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COOPER POWER
SERIES

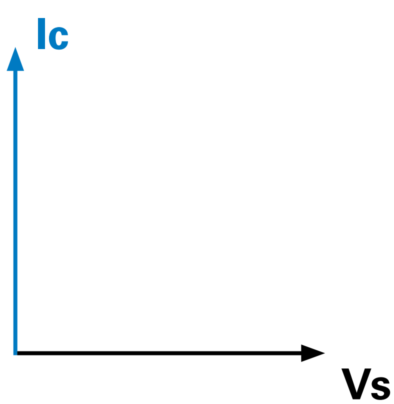
Proper evaluation of power factor in rectangular and circular coil small power transformer designs

Introduction

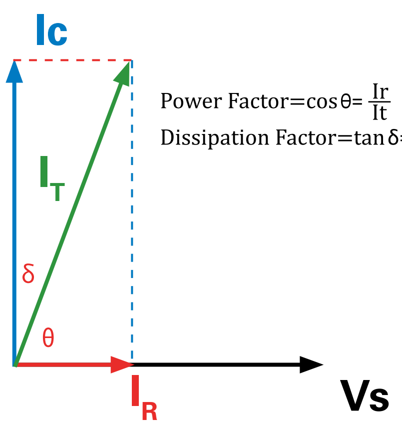
Power Factor (PF) is a means to assess the insulation of a transformer. The most common number that is referenced for acceptable insulation is 0.5% PF which represents circular coil power transformer designs. This paper will explore the differences between rectangular and circular coil designs as they relate to power factor and establish acceptable values for each.

PF testing theoretical

Insulation power factor tests are used to measure dielectric losses, which relate the wetness, dryness or deterioration of transformer insulation. With ideal insulation the circuit looks like a capacitor. Power factor is defined as the cosine of the phase angle between the voltage and current. For an ideal insulation the phase angle is 90°and the PF is equal to Cos (90) = 0. Therefore, the PF for an ideal insulator would be 0.



In reality insulation is not an ideal insulator therefore will always have some level of leakage current which consists of capacitive current and resistive current. The sum of which results in a total current leading the voltage by less than 90 degrees. The resistive current represents the heat loss in the insulation.



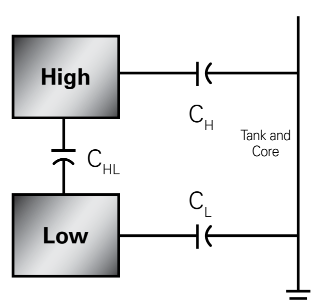
$$\text{Power Factor} = \cos\theta = \frac{Ir}{It}$$

$$\text{Dissipation Factor} = \tan\delta = \frac{Ir}{Ic}$$

Power factor and dissipation factor are used interchangeably when discussing insulation properties.

Power Factor testing examines the insulation in three areas:

- CH - Insulation between high-voltage conductors and grounded tank and core
- CL - Insulation between low-voltage conductors and grounded tank and core
- CHL - Insulation between high- and low-voltage windings



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Rectangular versus circular coils

Power transformers are commonly divided into two classifications based on MVA. These two classifications are:

- Large power - typically 20 MVA and up
- Small power - typically 20 MVA and less

For small power transformers (20 MVA and less), there are two options for building the transformers, circular and rectangular coil designs.

Short circuit forces act on the coils in two directions: axial and radial. Both rectangular and circular coils require added bracing to withstand rated short circuit forces. Axial bracing is used for the circular coil designs. Bracing in the radial direction is used in rectangular coil designs. Figure 1 shows a rectangular coil design which utilizes a core clamp for bracing. Taking a closer look at figure 1 reveals pack out material between each coil, and between the outer coils and the coil clamp. This pack out material is pressboard. The primary role of the pressboard is to shim the coils for mechanical bracing with the coil clamp

Figure 1. Rectangular coils

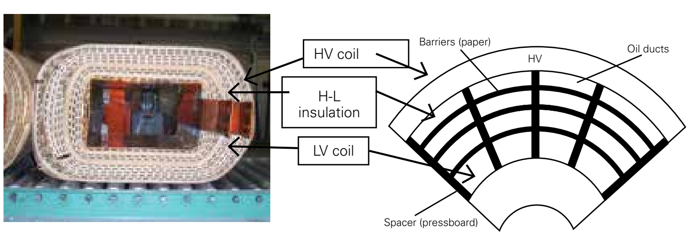

Figure 3. H-L insulation rectangular vs circular

Figure 3 shows a comparison of the two coils and the H-L insulation. Rectangular wound Eaton Cooper Power series transformers have solid, cured, insulation barriers built from multiple layers of "B" stage epoxy-coated insulation. The epoxy coated insulation creates a mechanically strong high-to-low, and winding-to-core barrier.

In circular coil designs, where insulation material constitutes a lesser percentage of the winding barrier, oil is the principal dielectric between windings. Oil has an inherently lower power factor level than insulation paper.

Table 1 below shows typical dissipation factors for various materials. As previously noted, power factor and dissipation factor are often used interchangeably when discussing insulation properties. Dissipation factor (PF) for new mineral oil is 0.05%, natural esters are 0.2% while paper and pressboard are 0.6 %.

Material	%DF (PF) at 20° C
Air	0
Askarels	0.4
Kraft paper, dry	0.6
Mineral oil	0.05
Natural ester fluid	0.2
Porcelain	2
Water	100

Table 1. Dissipation factors (PF)

The main components to the leakage current are moisture and inherent resistance. The additional paper and pack out material present in the rectangular coil design adds both moisture and resistance to the design that is not present in circular coil designs. Even if all the moisture was removed from both designs, there would still be the added resistive component that would drive the PF reading up in the rectangular coil design. The extra paper and pressboard material present in the rectangular coil design will produce a higher PF reading than a circular coil design. The benchmark PF reading for Eaton's Cooper Power series rectangular coil design is 1.5% maximum.

The table below shows acceptable PF readings for 3 different designs

Design type	PF
Oil filled circular coil power transformer	0.5%
FR3 filled circular coil power transformer	1.0%
FR3 filled rectangular coil distribution transformer	1.5%

C57.12.90-2015 IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers confirms there is variability in the PF of the different designs. The standard notes the following:

- Power factor is helpful in assessing the probable condition of the insulation when good judgment is used
- Comparative values of tests taken at periodic intervals are useful in identifying potential problems rather than an absolute value of power factor
- A factory power factor test will be of value for comparison with field power factor measurements to assess the probable condition of insulation. It has not been feasible to establish standard power-factor values for distribution and power liquid-immersed transformers for the following reasons:
    - o Experience has shown that the variation in power factor with temperature is substantial and erratic such that no single correction curve will fit all cases. We report power factor along with the top liquid temperature measured. We do not perform any temperature correction. Temperature correction of the power factor results for trending basis may be applied by the purchaser
    - o The various liquids and insulating materials used in different transformers result in large variations in insulation power-factor values.

ANSI/NETA ATS-2017 Standard for Acceptance Testing Specifications for Electrical Power Equipment and Systems makes a similar statement that maximum winding insulation power-factor/"dissipation-factor values of liquid-filled transformers shall be in accordance with the manufacturer's published data.

Conclusions

The benchmark power factor value for Eaton's Cooper Power series rectangular coil substation and pad-mount distribution transformers base rated at 46 kV, 12 MVA and below is 1.5%. Actual factory power factor results can be used to compare with field measurements with proper temperature correction to assess the condition of the insulation.

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