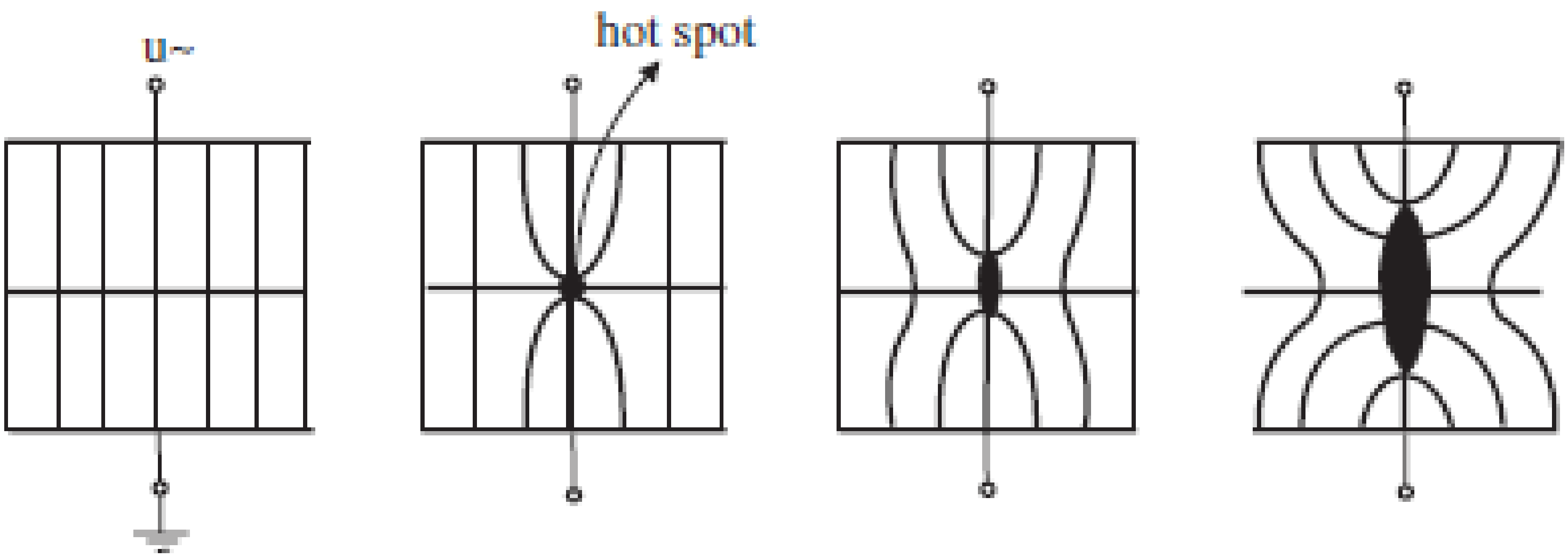
2. Breakdown of insulators

solid insulation breakdown

- **thermal destruction**

  - When voltage is applied to a solid insulating material, a small conduction current may occur.hot spotformation
  - Solid insulating material temperature rises, surface heat dissipation of insulating material occurs, and heat conduction phenomenon occurs.

  → Deterioration of dielectric strength



Isotherms in solid insulators

2. Breakdown of insulators

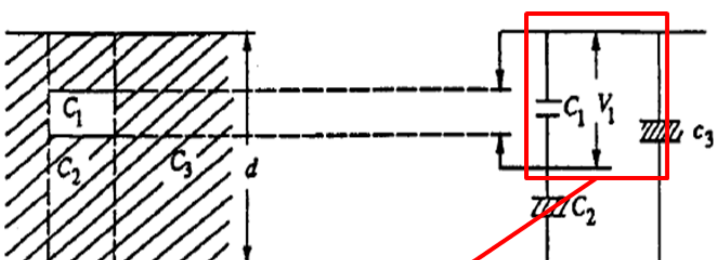
solid insulation breakdown

- **long-term insulation breakdown**

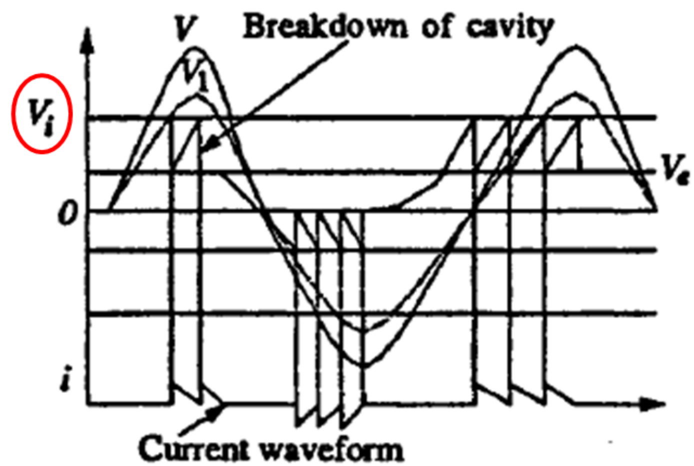
Electrical stress / **Erosion** → **Internal discharge** / **Tracking** / **Treeing** → **Breakdown**

- **Internal discharge (Internal discharge)**

  - Internal discharge (=partial discharge) occurs in weak insulation areas (Cavity, Void)
  - Low permittivity = High electric field concentration



$$V_1 = \frac{C_1 V}{C_1 + C_2} = \frac{d_1 V}{d_1 + \left(\frac{\varepsilon_0}{\varepsilon_1}\right) d_2} \cong \varepsilon_r V \frac{d_1}{d_2}$$



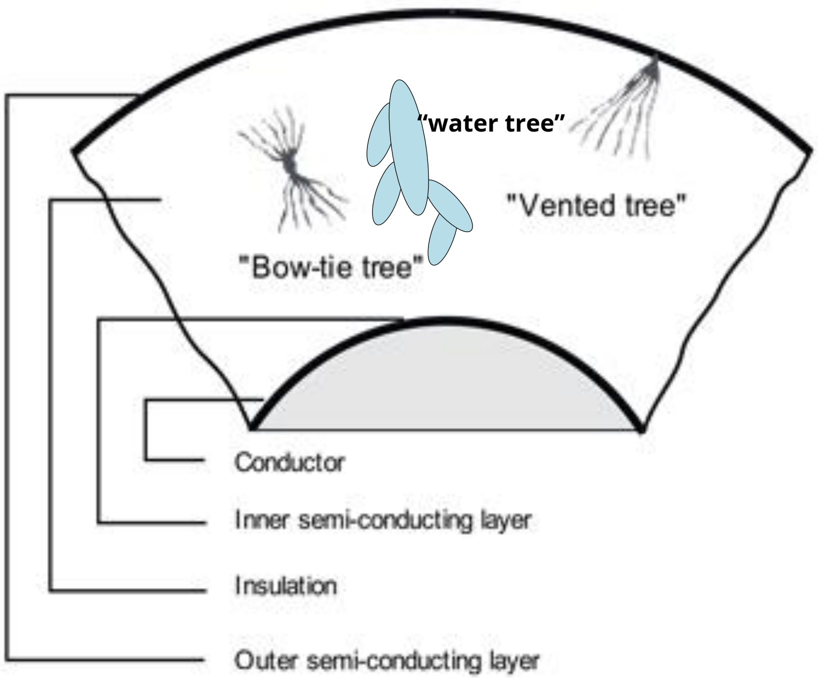
solid insulation breakdown

- Electric tree (Treeing)

- Occurs when high electrical stress is applied for a long period of time
- It shows signs of deterioration and can be identified as a sign of insulation breakdown.

- Electric tree type

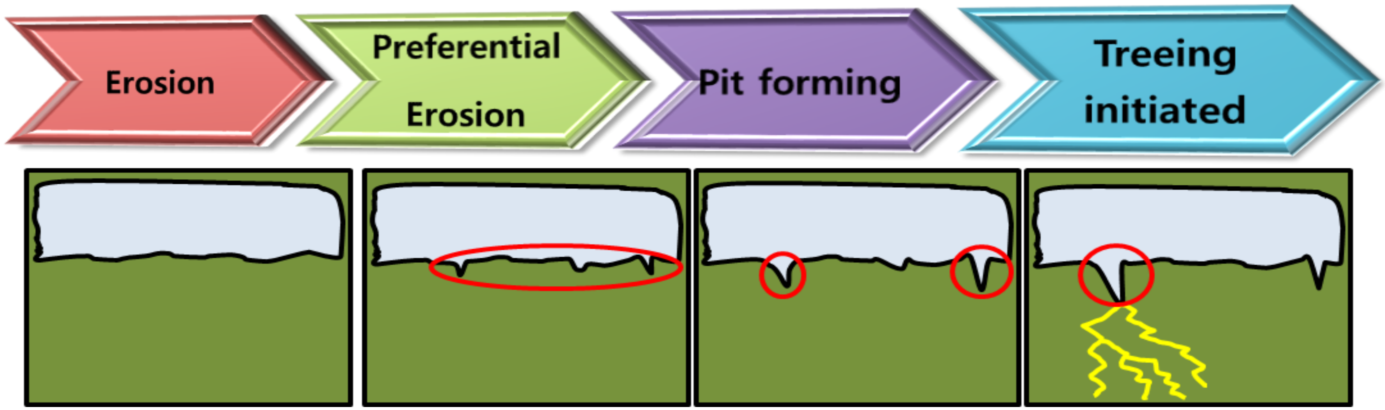
- Bow-tie tree:Occurs inside insulating materials and increases symmetrically when deteriorated
  → Effect on insulation performance
- Vented tree:Occurs at the electrode interface, Advance to the opposite electrode
  → Significant impact on insulation performance
- Water tree:Occurs in impregnated insulating structures
  → Deterioration of internal dielectric strength



2. Breakdown of insulators

solid insulation breakdown

- **Electric tree progress**



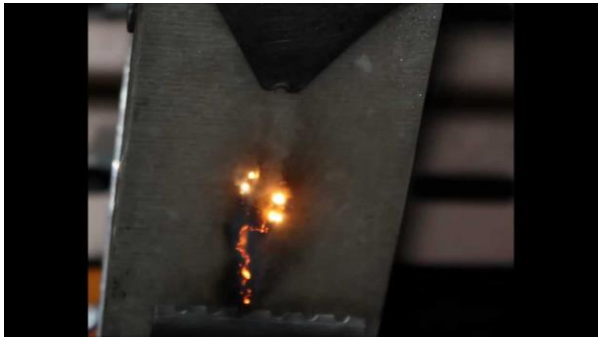
- **Tracking(Treeing)**

  - When it occurs, permanent electric current (Conduction path)Formation →The biggest weakness of solid insulation
  - Occurring factors

    - surface contamination: moisture or metal particles

      → Tracking due to increased leakage current

    - carbonization: Carbonization of insulation material due to insulation breakdown

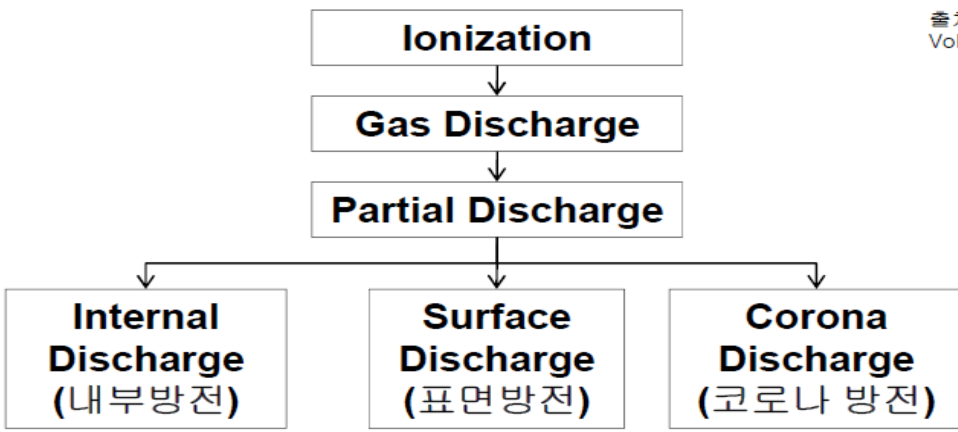


Occurrence of partial discharge

- **Partial discharge (Partial discharge)**
  - It is a local discharge phenomenon that does not cross between electrodes, and the applied voltage

    PDIV(Partial Discharge Inception Voltage)Occurs when exceeding

출처 : Discharge Detection in High Voltage Equipment, Dr. F.H.Kreuger

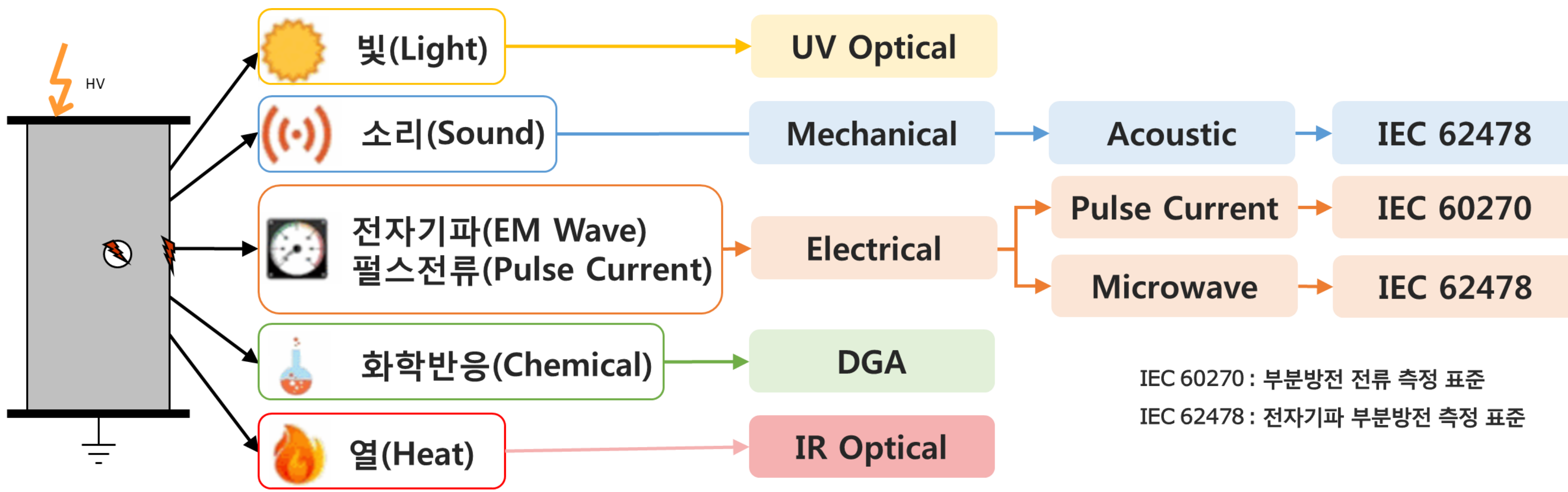


A gas discharge which does not bridge between the system electrodes (mentioned in std. IEC60270) **caused by insulation defect**

- ✓ **Discharge due to a Cavity (=Void) or a Fissure(고체방전)**
- ✓ **Corona discharge due to an floating electrode or sharp edge(기체방전)**
- ✓ **Tracking discharge along an interface(표면방전)**
- ✓ **Discharge from Electrical Tree growth(전기트리 방전)**

Characteristics of partial discharge

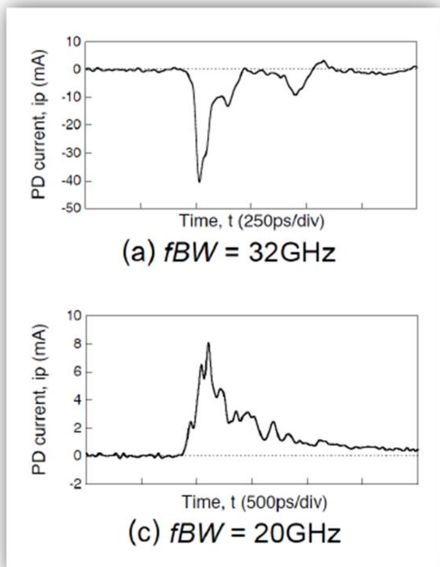
- Energy release in various forms



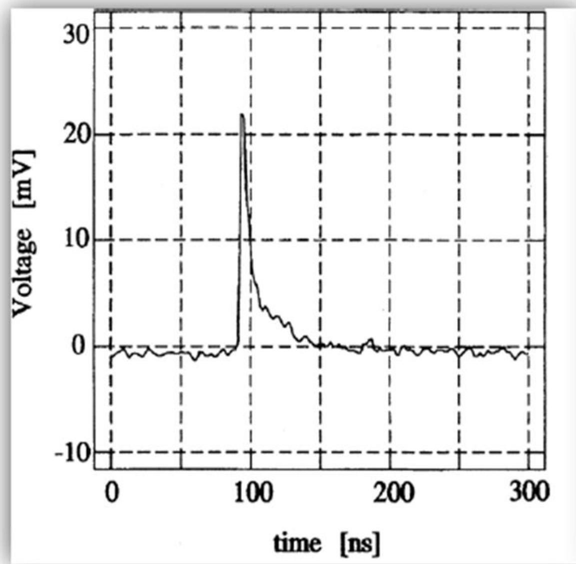
various forms of energygowide frequency rangeoccur simultaneously in

Characteristics of partial discharge

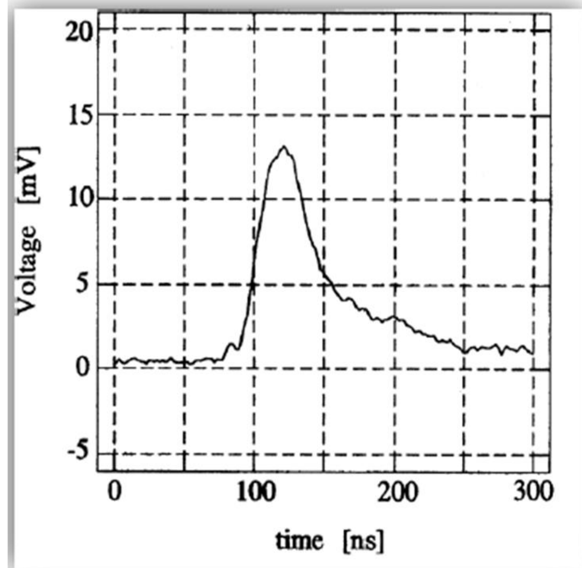
- **Measured as a pulse-shaped signal**



기체 내부 방전



액체 내부 방전



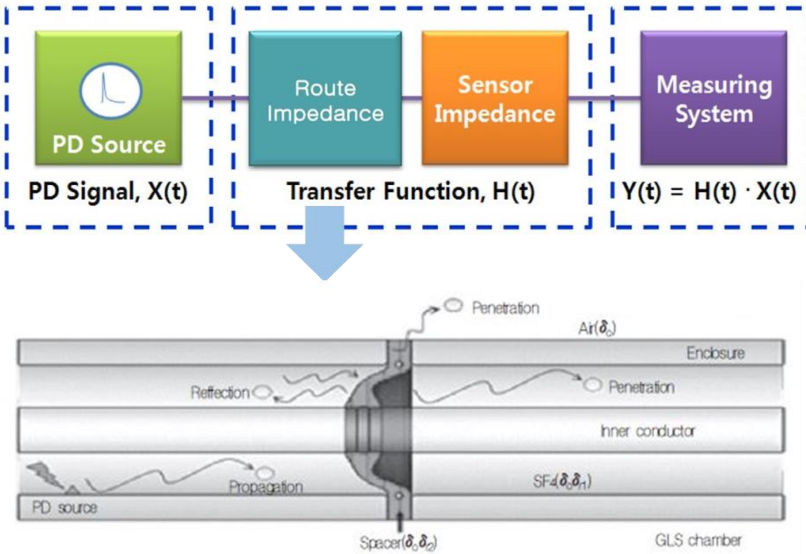
고체 내부 방전

- pulse formsignal of,Fast rise/durationIndicates (number of nsec)

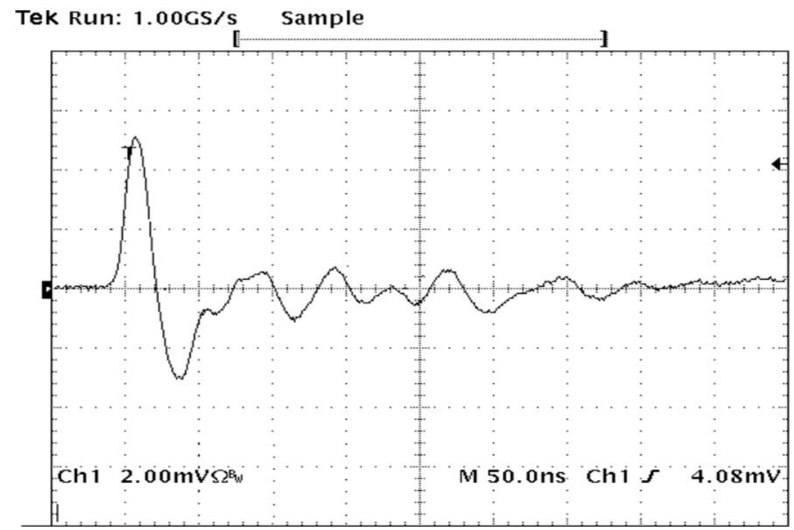
- The higher the dielectric constant, the longer the rise time and pulse duration are measured.

Characteristics of partial discharge

- **Synthetic wave generation due to various reflection elements within the propagation path**



부분방전 신호의 전파, 반사 및 합성파 투과



계측기를 통해 측정되는 부분방전 신호

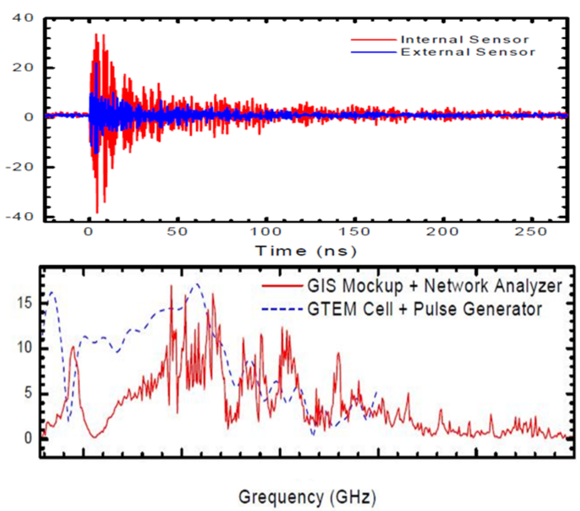
- Reflected waves are generated at the contact surface of media with different dielectric constants and combined with traveling waves.

- Spacers, enclosures, cable junction boxes, insulators, sensors, measuring instruments, etc.

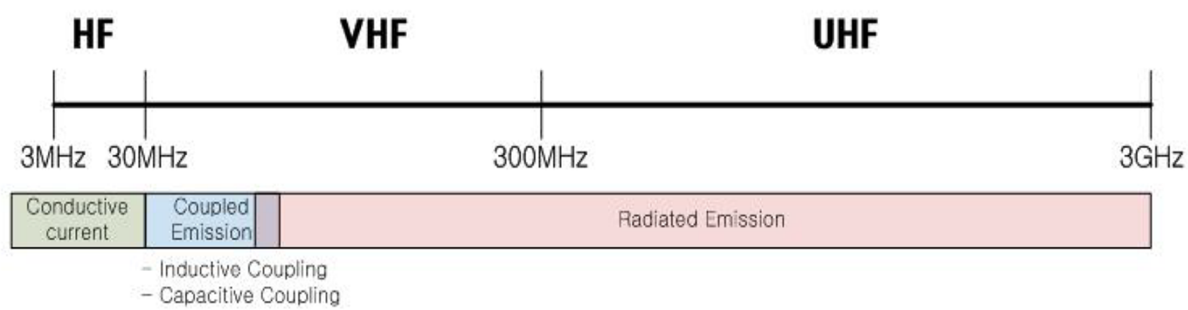
Characteristics of partial discharge

- **Contains frequency components of various bands**

  - The partial discharge signal iskHz to GHzHas a frequency component of up to
  - 350psce ~numbernsecRise time and number of degreesnsechas a pulse duration of about
  - P.D.Frequency differences in detection signals occur depending on the propagation path, detection sensor, etc.



부분방전 신호 및 주파수 스펙트럼



- HF/VHF ((Very) High Frequency) : 3M~300MHz,
- UHF (Ultra High Frequency) : 300M~3,000MHz

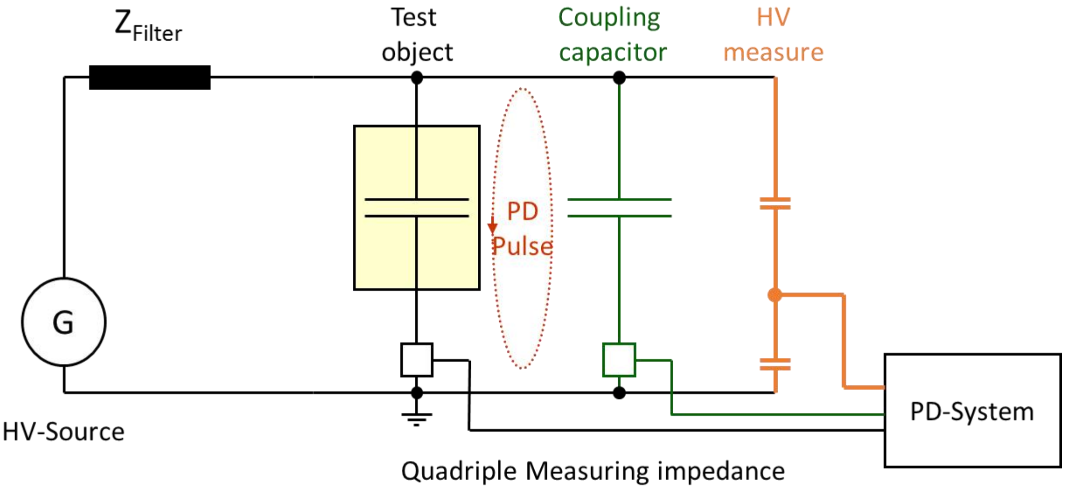
부분방전 신호 측정 주파수 영역 구분

Partial discharge detection

- **Partial discharge detection –IEC 60270**

- IEC 60270: High Voltage Test Techniques – PD Measurement
- Coupling Capacitor Utilization: DozenskHz ~numberMHzFrequency band measurements
- Vulnerable to external noise→Mainly used in shielded rooms

전자파 차폐실

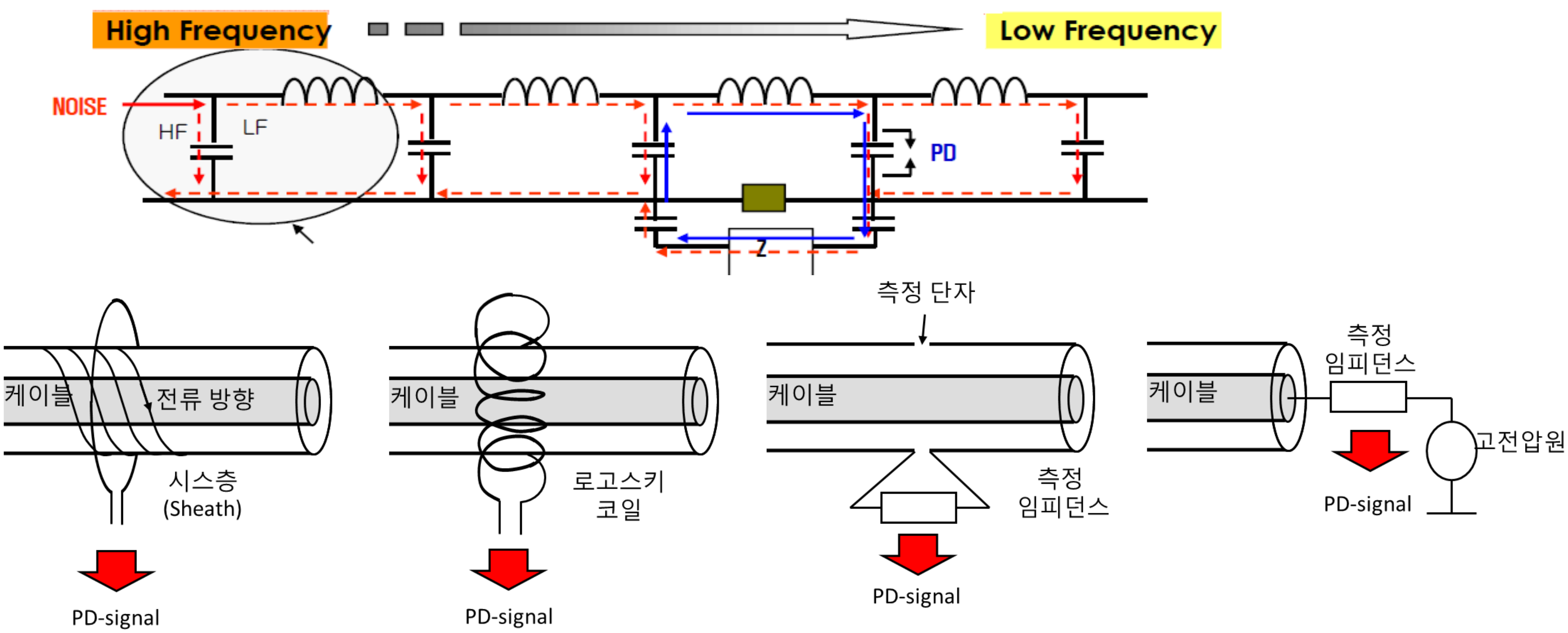


커플링 커패시터를 활용한 IEC 60270 측정 회로

Partial discharge detection

- Partial discharge detection –HF(High Frequency)

- In the case of cables, the influence of external noise is small.HFin the areaP.D.detection
- 1~50 MHzDetection of partial discharge current components in the band (CTusing sensors)
- CBecause the value is large, the area above ultra-high frequency (UHF)atP.D.No signal detected



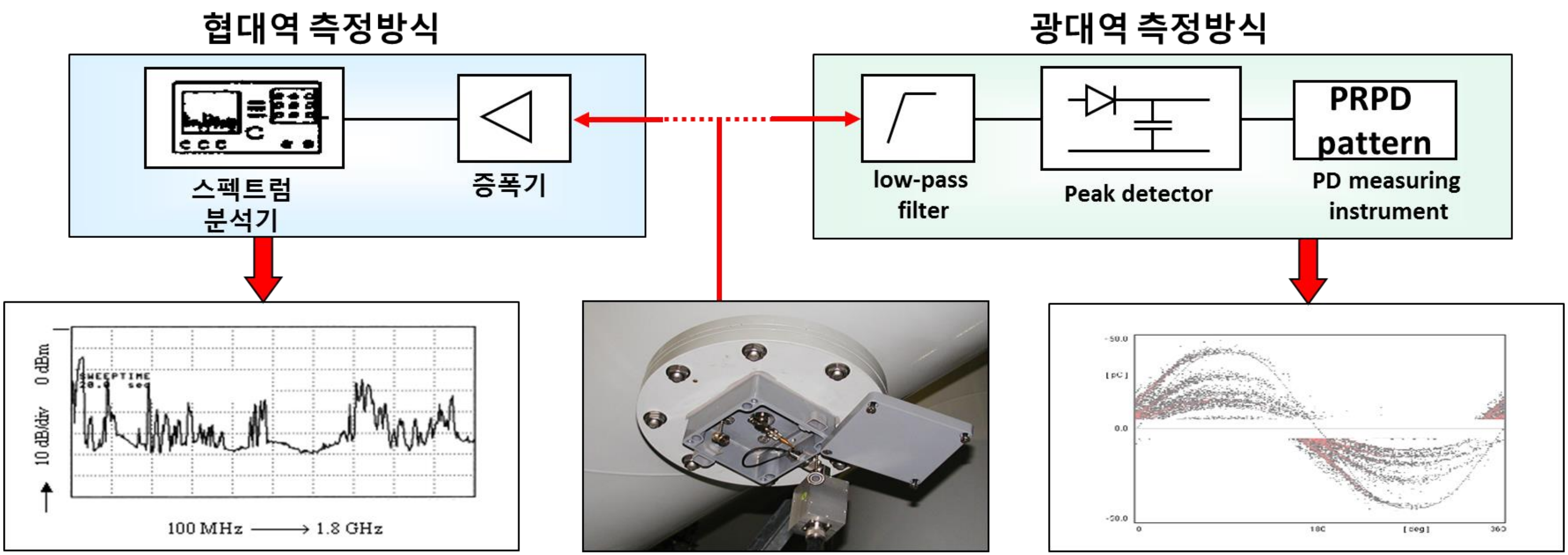
유도성 센서를 활용한 간접 측정법

측정 임피던스를 활용한 직접 측정법

Partial discharge detection

- Partial discharge detection –Ultra High Frequency (UHF)

- Substation facilities significantly affected by external noise (GIS,Mainly used in transformers)
- 500~1,500 MHz (300~1,800 MHz)Detection of electromagnetic wave components in the band (UHFelectromagnetic wave sensor)



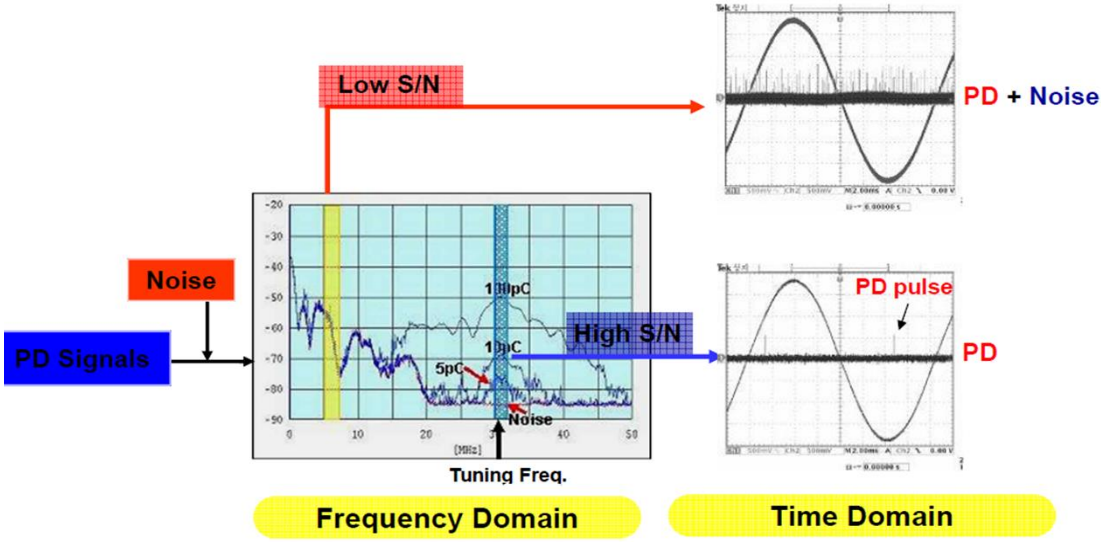
안테나 센서를 활용한 UHF 대역에서의 부분방전 측정

Partial discharge analysis method

- Pulse signal analysis method (Pulse Analysis)

- Measures the rise time and occurrence frequency of partial discharge pulses, etc.
- Additional measures are needed for external noise (Gating/Masking)

Utilizing sensors and oscilloscopes



Pulse analysis using frequency/time domain

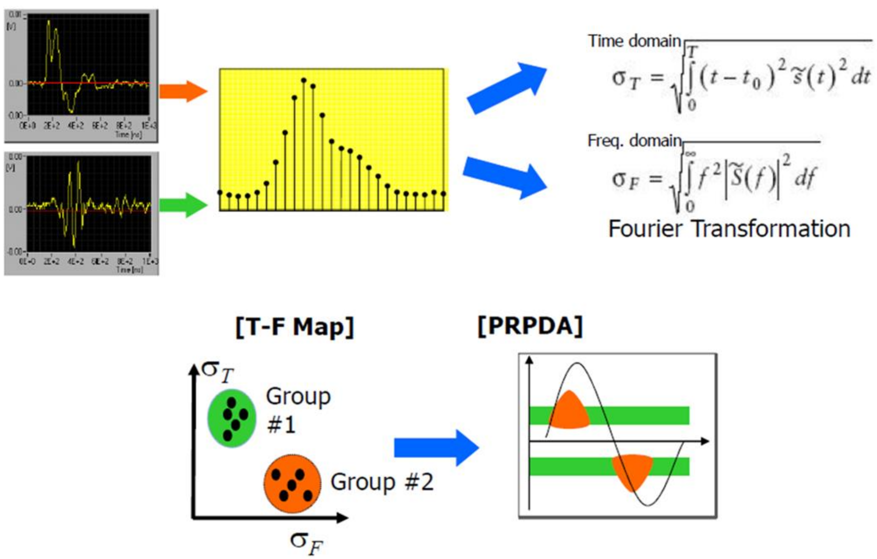
Partial discharge analysis method

- TF Map (Time-Frequency Map)

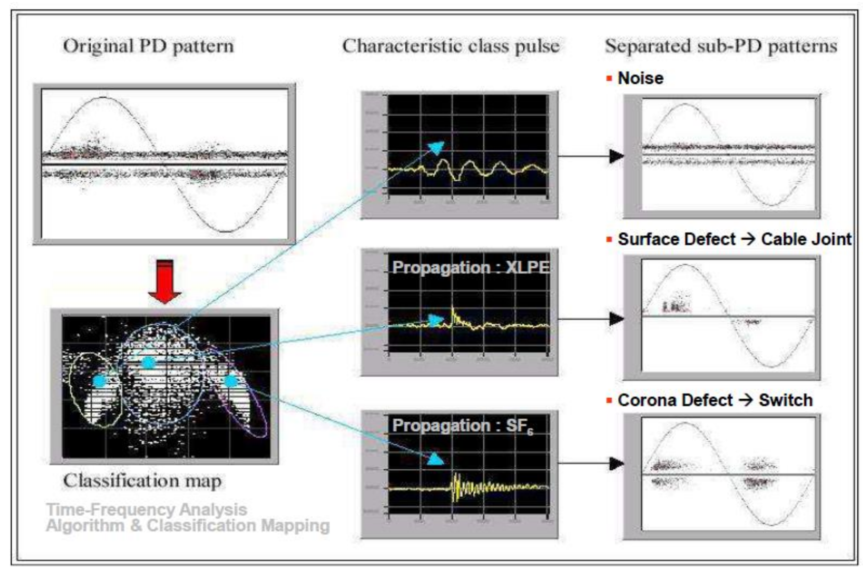
- 2DimensionMapForm clusters, partial by zonePRPDanalyze

  -XAxis: pulse duration,YAxis: pulse main frequency (FFT)

- Capable of separating partial discharge and noise signals arising from multiple defects



TF Map diagram

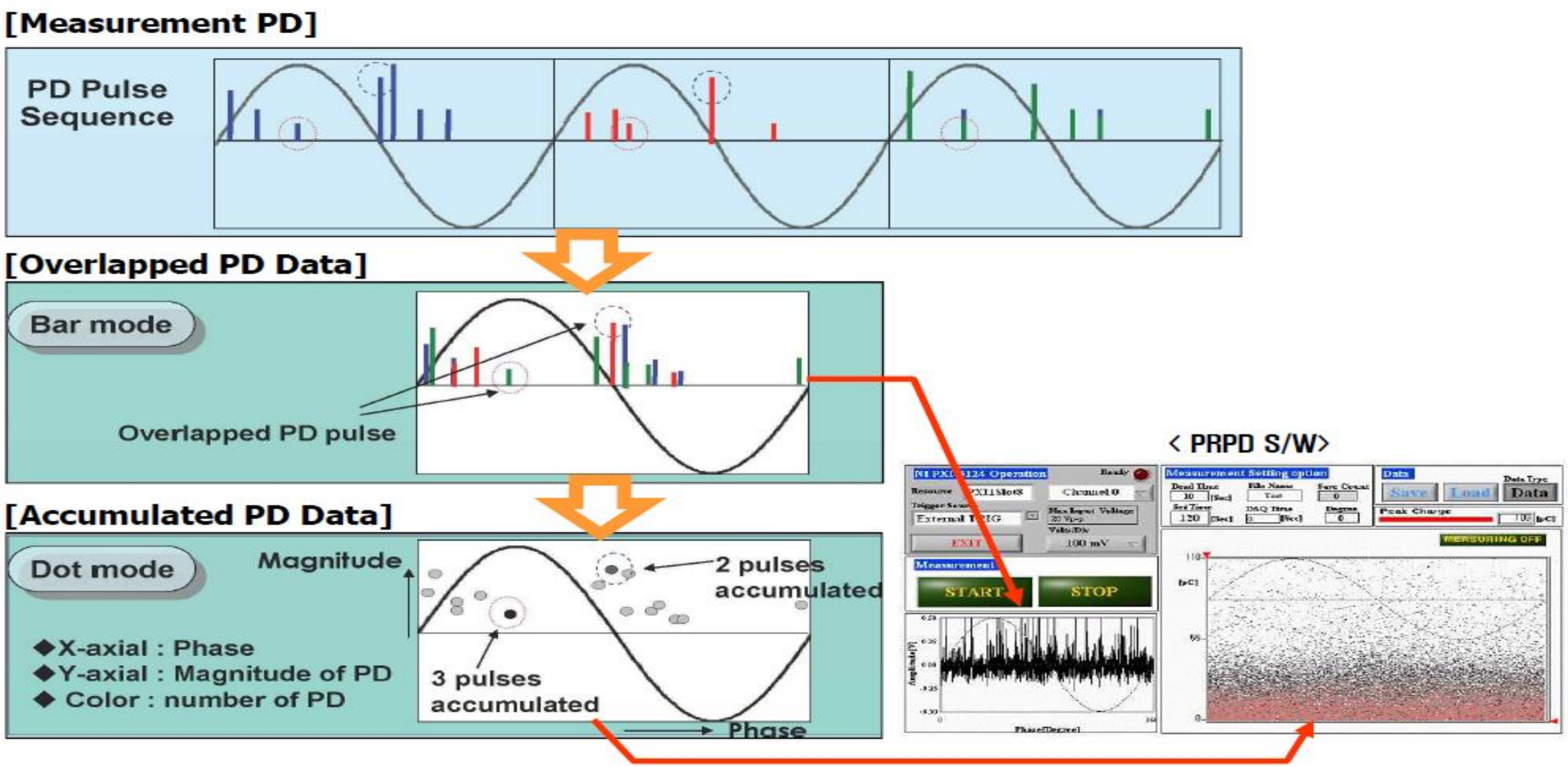


Defect classification using TF Map

Partial discharge analysis method

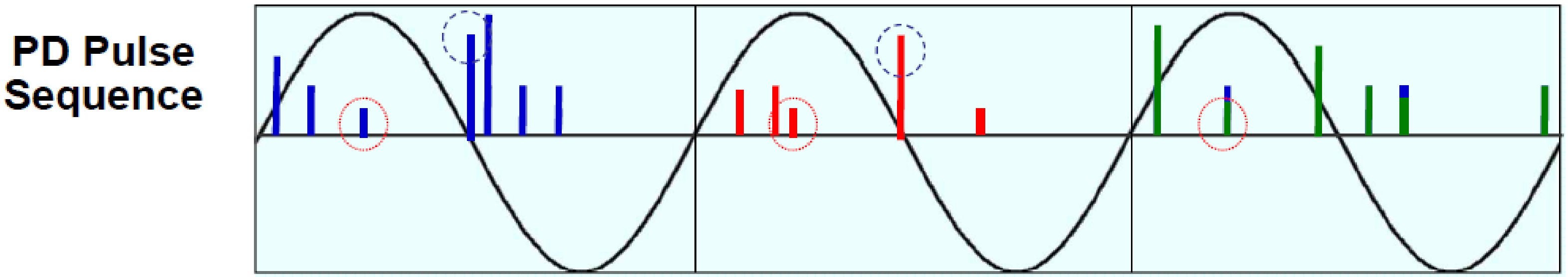
- Phase Resolved Partial Discharge (PRPD)

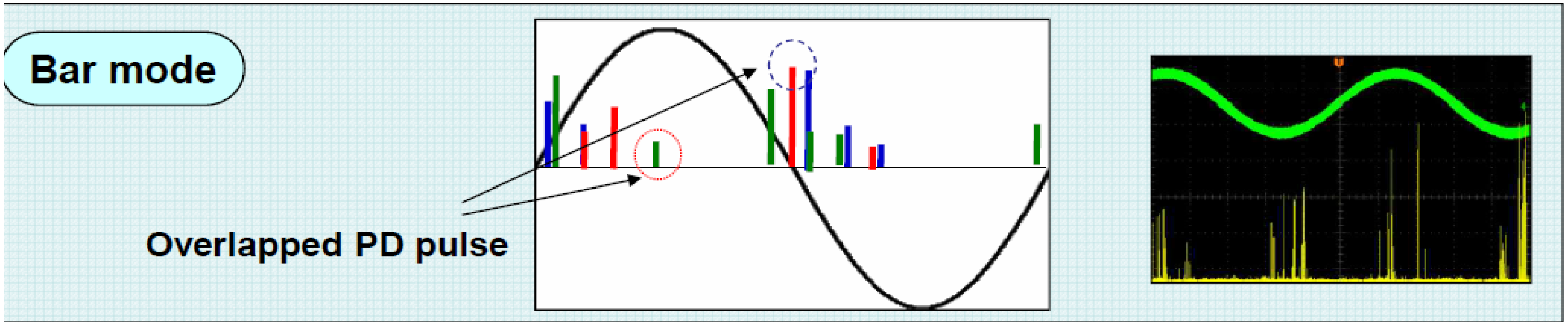
- Integrates the size and occurrence time of the discharge into the phase of the applied voltage.
- Displays various patterns depending on the defect
- In case of multiple discharges and severe noise, the accuracy of pattern distinction decreases.

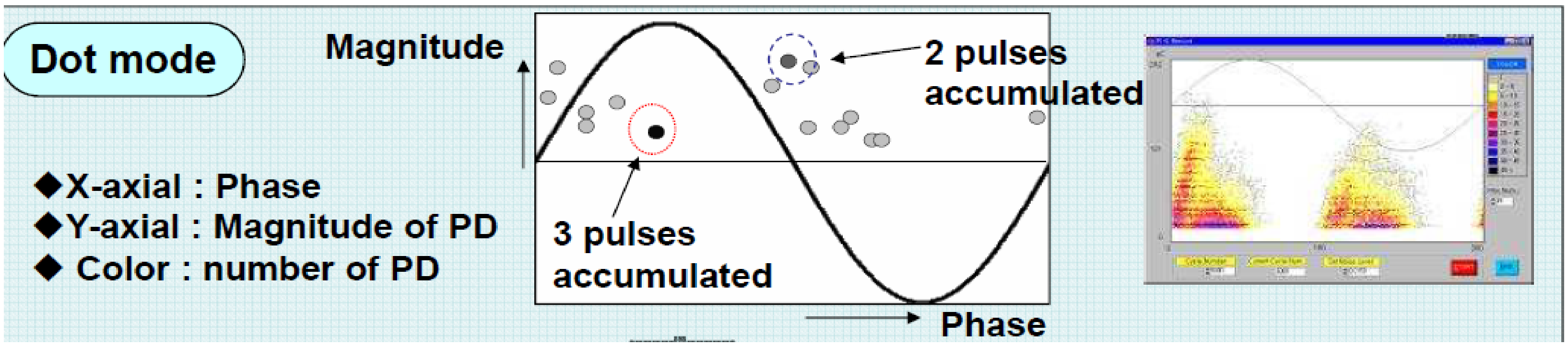


Partial discharge analysis method

- Phase Resolved Partial Discharge (PRPD)







◆X-axial : Phase
◆Y-axial : Magnitude of PD
◆ Color : number of PD

partial discharge signal

부분방전 결함에 따른 방전 유형 구분

- 절연물 내부 : **공극**(Void), **트리잉**(Treeing)
- 절연물 경계 : **코로나**(Corona), **연면방전**(Surface Discharge)
- 외부 요인 : **부유전극**(Floating), **자유도체**(Metallic Particle)

각 결함에서 발생하는 부분방전 펄스는 **서로 다른 시간/주파수 특성**을 가짐

- 구조적 차이로 인해 유전율이 다름→ 신호 전파특성이 상이함
- 결함 별로 **고유한 펄스 파형 및 PRPD 패턴**을 나타냄

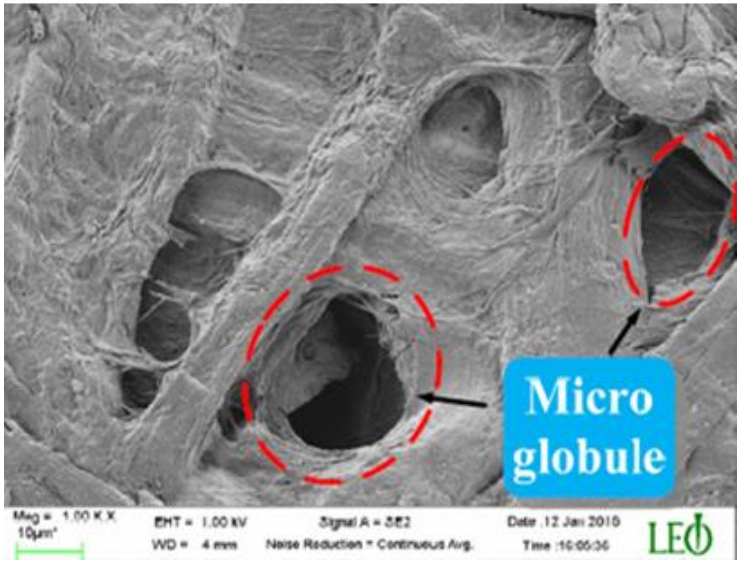
partial discharge signal

- **Internal discharge (Internal Discharge)**

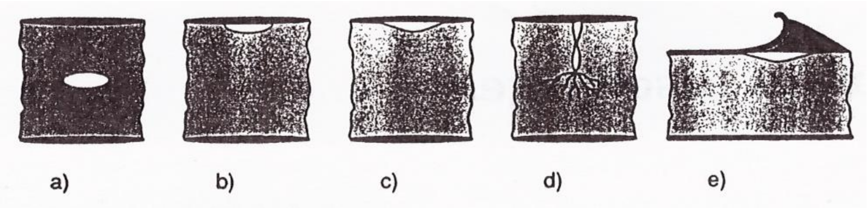
  - Gas-filled pores (mainly inside solid or liquid insulation)Gas-filled void)occurs in
  - Insulator-Void due to difference in permittivity of voids

    There is a strong electric field around[kV/mm]formation
  - The gas inside the void isPaschenfollow the rules

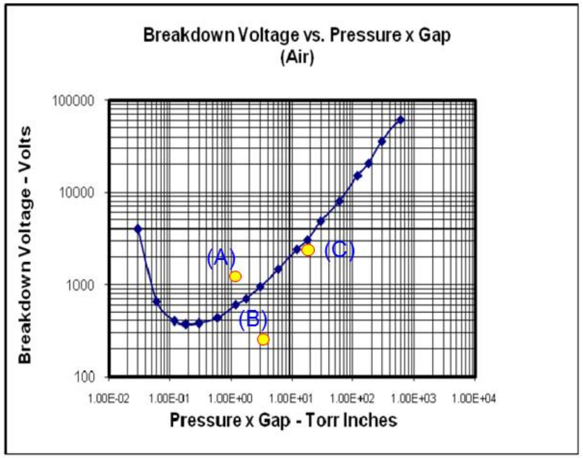
    → Discharge when electric field concentration exceeds breakdown voltage



Creation of voids inside the insulation



(a) Completely surrounded by the dielectric
(b) Electrode bounded cavity.
(c) Non-adhering electrode
(d) Initiated by treeing.
(e) In an interface with a longitudinal field.

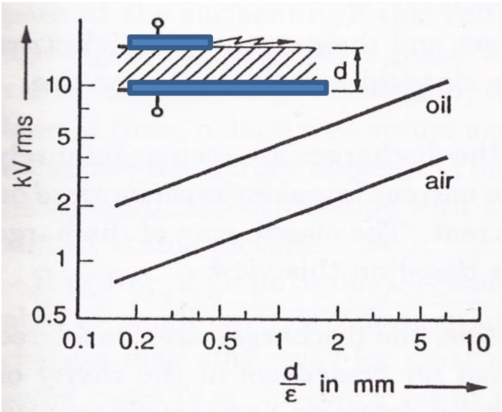


partial discharge signal

- **Surface discharge (Surface Discharge)**
  - Occurs at the interface of an insulating material with relatively weak insulation.
  - Insulating oil-air, between cable insulation layers, spacer surface, etc.

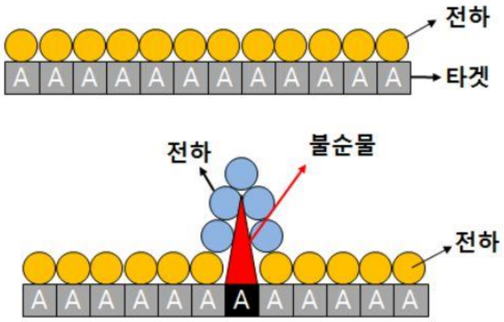
  Occurs at the insulator interface

  → Discharge start voltage: follows the strength of the weaker insulator

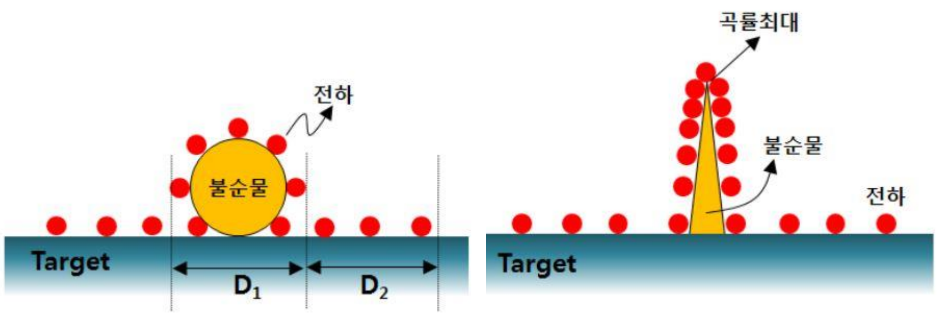


- **Corona discharge ((Corona Discharge)**
  - Protrusions on the electrode surface (Protrusion)When present, electric field concentration increases charge density.

  → If the electrode exceeds the allowable electron density per unit area, discharge (PDIV)



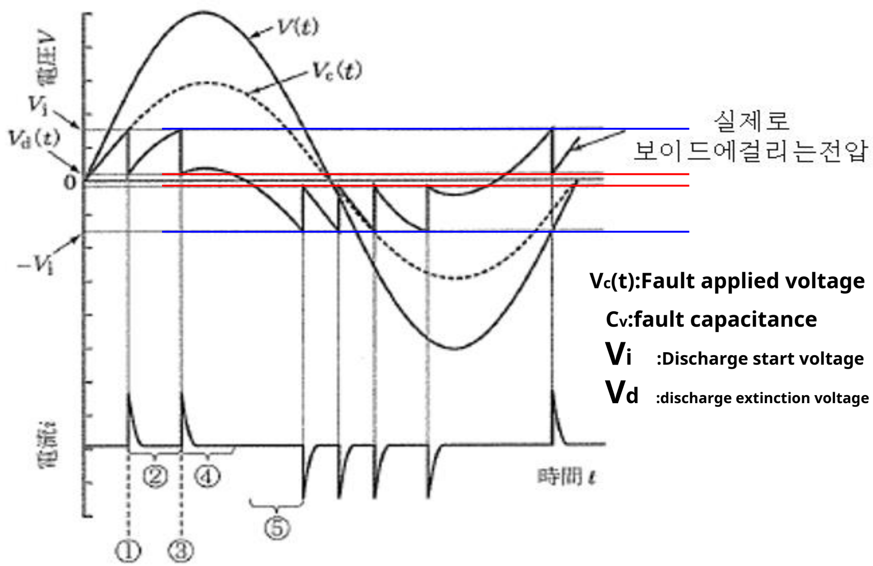
Charge density depending on protrusion

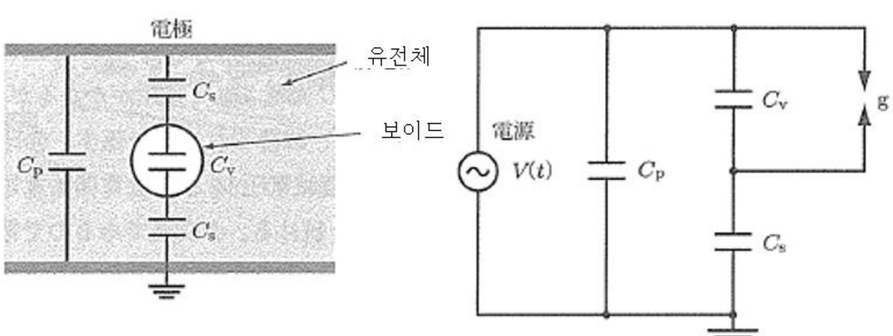


Charge density according to protrusion curvature

partial discharge signal

- **Partial discharge signal generation (void discharge)**





(a) 보이드 (b) 등가회로

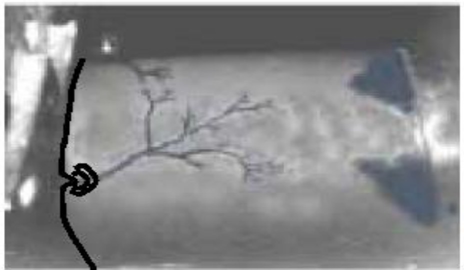
- $V_c(t)$Discharge start voltage exceeded
  - → Short circuit occurs in the internal air gap
  - → Discharge of charges accumulated in the void
- $V_c(t)$Discharge extinction voltage reached
  - → Discharge stops, charge accumulates again
- Repeat until maximum voltage

- Maximum applied voltage
  - → $V_c(t)$Is$V_i$failed to reach
  - → Maintain discharge stop state

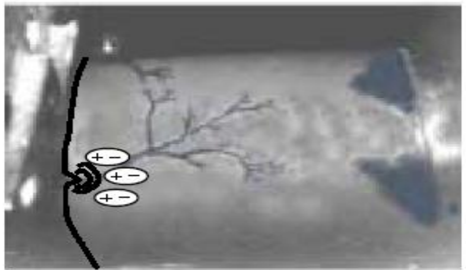
- Voltage Polarity Inversion
  - → Repeat the above process

partial discharge signal

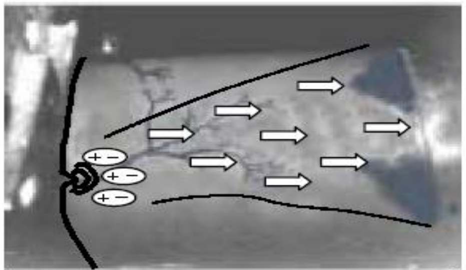
- **Partial discharge signal generation (creep discharge)**



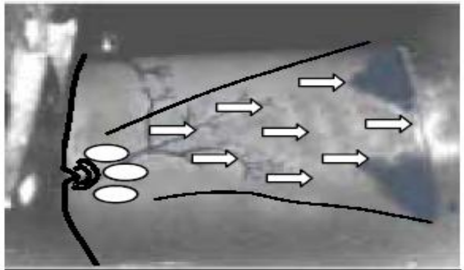
Irregular surfaces, with needle end-points create a High Electric Field at these pointed ends.



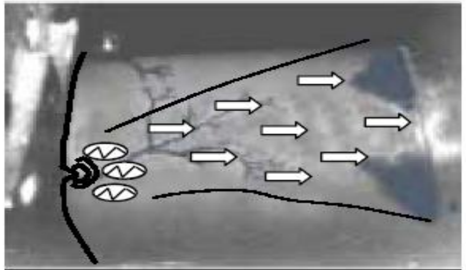
High Electric Field ionizes the surrounding air. Some partial discharges may occur in this region.



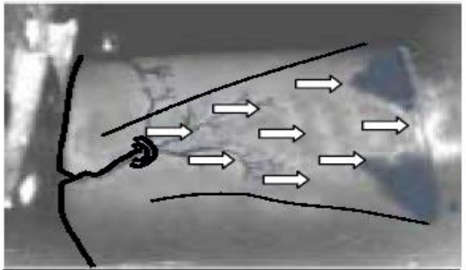
Additional surface contamination and moisture creates a leakage current path to ground.



The temperature rise from the leakage current evaporates the moisture, creating tiny islands, or very small voids. The current, which was flowing, is now interrupted across these tiny island voids.



Since all of the remaining surface is still conductive, most of the voltage drop will be applied to the dry surface creating an arc across it. Partial discharge arcing is more prevalent in the region of the ionized air.



As the partial discharges continue, the arcing burns the insulation material, creating a permanent carbon path. The new end points are even finer “needles” and the process continues across the insulation until failure results.

partial discharge signal

- **Comparison of void discharge and creeping discharge**

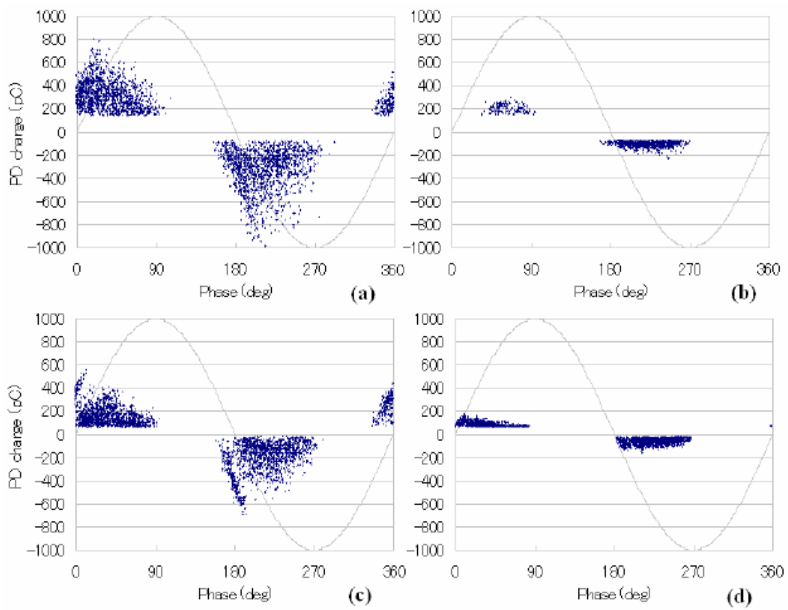


Figure 15. PD pattern transition under sine-wave with 200 Hz in sample B. The voltage peak value is 6 kV. (a) 1 min, (b) 25 min, (c) 180 min, (d) 520 min, (e) 600 min.

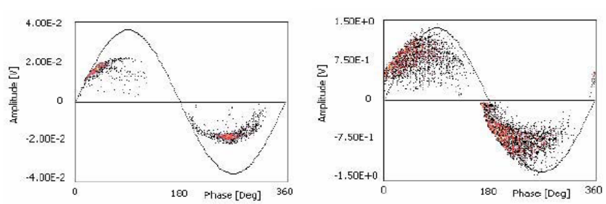


Fig. 8. PD pattern associated to a large (2 mm diameter) flat void between pressboard layers. Test voltages: 4.5 kV, ν=1.5 (left), 6 kV, ν=2 (right).

void discharge

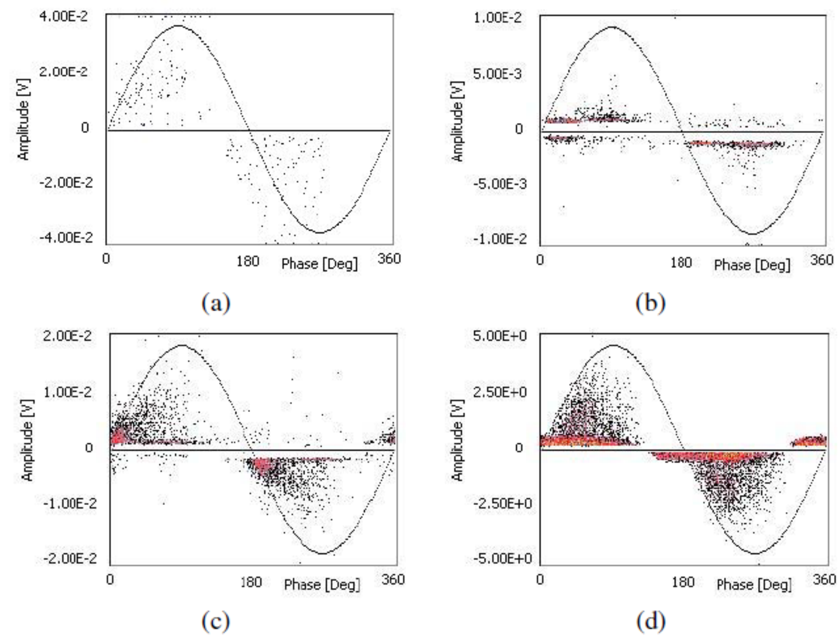


Fig. 2. PD pattern recorded from an electrode configuration consisting of a cylindrical electrode placed on a pressboard sheet. Test voltages: (a) 9 kV, ν=1, (b) 11 kV, ν=1.22 (c) 13 kV, ν=1.44 (d) 16.7 kV, ν=1.85, immediately before breakdown.

creeping discharge

partial discharge signal

- free conductor

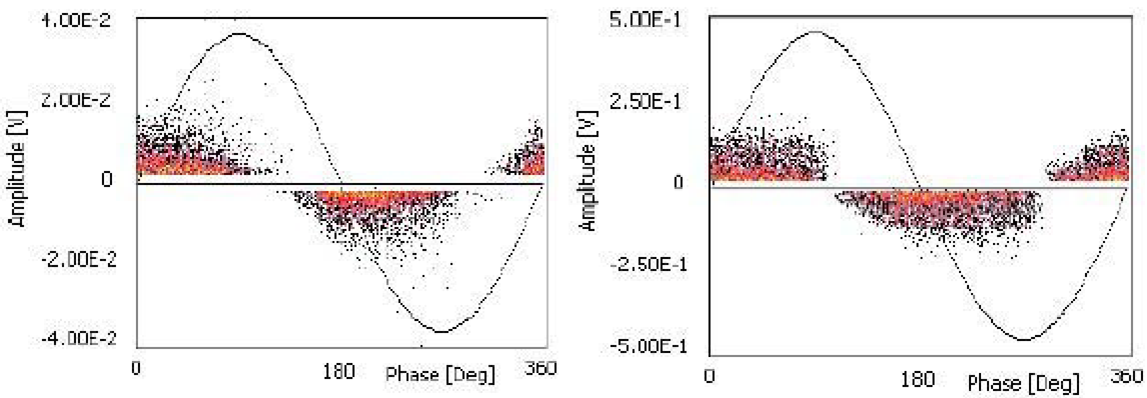
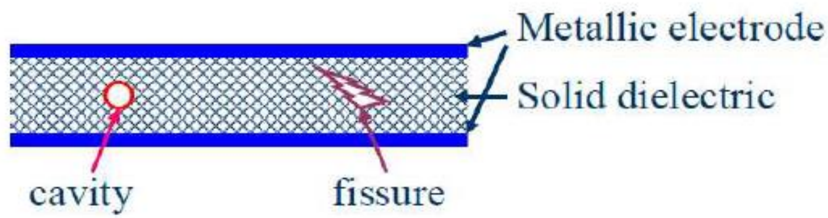


Fig. 2. PD pattern obtained from a point/plane electrode configuration: oil contaminated with free metallic particles. Test voltages: 10 kV, ν=2 (left), 20 kV, ν=4 (right).

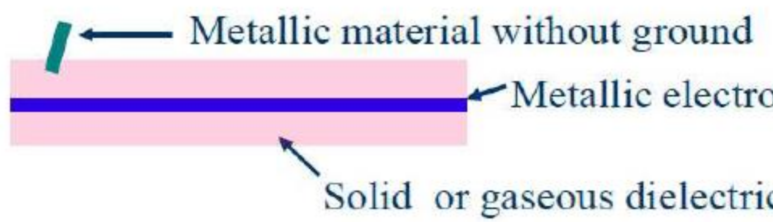
Occurrence of partial discharge

- **Other insulator defects that can cause partial discharge**

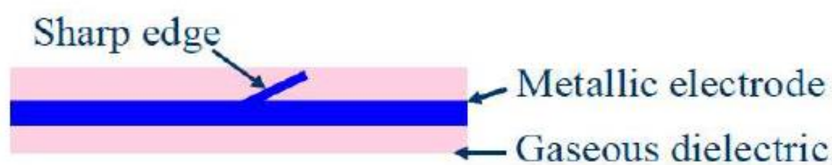
- **Cavity or Fissure**



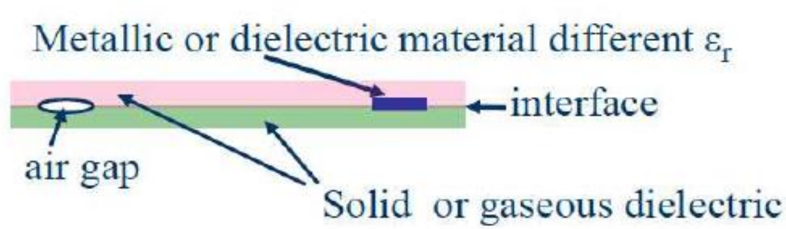
- **Floating Electrode**



- **Sharp Edge**



- **Interfacial Defects**



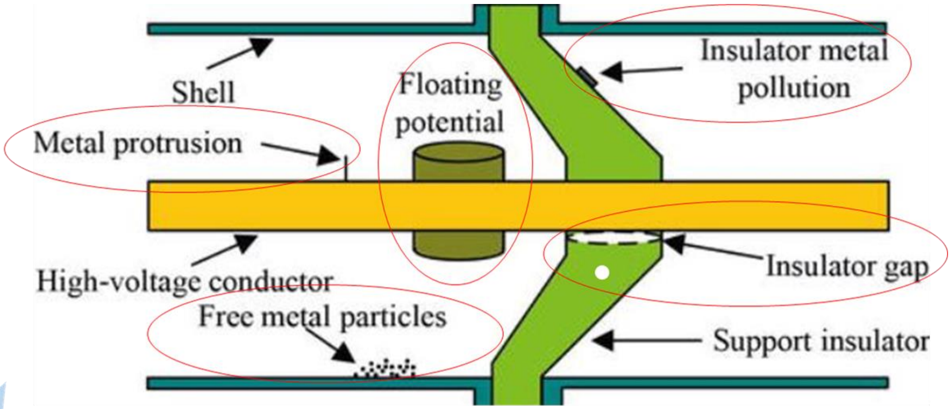
출처 : IEC 60270

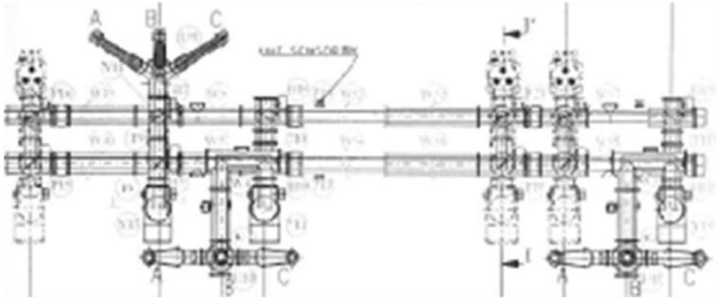
GIS partial discharge measurement

- GIS PDCauses

GIS PD 발생 원인

- 절연물 이상 : 스페이서 내부 공극 또는 크랙
- 도체 돌출 : 제작불량/용삭 등
- 금속 분진 : 시공/조립 불량 등
- 부유 전극 : 볼트 체결 풀림, 접점 마모 등





GIS PD 진단

- 스페이서를 통한 구역 분리
- 철 외함으로 인한 전기적인 내부 차폐

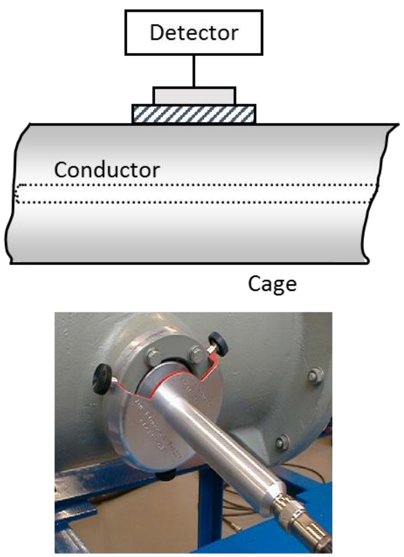
  → UHF 진단이 효율적

GIS partial discharge measurement

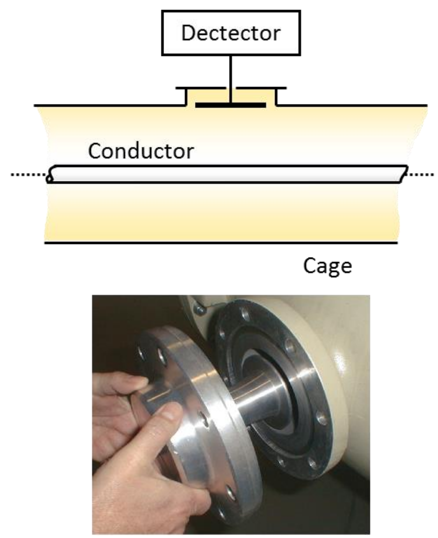
- **GIS PDsignal acquisition**

내/외장 UHF 안테나 센서를 활용한 전자파 신호 측정

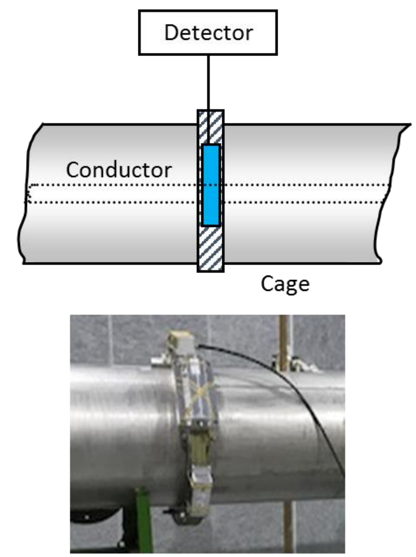
- 측정 주파수 대역 : 500 MHz ~ 1,500 MHz



감시창 부착 센서(외장형)



Dics/cone type 센서(내장형)



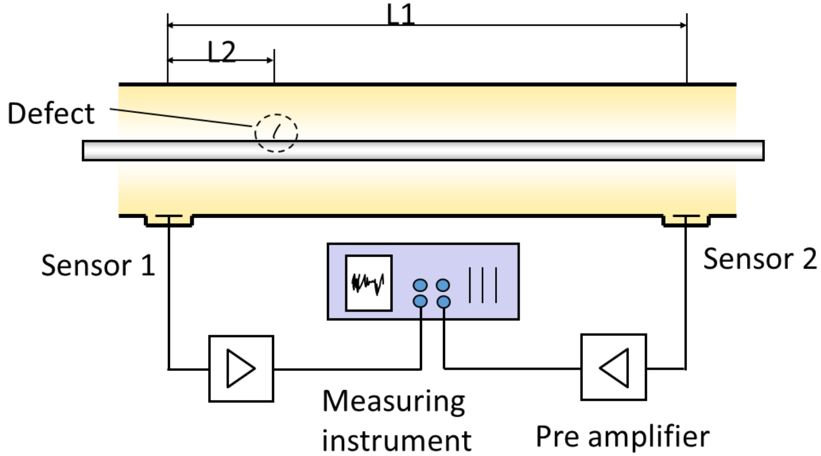
스페이서 부착 센서(외장형)

GIS partial discharge measurement

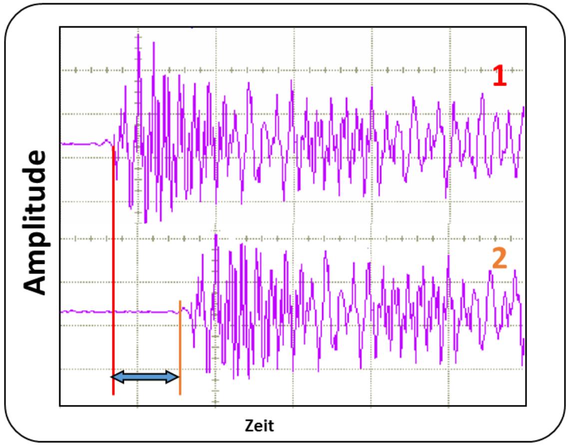
- **GIS PDLocation estimation**

센서에 도달하는 전자파 신호의 시간차를 활용한 위치 추정

- 방전 신호는 광속(c=3x10^{10})으로 진행, 시간차를 통한 거리 산출



Schematic arrangement



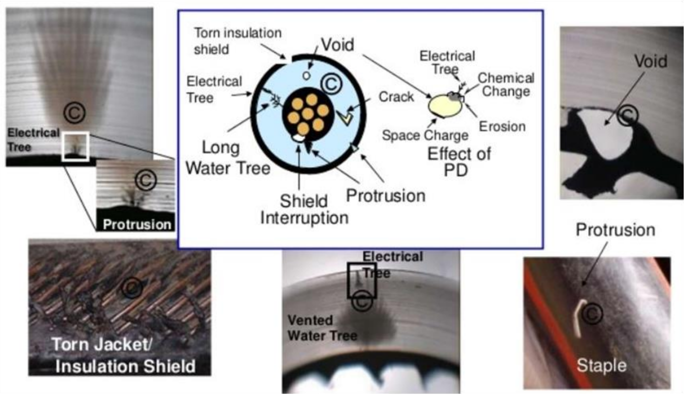
Time delay
1 ... Sensor 1
2 ... Sensor 2

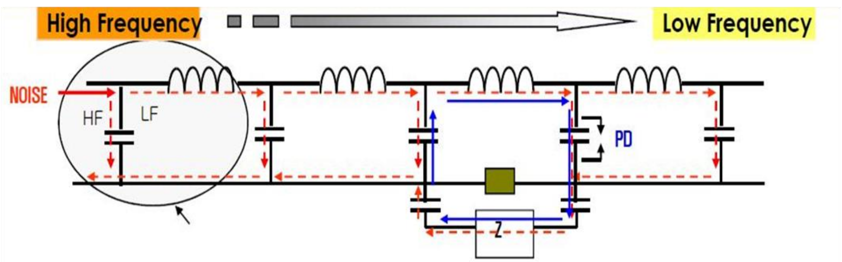
Cable partial discharge measurement

- **cableP.D.Causes**

케이블 PD 발생 원인

- 절연물 이상 : 수분 침입, 내부 절연물 열화
- 도체 돌출 : 제작불량/용삭 등
- 금속 이물 : 시공/조립 불량 등





케이블 PD 진단

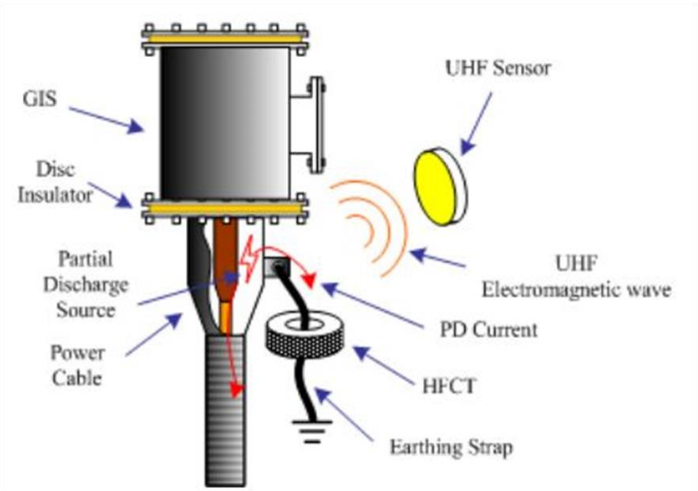
- 중간 접속함을 통한 구간 분리
- 방전 신호의 전파 거리가 길어 고주파 성분 소멸
  → HF 진단이 효율적

Cable partial discharge measurement

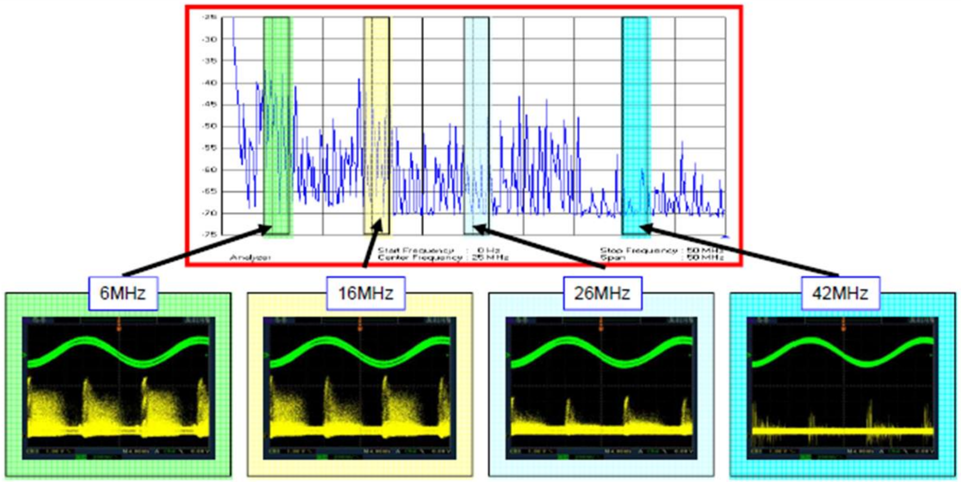
- cableP.D.signal acquisition

HFCT를 활용한 접지 측 방전 전류 측정

- 외부 노이즈에 취약하여 협대역(Narrow-band) 방식 채택
- 측정 주파수 대역 : 1 MHz ~ 50 MHz (2MHz 이하 필터링)



케이블 접속함 HFCT 센서 장착

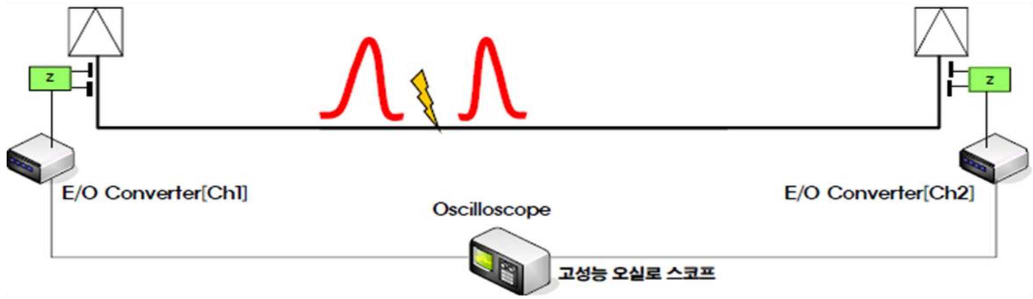


협대역 방식에 따른 대역 별 부분방전 신호 차이

Cable partial discharge measurement

- cableP.D.Fault location estimation

양단의 펄스 도달 시간차 / 전파 방향 분석을 통한 결함 위치 추정

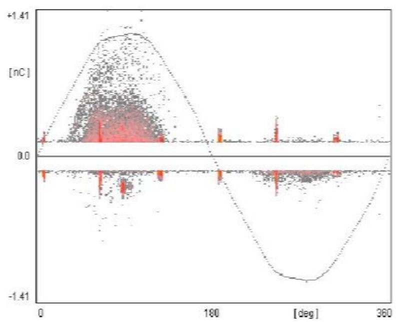


펄스 도달 시간차를 활용한 결함 위치 추정

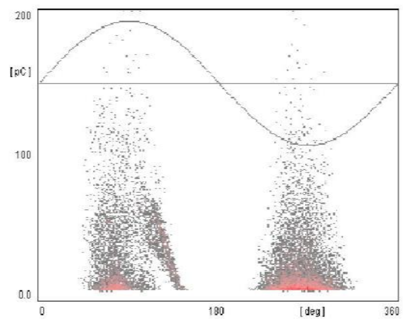
진행 방향에 따른 결함 위치 추정

4. PRPD pattern example

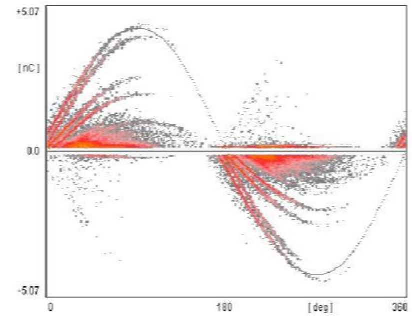
PRPD pattern recognition



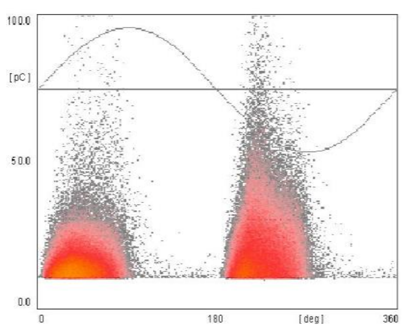
(a)



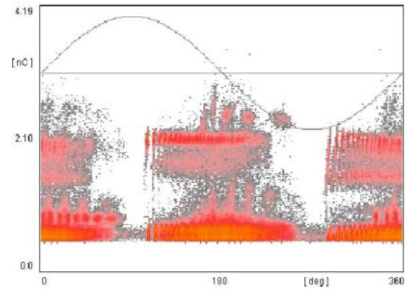
(b)



(c)



(d)



(e)

4. PRPD pattern example

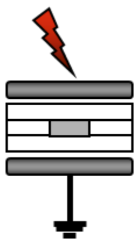
PRPD pattern recognition

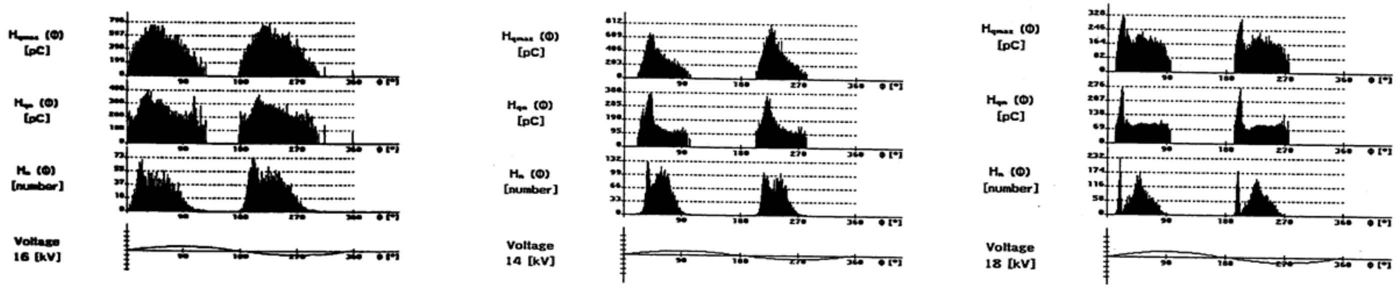
Various partial discharge patterns

PD Patterns	특 성	결함의 형태
a)	- 반주기의 중심(90도, 270도)으로부터 대칭적으로 일정한 크기의 펄스 발생. - 전압증가에 따라 펄스수 증가, 크기변동 없음.	-전극의 뾰족함(기체절연,코로나) 고전압 전극: 음의 반주기에서 펄스 발생 접지 전극 : 양의 반주기에서 펄스 발생
b)	- 반주기의 중심(90도, 270도)으로부터 대칭적으로 일정한 크기의 펄스 발생.(작은 펄스의 크기는 일정함) - 전압증가에 따라 펄스수 증가.	전극의 뾰족함 (액체 절연) 고전압 전극 : 낮은 전위로 양의 반주기에서 큰 펄스 발생 접지전극 : 음의 반주기에서 큰 펄스 발생
c)	- ¼주기와 ¾ 주기에서 크고 작은 펄스 발생. - 두 구간에서 평균적인 펄스 크기는 동일함.	-고체절연체 내의 보이드 - 액체절연체 내의 기포 - 절연체로 감싸인 도체간의 접촉
d)	- ¼ 주기와 ¾주기에서 크고 작은 펄스 발생. - 한족 구간의 평균적인 펄스 크기가 더 큼	-도체·고체절연체 사이의 보이드 -전극에서의 표면 방전 고전압 전극: ¼ 주기에서 큰 펄스 출현 접지 전극 : ¾ 주기에서 큰 펄스 출현
e)	- 0을 지나는 점을 중심으로부터 대칭적으로 크고 작은 펄스 발생.	-도체·반도전층 사이의 접촉 불량

4. PRPD pattern example (Void)

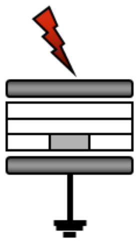
◆ **Dielectric bounded cavity**

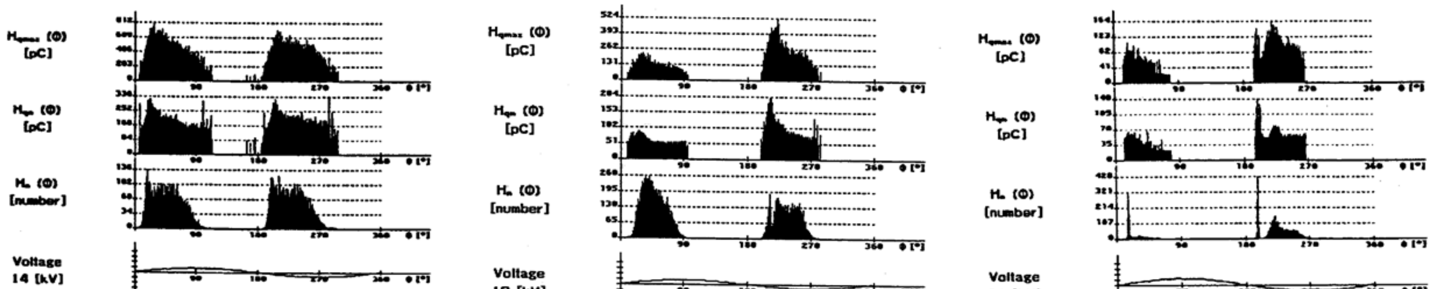




※ 전압이 증가함에 따라 방전량은 일정

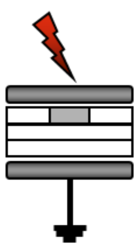
◆ **LV bounded cavity**

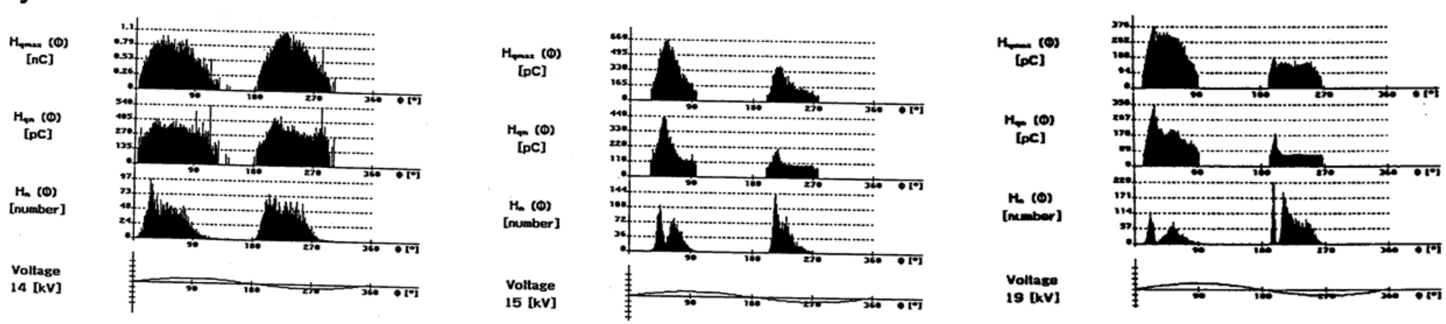




※ 전압이 증가함에 따라 방전량은 일정하고 양쪽반주기에 발생하는 방전량이 상이함

◆ **HV bounded cavity**

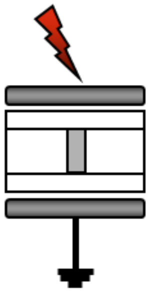


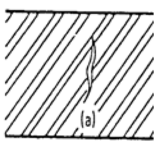


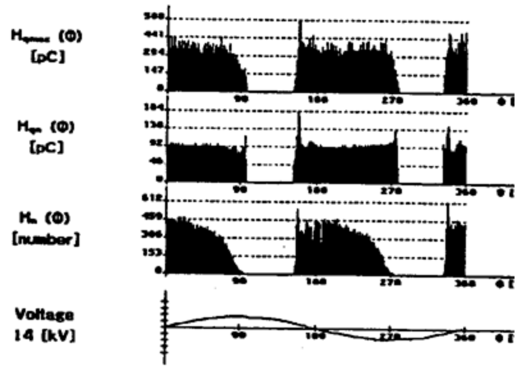
< Virgin Stage > < Conditioned Stage > < Aged Stage >

4. PRPD pattern example (Void)

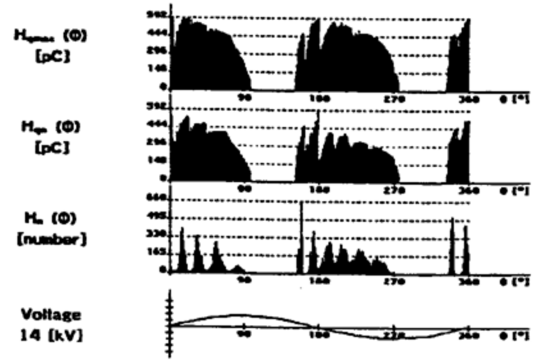
◆ Dielectric bounded cavity with time



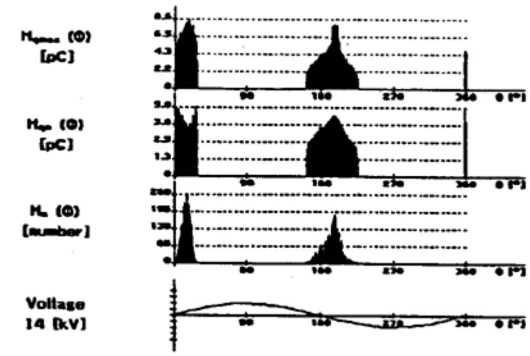




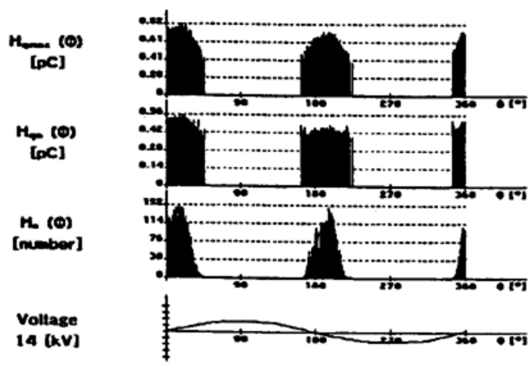
< Stage 1 > ~ 0.2 h



< Stage 2 > ~2 h



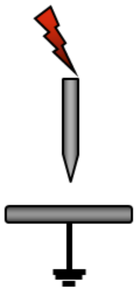
< Stage 3 > ~93 h

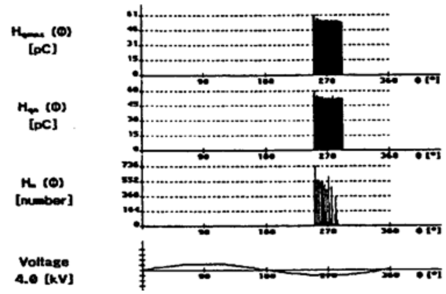


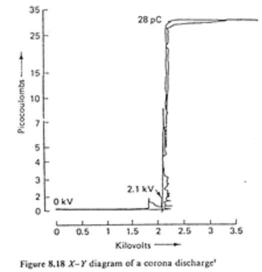
< Stage 4 > ~285 h

4. PRPD pattern example (Corona)

◆ HV single-point corona in air

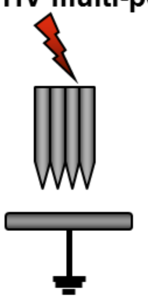


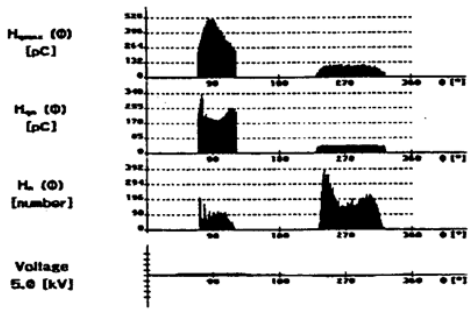


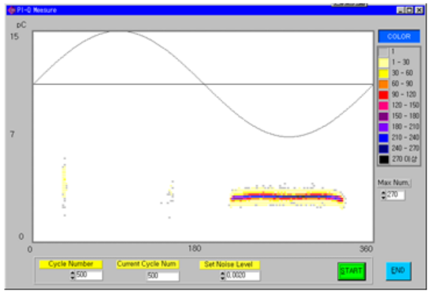


전압이 증가함에 따라 방전량은 일정

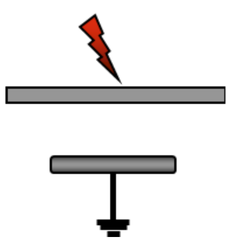
◆ HV multi-point corona in air

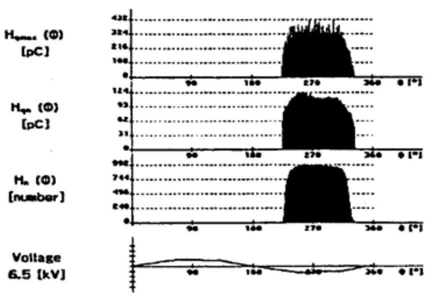






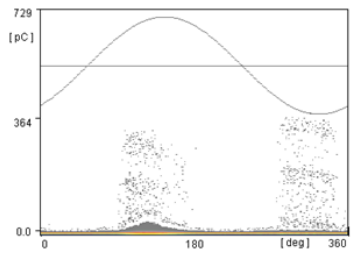
◆ HV wire-plan corona in air

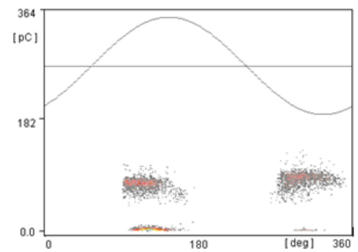


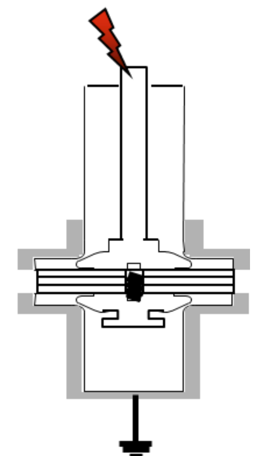


4. PRPD pattern example (Corona)

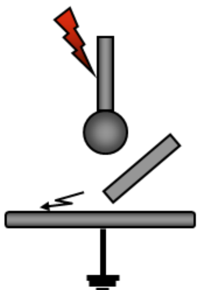
◆ EBA(by metal foil electrode in high frequency)

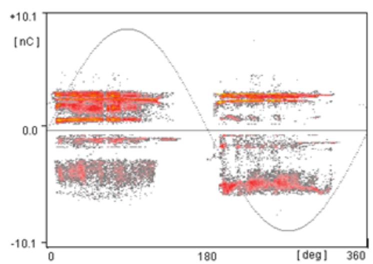


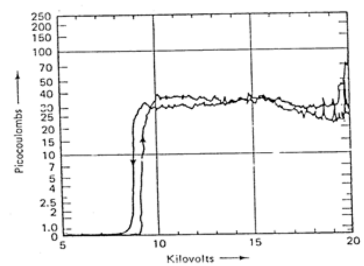




◆ Floating metal(Conventional sensor)

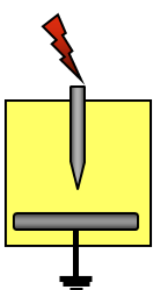


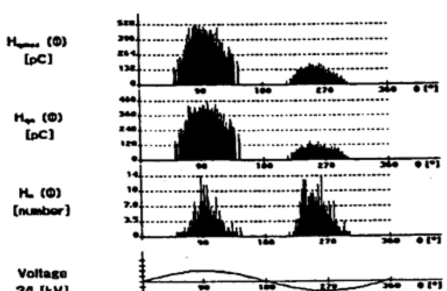




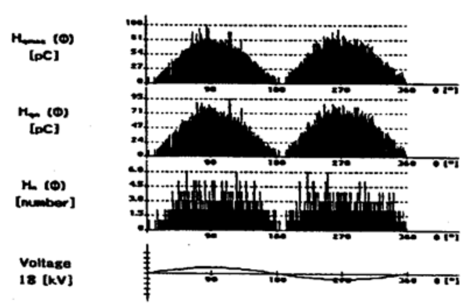
전압이 증가함에 따라 방전량은 일정

◆ HV single-point corona in oil



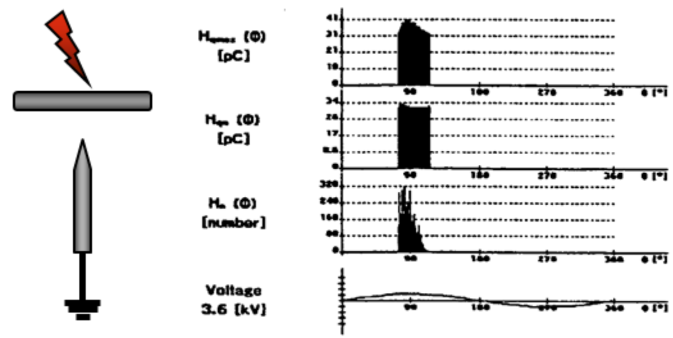


◆ Air bubbles in oil

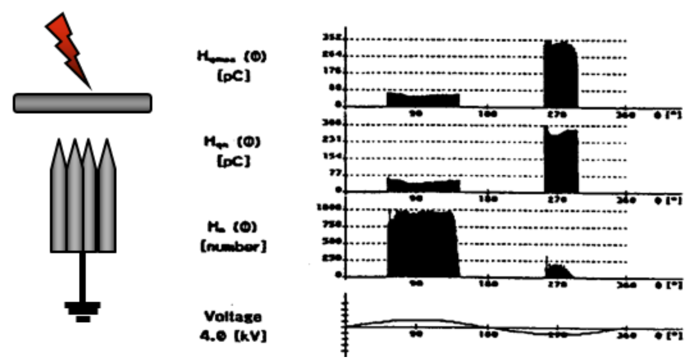


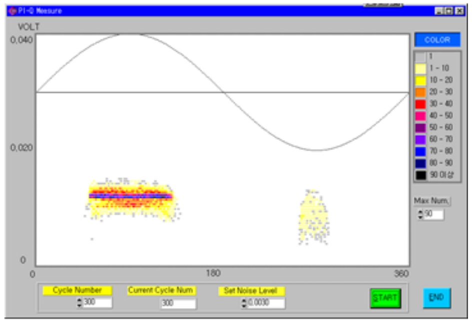
4. PRPD pattern example (Corona)

◆ LV single-point corona in air



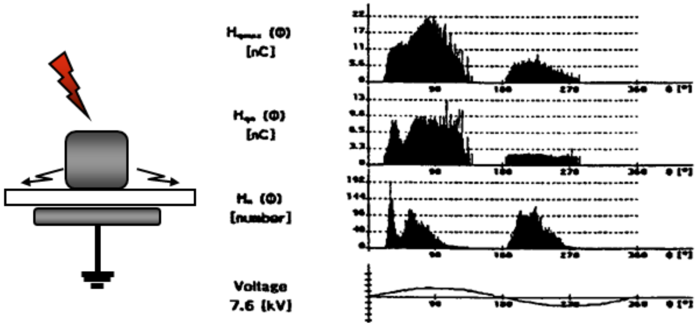
◆ LV multi-point corona in air

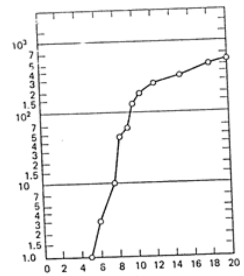




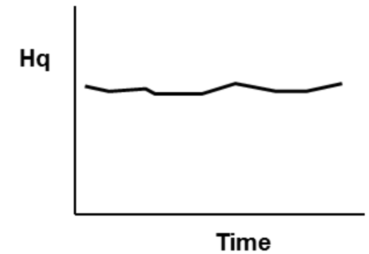
4. PRPD pattern example (Surface)

◆ HV surface discharge in air



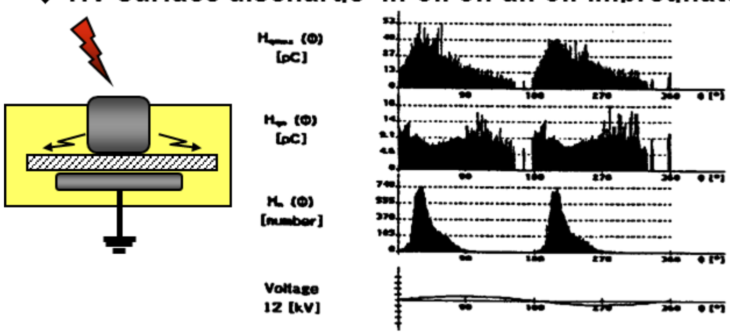


Increasing magnitude of PD according to voltage

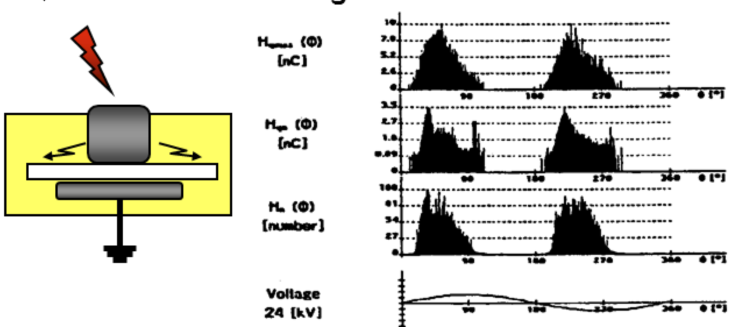


Constant magnitude of PD according to time

◆ HV surface discharge in oil on an oil-impregnated paper

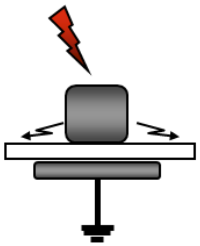


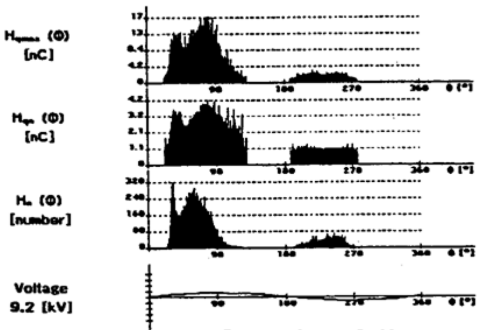
◆ HV surface discharge in oil on a PE slab



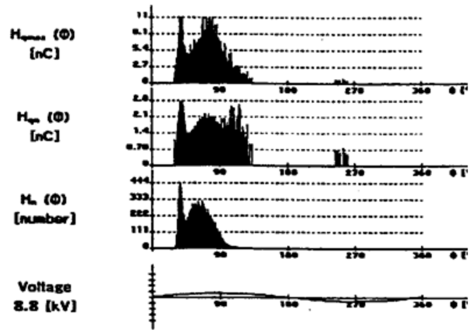
4. PRPD pattern example (Surface)

◆ HV surface discharge in air with time

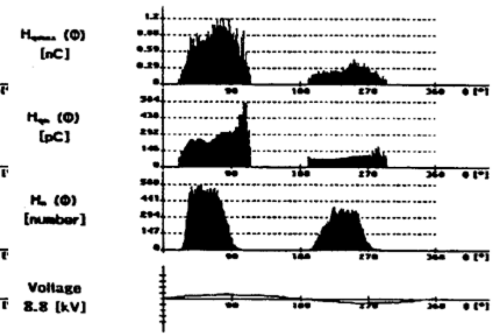




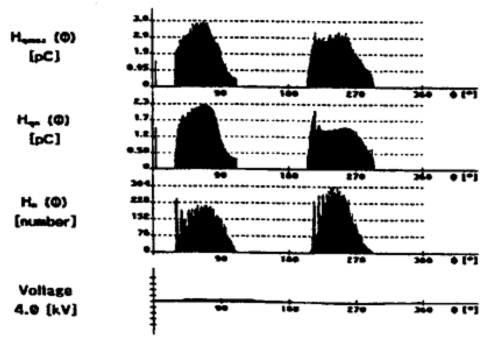
< Stage 1 > ~0.1h



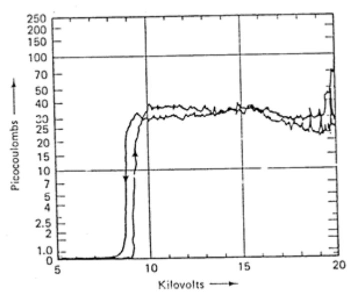
< Stage 2 > ~4h



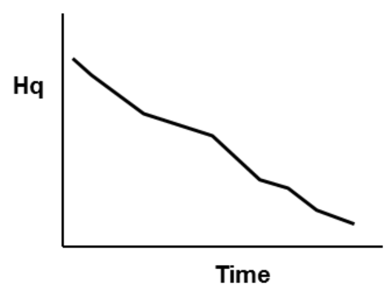
< Stage 3 > ~772h



< Stage 4 > ~1230h



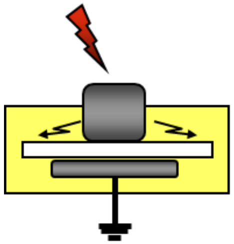
전압이 증가함에 따라 방전량은 일정

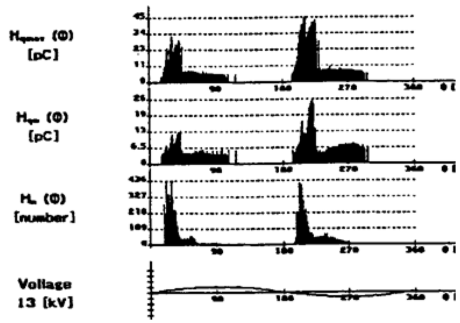


시간이 증가함에 따라 방전량은 하강

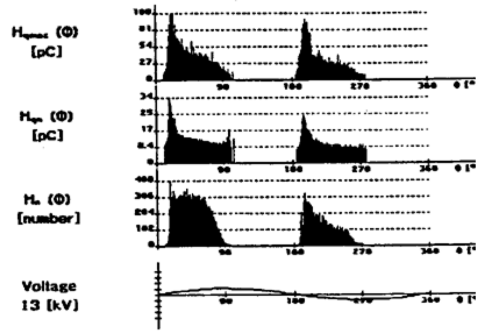
4. PRPD pattern example (Surface)

◆ HV surface discharge in oil with time

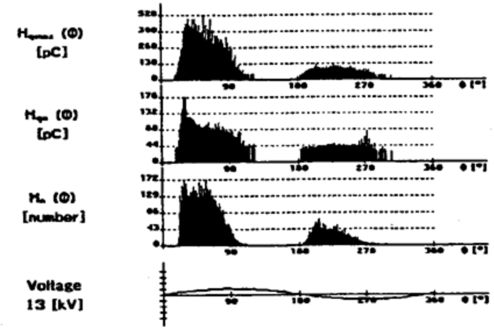




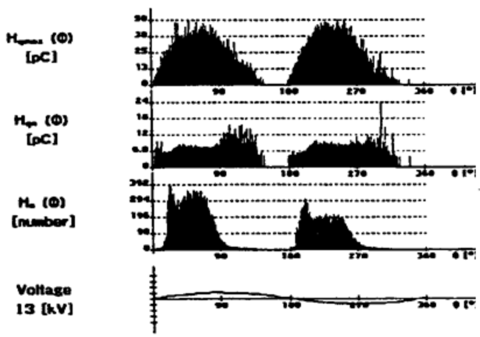
< Stage 1 > ~0.2h



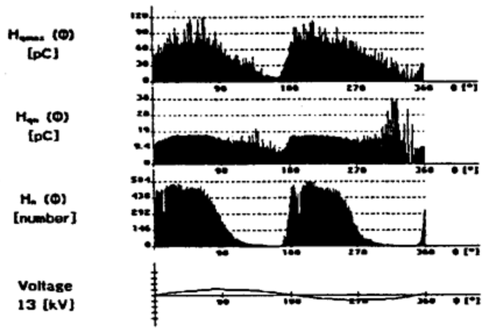
< Stage 2 > ~4h



< Stage 3 > ~25h



< Stage 4 > ~170h



< Stage 5 > ~340h

thank you