Knowledge Is Power℠

Apparatus Maintenance and Power Management for Energy Delivery

Basic Insulation & Power Factor Theory

PROPRIETARY INFORMATION

Doble Engineering Company ("Doble"), has full title, right and interest to all subject matter contained in these materials ("proprietary Information") regardless of the medium. You have been provided these materials for private reference purposes only. Doble's delivery to you of Doble Proprietary Information does not constitute in any way whatsoever a license of any kind or vests any interest in Doble's Proprietary Information (other than private reference use), including, without limitation, the rights to copy, disseminate, distribute, transmit, display or perform in public (or to third parties), reproduce, edit, translate or reformat. You, as recipient, acknowledge and agree to these terms by your first viewing of this Proprietary Information, you further acknowledge and agree that Doble shall not have an adequate remedy at law in the event of your breach hereunder, that Doble will suffer irreparable damage and injury if you breach any of the terms stated above, and that if you breach any of the terms stated above, Doble, in addition to any other rights and remedies available herein or otherwise, shall be entitled to seek an injunction to be issued by a tribunal of competent jurisdiction restricting the recipient from committing or continuing any breach of these terms.

What is a Doble Test?...

The underlying principle of the Doble Test is to measure the fundamental AC electrical characteristics of insulation.

Insulation

IEEE Defines Insulation as:

"Material or a combination of suitable non-conducting material that provides electrical isolation of two parts at different voltages."

Insulation vs. Dielectric . . .

- ***Insulation*** usually suggests simply and generally that the medium or material is a poor conductor of electricity (i.e. current)

- ***Dielectric*** implies that the medium or material has specific measurable properties such as: *Dielectric Strength, Dielectric Absorption, Dielectric Constant, Dielectric Loss and Power Factor.*

Examples of Material With Insulating Properties

Gaseous	Liquid	Solid
High Vacuum	Hydrocarbon-Based Oil	Cellulose
Air	Silicone Oil	Porcelain
Sulfur Hexafluoride (SF_6)	Distilled Water	Phenolics

Why Doble Test???

- Enhance System Reliability
- Minimize Damage to Apparatus
- Enhances Safety to Personnel
- Minimize Loss of Revenue
- Extension of Apparatus Life
  - Degradation of Insulation, if detected before failure, can generally be restored to its original condition
  - Defer replacement costs

Why Doble Test???

- Better Utilization of Resources
  - Inspection interval may be safely extended or scheduled to utilize resources efficiently and effectively
- Acceptance of New Apparatus
  - Verify that new apparatus meets purchased specification and agrees with factory test reports
  - Assures proper field Assembly

Dielectric Strength

Basically looking for a deterioration *of the Insulation*

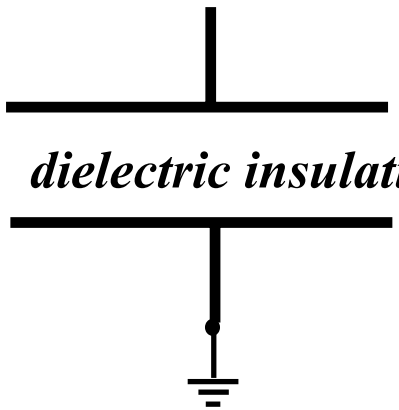
- Changes in original characteristics can be:
  - *Electrical*
  - *Mechanical*
  - *Thermal*
  - *Chemical*
- Detected by:
  - *Destructive Tests*
  - *Non-Destructive Tests*

Destructive & Non-destructive

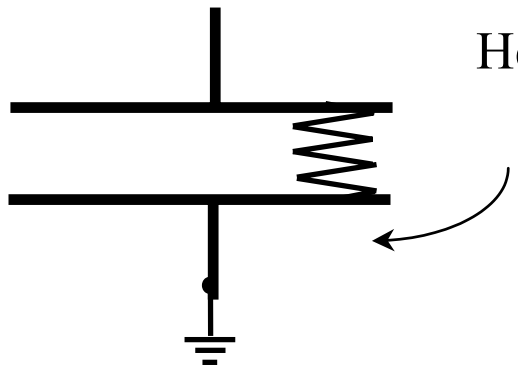
- Destructive Test- Test in which the specimen will be broken down or destroyed as a requirement of the test
- Non-destructive Test-
  - High Stress Test - specimen is submitted to a voltage above the level at which it normally operates
  - Low Stress Test - specimen is submitted to a voltage below the level at which it normally operates
  - Zero Stress Test - specimen has no possibility of damage in the process of performing the test

Insulation

Insulation is basically two plates separated by one or more dielectrics. One plate is at a high potential and the other at a lower or ground potential.



Current generated by polar contaminants in the dielectric shows up as Watts.



Doble Test Parameters

Basic Insulation Characteristics

- Capacitance (Total Charging Current)
- Dielectric Loss
- Power Factor
- Power Factor Change With Test Voltage (Tip-up)

Other Characteristics

- Transformer Excitation Current
- Transformer Voltage Ratio
- Leakage Reactance

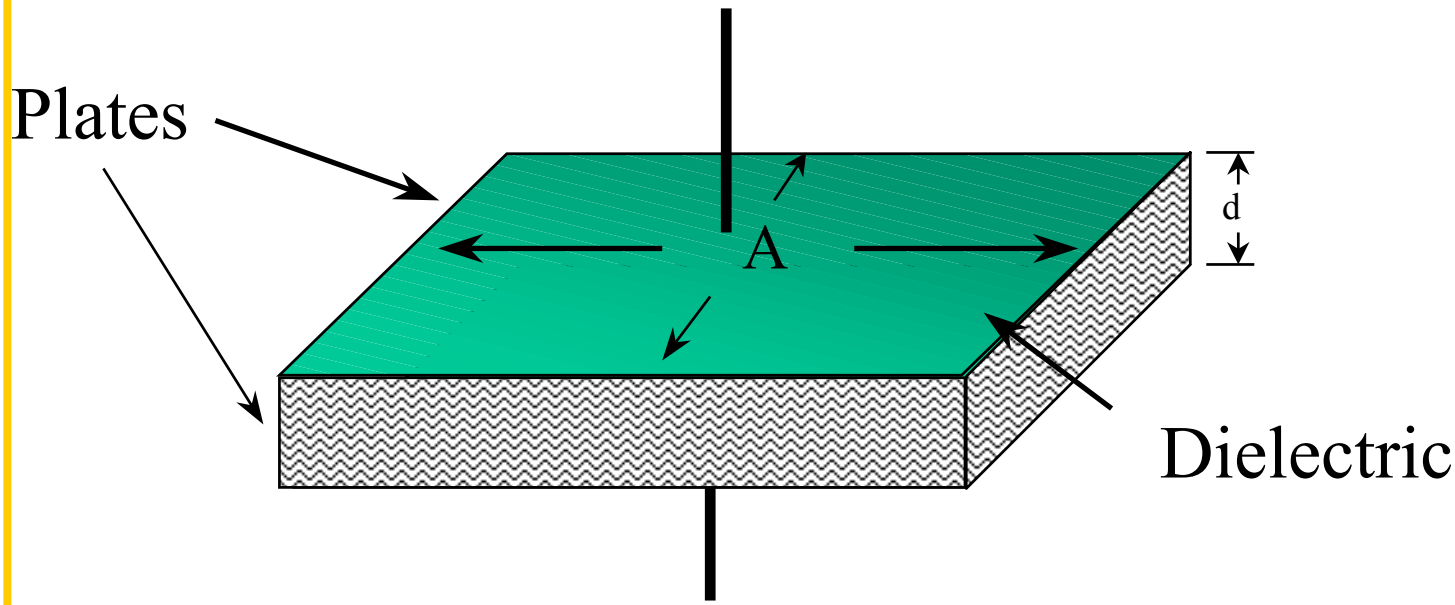
Suggested Test Intervals

- When received new on site
- Within warranty period
- Every 3 years
- RCM may lengthen intervals

Current & Capacitance

- Ic represents PHYSICAL characteristics of insulation such as:
  - Area of plates (insulation)
  - Distance between the plates
  - Dielectric constant of the insulation

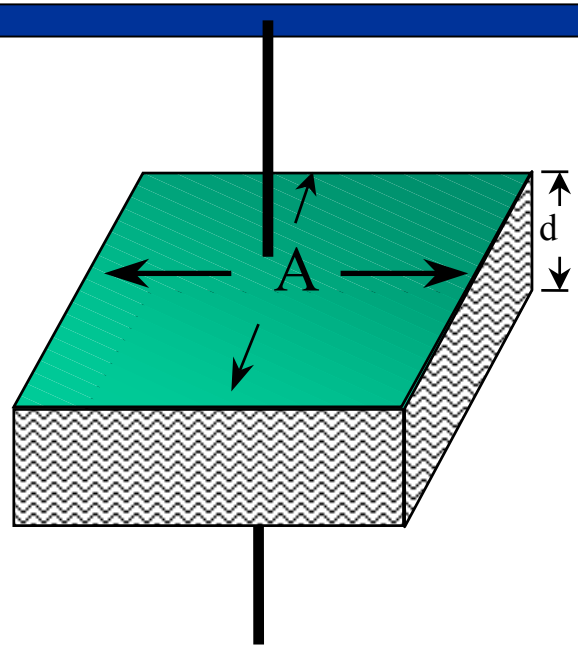
The Capacitor



Two conducting plates with area A separated by a dielectric with a thickness of d and dielectric constant ε

Capacitance

$$C = \frac{A\varepsilon}{4\pi d}$$



C = Capacitance

ε = dielectric constant

d = Distance between plates

- All of these variables are **Physical Parameters**

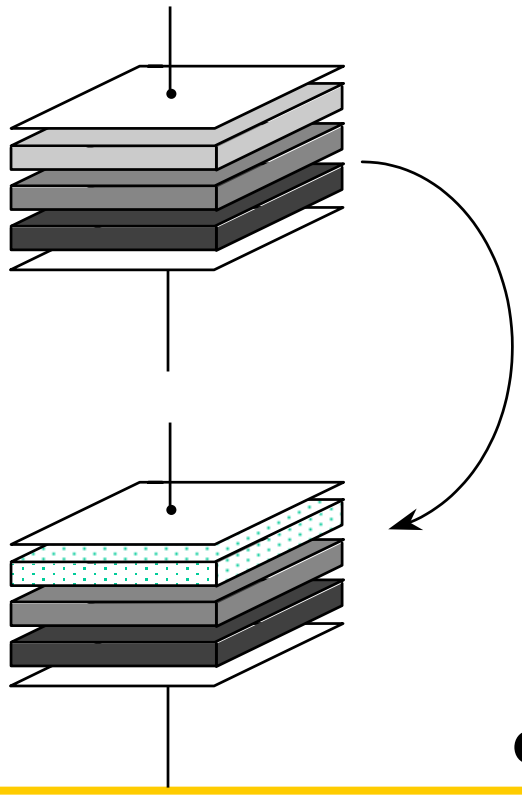
Various Dielectric Constants

Material	Constant
Vacuum	1.0
Air	1.000549
Mica	5.4
Dry Paper	2
Porcelain	7
Oil	2.2
Silicone Fluid	2.75
Water (20^{o} C)	80

Example: Oil leaking from an Insulation System

Oil = 2.1
Porcelain = 7.0
Paper = 2.0
Air = 1.0

Given three dielectrics in series the dielectric constant ε is:



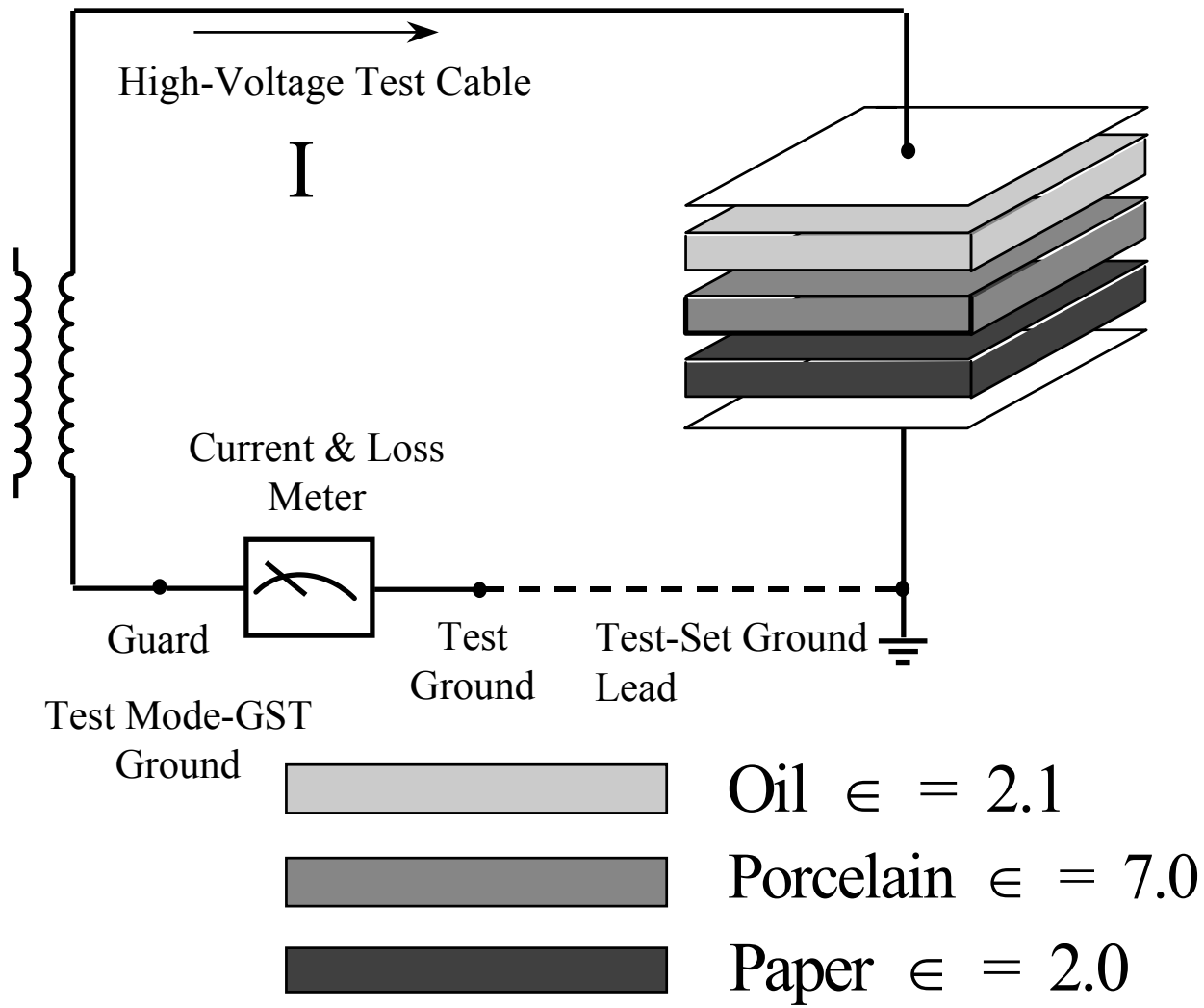
$$\varepsilon_{before} = \frac{2.1 \times 7.0 \times 2.0}{2.1 + 7.0 + 2.0} = 2.65$$

If the Oil leaks out and is replaced by air...

$$\varepsilon_{after} = \frac{1 \times 7.0 \times 2.0}{1 + 7.0 + 2.0} = 1.4$$

$$\therefore \quad C \downarrow \Rightarrow I_t \downarrow$$

Typical Insulation System



Changes in Current/Capacitance

- Significance
  - Indicate a physical change
    - Bushings - shorting of capacitive layers
    - Transformers - movement of core/coils
    - Arresters - broken elements
- Suggested Limits
  - ± 5% - Investigate
  - ± 10% - Investigate/remove from service

Dielectric Loss

Dielectric Loss is the time rate at which electric energy is transformed into heat in a dielectric when it is subjected to an electric field. The heat generated is given in terms of Watts.

$$i_R \approx Watts$$ **(from vector diagram)**

$$Watts = E\, I_R$$ **(from dielectric model circuit, parallel R/C network)**

$$Watts = Contamination + Deterioration$$

$$Contamination = Water + Carbon + Dirt$$

$$Deterioration = Carbon + Corona$$

Dielectric Loss and Power Factor:

What are they good for...

The Dielectric Loss and Power Factor are sensitive to soluble polar, ionic or colloidal materials:

Moisture (free, in cellulose, with particles in oil)

Products of Oxidation or mineral oil

Carbon (with moisture)

Metal Soaps

At Higher voltage:

Ionization in solid insulation

Definition of Power Factor

Power factor is a measurement of the efficiency of insulation system.

Power Factor Is:

- Independent of specimen size
- Non-destructive
- Temperature sensitive
- Not time dependent

The Term *Power Factor* Describes:

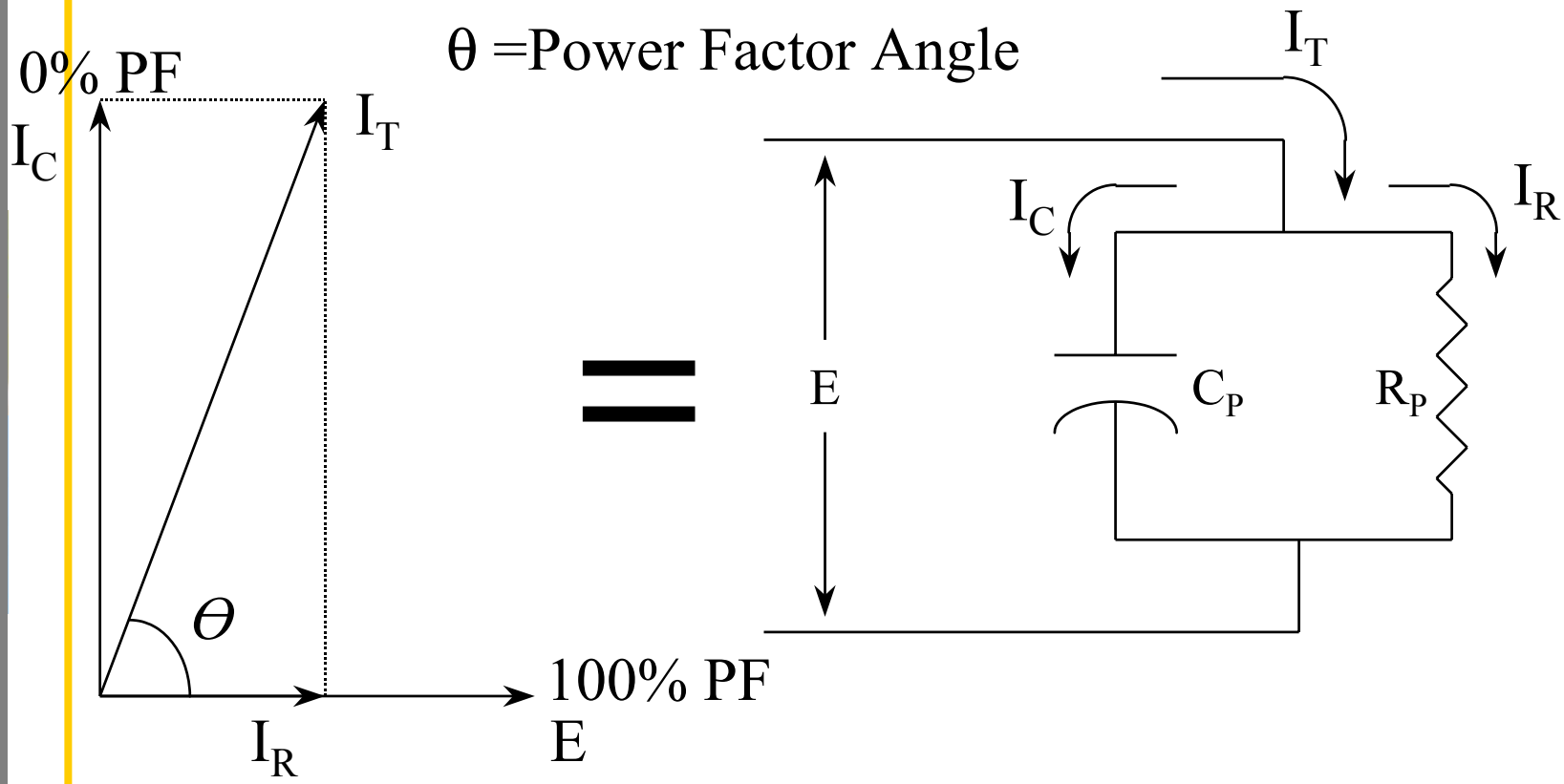
- The phase angle relationship between the applied voltage across and the current through a specimen.
- The ratio of the real or average power to the apparent power.
- The efficiency of a power system in terms of real and reactive power flows.

Basic Power Factor

I_T=Total Current I_C=Capacitive Current

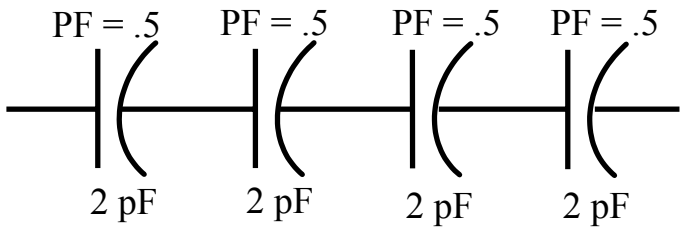
I_R=Resistive Current E=Applied Voltage

θ =Power Factor Angle



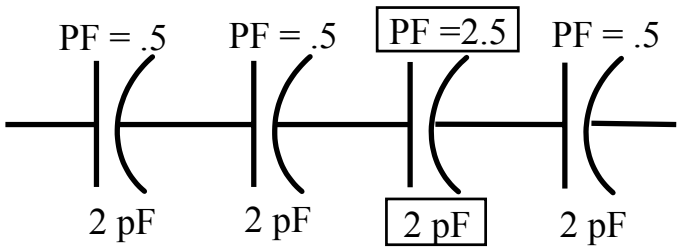
Is the Doble Test Effective for Detecting Defective Insulation?

1)



$$PF_{\Sigma} = \frac{.5 + .5 + .5 + .5}{4} = .5$$

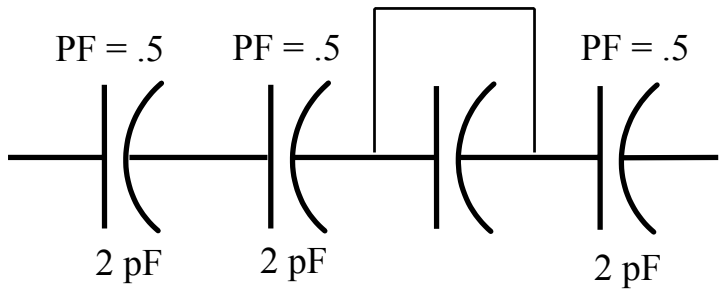
$$\frac{1}{c} = \frac{1}{2} + \frac{1}{2} + \frac{1}{2} + \frac{1}{2} \qquad c = \frac{1}{2}\,pF$$



$$PF_{\Sigma} = \frac{.5x3 + 2.5}{4} = 1.0 \qquad c = \frac{1}{2}\,pF$$

Is the Doble Test Effective for Detecting Defective Insulation?

2)



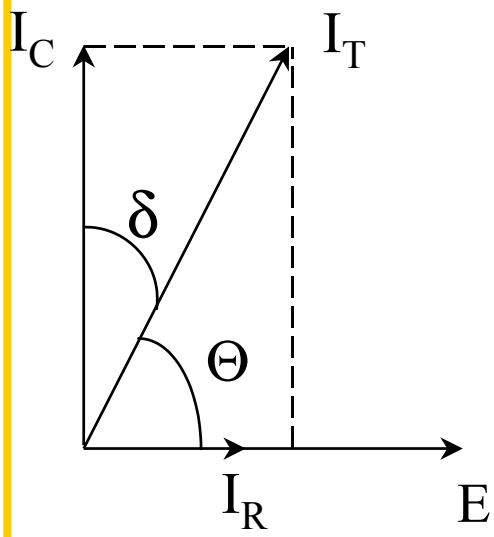
$$PF = \frac{.5+.5+.5}{3} = .5$$

$$\frac{1}{c} = \frac{1}{2} + \frac{1}{2} + \frac{1}{2} = 1.5 \qquad c = .667$$

Analysis of Percent Power Factor

- Compare to limits published by Doble
- Compare to previous results
- Compare among similar or sister units
- Examine the trend
- Do not use PF if current is less than 200μA

Power Factor vs. Dissipation Factor



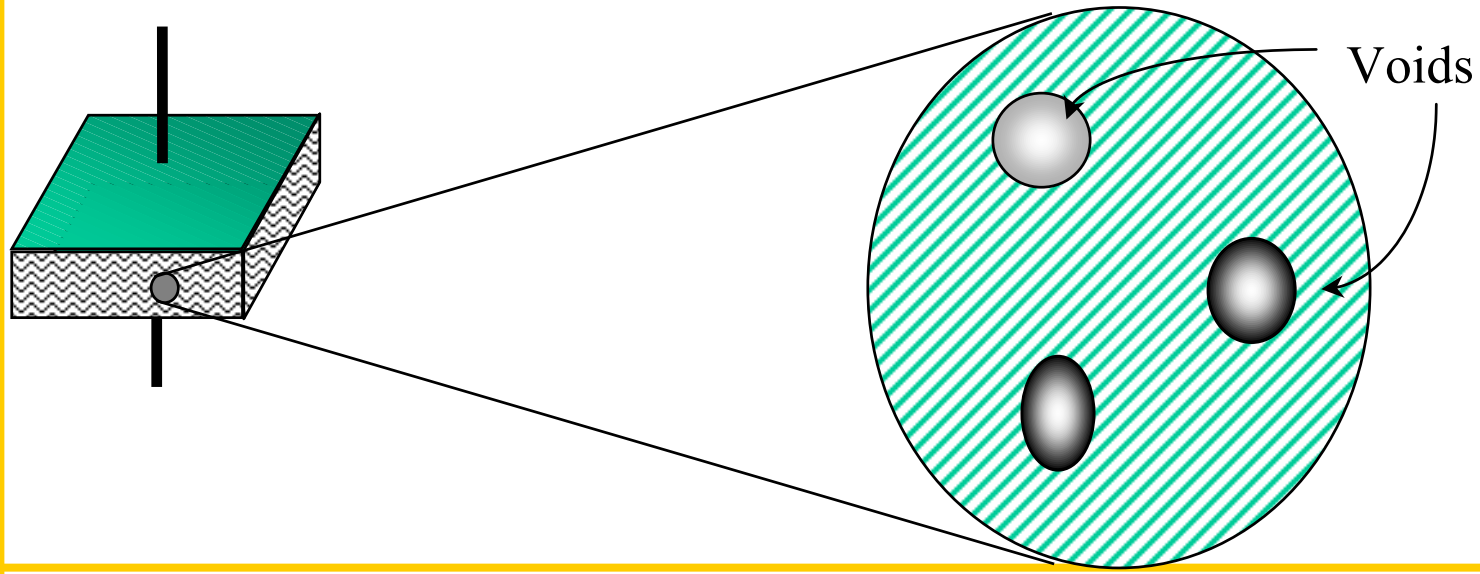
$$\text{Power Factor} = COS\,\Theta = \frac{I_R}{I_T}$$

$$\text{Dissipation Factor} = TAN\,\delta = \frac{I_R}{I_C}$$

Θ°	% PF (% COS Θ)	δ°	% DF (% TAN Δ)
90	0	0	0
89.71	.500	.29	.500
84.26	10.00	5.74	10.05
0	100.00	90	INFINITY

Voids and the Power Factor Tip-Up Test

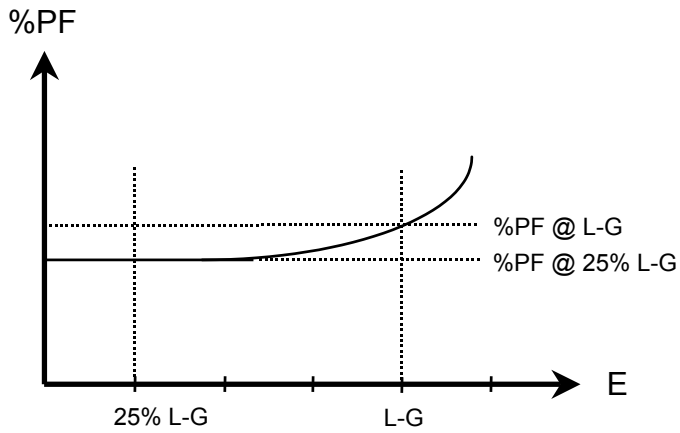
When we closely examine insulation, very small gaps or “voids” exist. These voids develop an electrostatic potential on their surfaces. These small gaps become ionized: Partial Discharge/Corona.



Power Factor Vs. Test Voltage

As test voltage is increased, the power factor will increase depending on the void density.

Tip-Up = Power Factor at Line-to-ground voltage -
Power Factor at 25% Line-to-ground voltage



Tip-up occurs in dry-type insulation specimens such as Dry Type Transformer, generators, etc.….

Negative UST Situations

- Condenser Bushings
  - Excessive upper/lower porcelain surface leakage (contamination)
  - Excessive contamination on the inner porcelain surface
  - Tracking between condenser layers
  - Poor flange ground

Resistive Path-to-Ground

Kv	mA	Watts	Measure % Power Factor
10	1.313	-.007	-.053

Negative UST Situations (cont.)

- Generators/Motors
  - Semi-conducting paint on the end turns can cause negative results
- Transformers
  - Poor tank ground
  - Deteriorated interwinding shield