

DISSIPATION FACTOR, POWER FACTOR, AND RELATIVE PERMITTIVITY (DIELECTRIC CONSTANT)

By I.A.R. Gray

Transformer Chemistry Services

Background:

There is a relationship between the dissipation factor, the power factor, and the permittivity or dielectric constant. They all relate to the dielectric losses in an insulating fluid when used in an alternating electric field. The permittivity is represented as a complex quantity in the following manner: $\epsilon^* = \epsilon' - j\epsilon''$; where ϵ^* is the complex permittivity, ϵ' is the real or measured permittivity, and ϵ'' is the imaginary permittivity. In the presence of an alternating field there is created a capacitance current and a resistive current that are 90° out of phase with respect to each other. The vector sum of these two currents represents the total current and the angle between the capacitance current vector and the resultant total current vector is defined as the loss angle, d . The ratio of the imaginary to the real part of the permittivity is equal to $\tan d$; i.e. $\tan d = \epsilon'' / \epsilon'$. The factor $\tan d$ is defined as the dissipation factor, D , and represents the dielectric loss in the insulating fluid. The power factor, P , is defined as $\cos d$. The relationship between D and P is the following: $D^2 + P^2 = 1$, thus if you know one value you can calculate the other. Furthermore for small values of d , $\tan d \sim \sin d$, thus for values of $\tan d$ up to 0.05 the power factor and the dissipation factor are the same within one part in a thousand.

Procedure:

The details of the entire procedure are given in the ASTM D 924 standard and are only briefly mentioned here. The measurements are made in specially designed cells that are machined to precise dimensions. The measurements are done at precise temperatures, usually 25 and 100 °C, thus the cells have to be kept at a constant temperature. The actual measurement is one of comparing the capacitance of the cell filled with the insulating fluid sample in a sensitive electronic bridge circuit. The result is usually expressed as a percentage for the dissipation factor or power factor.

Significance:

The dielectric loss factor relates to the inability of molecules in the insulating fluid to reorient themselves with an alternating electric field. This ability is dependent on the temperature of the sample, the size of the molecules involved, and their polarity. It is also dependent on the frequency of the alternating field. The dissipation factor and the permittivity are both affected by the molecular size, composition, and relative orientation of functional groups within the molecules. In general within a series of similar molecules, the permittivity will increase as the molecular weight increases. The above-described factors are electrical characteristics of the insulating fluid and can be used to monitor the quality of the oil with regard to deterioration in use and for the presence of contaminants.

Power Factor Test

The power factor of insulating oil equals the cosine of the phase angle between an AC voltage applied to oil and the resulting current. Power factor indicates the dielectric loss of oil and, thus, its dielectric heating. The power factor test is widely used as an acceptance and preventive maintenance test for insulating oil. Oil power factor testing in the field is usually done with the Doble type MH or M2H test set in conjunction with power factor tests of the oil-filled equipment. The power factor of new oil should not exceed 0.05 percent at 25°C. A high power factor in used oil indicates deterioration, contamination, or

both with moisture, carbon, varnish, Glyptal, sodium soaps, or deterioration products. Used oil with a power factor in excess of 0.5 percent should be further analyzed in a laboratory to determine the cause of the high power factor. Oil with a power factor in excess of 2.0 percent may be an operational hazard. It should be investigated and either reconditioned or replaced

The IEEE has suggested guidelines for Power Factors depending on the type of oil and the unit it is being used in (IEEE C57, 106-1991). Some representative values are given below:

Type of Oil/Unit	Power Factor	
	@ 25 °C	@ 100 °C
Shipment of New Oil from Refinery	max. 0.05%	max. 0.3%
New Oil Received in New Equipment		
< or = 69 kV	max. 0.15%	max. 1.50%
69 - 288 kV	max. 0.10%	max. 1.00%
> 345 kV	max. 0.05%	max. 0.30%
New Oil for Circuit Breakers	max. 0.05%	max. 0.30%
Suggested Limits for Oil used in Circuit Breakers	max. 1.0%	Not Spec.

The IEC has recommended Limits depending on the type of Type of equipment based on the IEC Test Method 60247 (Dissipation Factor @90°C)

IEC 60422 Table 2 – Categories of equipment

Category	Type of equipment
Category O	Power transformers/reactors with a nominal system voltage of 400 kV and above.
Category A	Power transformers/reactors with a nominal system voltage above 170 kV and below 400 kV. Also power transformers of any rated voltage where continuity of supply is vital and similar Equipment for special applications operating under onerous conditions.
Category B	Power transformers/reactors with a nominal system voltage above 72,5 kV and up to and including 170 kV (other than those in category A).
Category C	Power transformers/reactors for MV/LV application e.g. nominal system voltages up to and including 72,5 kV and traction transformers (other than those in category A). Oil-filled circuit breakers with a nominal system voltage exceeding 72,5 kV. Oil-filled switches, a.c. metal-enclosed switchgear and control gear with a nominal system voltage greater than or equal to 16 kV.
Category D	Instrument/protection transformers with a nominal system voltage above 170 kV.
Category E	Instrument/protection transformers with a nominal system voltage up to and including 170 kV.
Category F	Diverter tanks of on-load tap-changers, including combined selector/diverter tanks.
Category G	Oil-filled circuit breakers with a nominal system voltage up to and including 72,5 kV. Oil-filled switches, a.c. metal-enclosed switchgear and control gear with a nominal system voltage less than 16 kV.

**Dielectric Dissipation Factor IEC 60422
Recommended Action Limits**

**Transformers
Recommended Action Limits**

Category	Good	Fair	Poor
O, A	<0.10	0.10-0.20	>0.20
B, C	<0.10	0.10-0.50	>0.5
D	<0.01	0.01-0.03	>0.03
E	<0.10	0.10-0.30	>0.3
Note-0.10 is 10% DDF			

Recommended Actions

O, A, B, C	Good: Continue normal sampling Fair: More frequent sampling Poor: Reclaim or replace the oil
D	Refer to manufacturer's best practice Catastrophic failures have been reported at 0.04 DDF In VHV and EHV type D transformers
E	Refer to manufacturer's best practice

Resistivity at @20° C

**Transformers
Recommended Action Limits**

Category	Good	Fair	Poor
O, A	>200	20-200	<20
B, C	>60	4-60	<4
D	>800	250-800	<250
E	>60	7-60	<7

Resistivity at @90° C

Category	Good	Fair	Poor
O, A	>10	1-10	<1
B, C	>3	0.2-3	<0.2
D	>50	10-50	<10
E	>3	0.4-3	<0.4
Note-Units are G M			

Recommended Actions

Good: Continue normal sampling Fair: More frequent sampling. Check other parameters. Poor: Reclaim or replace the oil
Note : Not a routine test

Testing In Service Transformer Oil (Routine Monitoring Tests)

When insulating fluid is subjected to an AC current, there are dielectric losses, which cause two effects. The resulting current is deflected slightly out of phase with the AC field that has been applied, and the energy of the losses is dissipated as heat. Liquid power factor and the closely related dissipation factor are direct measure of these dielectric losses. (Liquid power factor is calculated as the sine of the loss angle- while the dissipation factor is the tangent of the same loss angle)

New, clean, and dry transformer oil has a very low value. Contamination by moisture or by many other contaminants will increase the liquid power factor. The aging and oxidation of the oil also elevates the values. Therefore this is an extremely useful test because almost everything “bad” that can happen to the insulating oil will cause the liquid power factor to increase.

The Transformer Maintenance Institute (TMI) has recommended In service values for all primary voltage classes:

Liquid Power Factor Values

	AC (acceptable)	QN (questionable)	UN(unacceptable)
@ 25° C	<0.10%	0.1% 0.30%	>0.3%
@ 100° C	<3.0%	3.0% 4.0%	>4.0%

The 100° C value is always considered more carefully than the 25° C when determining whether there is a problem. QN or UN values should be investigated and the cause diagnosed. Reclaiming (regenerating) the oil or hot oil cleaning the transformer will reduce the liquid power factor. Drying out the oil will improve the 25° C value.

TEST METHOD

Tan Delta

This test is also known as the Loss Tangent or Dielectric dissipation factor measurement. Tan delta may be defined as the measurement of the cosine of the phase angle or the sine of the loss angle. It is basically the measurement of the leakage current through the oil, which in turn is a measure of the contamination or deterioration of the oil. The oil is non-polar and most contaminants are polar, enabling a dipole action, which this test depends upon. A normal degree of refining will result in a low value for the power factor. The presence of contaminant such as engine oil will easily be detected with this parameter.

IEC 247

RHO is the Ohmmeter result measured with negative voltage (in this case with -500 V), +RHO is the Ohmmeter result measured with positive voltage.

+500V is the test voltage DC. The RHO difference is the difference between the both Ohmmeter results (the negative and the positive result).

The ASTM D 1169 - 02 says:

The resistivity of a liquid is a measure of its electrical insulating properties under conditions comparable to those of the test. High resistivity reflects low content of free ions and ion-forming particles, and normally indicates a low concentration of conductive contaminants.

If the difference in the resistivity values of the two test specimens is within 20 % of the higher of the two values, no further tests are required and report the average of the two test specimens as the resistivity of the sample. If the difference in the values of the two test specimens is not within 20 %, test a third specimen. If the difference in the values between any two of the three test specimens is not within 20 %, clean the test cell and test specimens from another sample until the difference in the resistivity of two test specimens is within 20 %.

According to IEC 247:

The measurements on two consecutive fillings should not differ from each other by more than 35% of the highest of the values. If this requirement is not met, continue with further fillings until values of resistivity from consecutive samples agree to within 35% of the highest.

These shall be accepted as valid measurements.

Note: A second measurement on each filling, made with the polarity of the applied voltage reversed, may provide information on the cleanliness of the cell and other phenomena. In order to avoid erroneous results care is necessary with certain electronic instruments that do not have a switch for such reversal.

If the resistance test is selected, + RHO and - RHO are measured and the difference on a difference > or < 35% will be controlled (IEC 247). The JIS C2101 demands however only a measurement! Differently from the ASTM 1169. It computes the average from +RHO and -RHO and compares this value with a completely new measurement. The two average values should be within 20%.

REFERENCES

- [1] IEEE C57,106-1991
- [2] ASTM D 924
- [3] IEC 247
- [4] M. Perkins, L.Pettersson, N.L.Fantana, T.V.Oommen, S.Jordan, "*Transformer Life Assessment Tools with Special Application to Nuclear Power Station Generator Transformers*" IEEE Transformer Committee Meeting, November 1999, Monterrey Mexico
- [5] Stan Lindgren & Barry Ward, EPRI, "*Management of Aging Power Transformers*" CEA Electricity Conference, 1999
- [6] IEEE P C57.XX Draft 10, October 2001, "IEEE Guide for Application of Monitoring to Liquid Immersed Transformers and Components", Donald Chu, Chair
- [7] IEEE P C57.140, Draft 8, October 2002, IEEE Guide for the Evaluation and Reconditioning of Liquid Immersed Power Transformers, Rowland James, Chair
- [8] David J. Woodcock, Weidmann Systems International, Inc. "*The Key to Condition-Based Asset Strategies for Power Transformers*"
- [9] A Guide to Transformer Maintenance (1st, 2nd, 3rd edition)