AC Testing of Dry-Type Distribution and Power Transformers

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Introduction

Dry-type transformers have more and more common, especially with their use at wind farm sites. On smaller dry-type transformers, such as the one shown in Figure 1, not a lot of time and money is spent on their testing and maintenance. Usually, if any testing is done it will be a turns ratio test, insulation resistance test or Polarization Index (PI), especially on units that are less than 167kVA (single-phase) or 500kVA (three-phase). The additional costs associated with performing insulation power factor testing on these smaller units are difficult to justify. However, larger dry-type transformers, especially ones that provide critical power, should be given an insulation power factor test to ensure continued serviceability.

Figure 1
Small Dry-Type Transformer
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Turns Ratio

The turns ratio test, also known as a TTR (transformer turns ratio) is, like most tests, easier to perform now than it used to be. The only TTR available at one time was a single-phase unit that was cranked by hand to produce an output voltage of 8V. The polarity of the connection had to be verified with each winding tested, because the leads would be moved from winding to winding.

Today, these test sets can be three-phase, where connections are made once and the on-board computer (maybe that's a bit too generous) will change the lead positioning internally. These are manufactured by several companies. Figures 2a and 2b show just a couple TTRs that are available.

Figure 2a
Three-Phase TTR
Courtesy Raytech USA

Figure 2b
Single-Phase TTR
Courtesy AEMC Instruments

Whereas the old single-phase TTR would put out 8V and be connected to the low-voltage winding, thus stepping it up. The newer test sets put out 100V and up and are connected to the high-voltage winding. This is inherently safer, as the voltage is being stepped down, instead of up. Another advantage is the test sets will store test results for many, many tests, decreasing the need to complete paperwork immediately.

The TTR test will show the ratio between the primary and secondary windings, not the actual number of turns. As an example, a common transformer will have a 13,800 V primary and a 480V secondary. 13,800V ÷ 480V produces a ratio of 28.75:1. For every turn on the 480V winding, there is 28.75 turns on the 13,800V winding. IEEE Standard C57.91, *Test Code for Dry-Type Distribution and Power Transformers*, allows a 0.5% deviation in the measured ratio and the nameplate ratio.

This test is especially important on newly-installed transformers, as it will verify the ratio and polarity are correct as delivered from the factory. It is uncommon, but I personally witnessed a single-phase 69kV transformer lift off the ground by about an inch when it was connected with the polarity reversed on a transformer that had just been delivered from the manufacturer. After the mess was cleared, it was determined the nameplate data was incorrect, showing the wrong polarity.

Core Excitation Current Test

This test is normally performed with an insulation power factor test set. Voltage is applied to the high-voltage windings, one at a time. The applied voltage will be limited by the test set's power supply, but in no case should the test voltage exceed the line-to-ground voltage of the winding. This test can be a maintenance test, but can be especially useful if the transformer is suspected of being damaged by a through-fault or lightning strike. In the case of a suspected damaged winding, run the test twice, reversing the polarity of the connection. Figure 3 shows the concept on a single-phase winding for clarity.

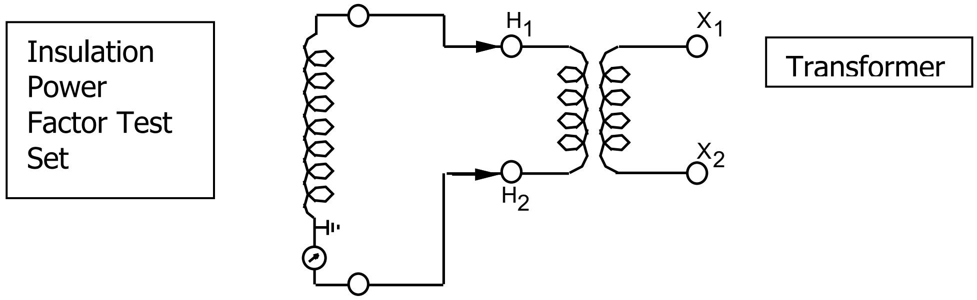


Figure 3
Core Excitation Test Connections on a Single-Phase Transformer

One of two patterns will show up when the test is performed; two higher currents that are similar to each other (normal) and one lower or, on some delta-connected transformers, two lower readings and one higher. The similar readings in both cases should be within 5% of each other.

If the circuit breaker on the test set trips when performing this test it is either caused by a core problem, or the impedance of the transformer is more than the test set can overcome. If this is the case, an ac hipot can be carefully used.

Types of Dry-Type Transformers

There are two general types of dry-type power transformers; ventilated and non-ventilated. A ventilated dry-type transformer is constructed so that ambient air can circulate through the core and windings to cool them. Non-ventilated dry-type transformers are constructed so that no additional cooling is created by ambient air circulation. A transformer is considered to be a power transformer if it is above 500kVA for a three-phase unit or 167kVA for a single-phase unit. If it has windings above 600 volts, it could be considered a power transformer, also.

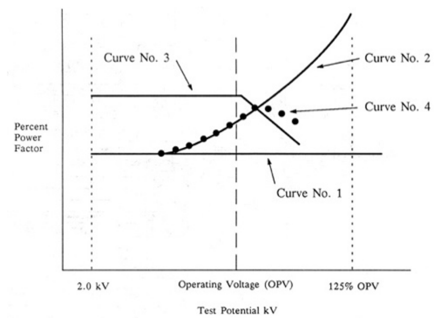
Performing an Insulation Power Factor Test

An insulation power factor test does not provide concrete data. It provides indications of whether or not the insulation is in distress or not. Doble Engineering, in their test data references, note that test results can be well outside the "normal" range and the transformer still be good. There is a lot that goes into the manufacture of transformers and one thing that deviates from the normal supply chain could cause differences that will be seen in the test report. However, in-service transformers should be fairly consistent with their test values.

Applied Voltage and Corona

Corona can be a problem when testing dry-type transformers, so it is recommended that a power factor test be conducted at a lower voltage (something below the corona inception point), and then at the normal test voltage. If the low-voltage test result is satisfactory, then the test can proceed at the normal test voltage. If the power factor increases with an increase in voltage however, corona is indicated. Running the lower-voltage test first will reduce the possibility of corona damage from occurring. The phase-to-ground voltage or the winding voltage should not be exceeded. Because of the corona issues, it is likely that the test voltage will have to be kept lower than the winding voltage.

A transformer's power factor versus voltage characteristics can be helpful in troubleshooting a suspect unit. Increase the voltage in several steps and record the percent power factor on graph paper. A characteristic that is flat (Curve No.1) indicates no appreciable ionization. Power factor tip up, where the percent power factor increases with voltage, (Curve No. 2) indicates the presence of voids or ionization within insulation. If the tip up occurs below the operating voltage, this could spell big trouble in the near future. If a tip down is measured (Curve No. 3), it could indicate a missing core ground or possibly surface moisture. Increasing the voltage could eliminate the tip down by drying the surface. Test voltages up to 125% of the operating voltage can usually be applied to conduct this test. However, many of our customers will not allow us to apply more than rated voltage to any winding.



Curve #1 – Flat characteristics
Curve #2 – Power factor tip up
Curve #3 – Power factor tip down
Curve #4 – Combining curves #2 and #3

Figure 3
Power Factor vs. Voltage Characteristic Curve
Courtesy Doble Engineering

The Effects of Temperature

Although temperature can affect the power factors of dry-type transformers, there are too many variables with the insulation to assemble a standard temperature correction chart. Since the major insulation component is air, the temperature characteristic curve should be fairly flat. As with all tested devices, if the test results are questionable at high temperatures, allow the unit to cool and retest when its temperature is closer to 20^0C.

Test Results Analysis

The best possible evaluation of insulation power factor test results is by comparing them to the base line results of the specific unit. Base line tests are performed when the unit is first installed using the same (or similar) field test equipment under the same conditions that the tests will be performed in the future. Sometimes there are no base line results available, so the results can be compared to like units tested under similar conditions or with factory test data, if available. Some manufacturers do not perform a power factor test as a standard test, but will do it if it is requested.

Capacitance

Capacitance should be recorded whenever a power factor test is performed. If the capacitance changes, it would indicate deterioration of the insulation or possibly winding movement.

Acceptable Insulation Power Factors for Ventilated Dry-Type (Power and Distribution)

C_{HL} (High-to-Low)	2.0%	84% of reported units
C_L (Low-to-Ground)	4.0%	75% of reported units
C_H (High-to-Ground)	3.0%	85% of reported units

Note that these power factors are based on the majority of the units tested falling at or below the recommended percent power factors listed. It is possible that a transformer could exceed these values and still be serviceable. A transformer that exceeded these values would be marked as needing further investigation to determine why the insulation power factor was higher. In tabulating these results, Doble excluded "high contributors". A transformer was considered to be a high contributor if its results caused the average to be increased significantly. All results are for service-aged transformers.

Epoxy-Encapsulated Type (Power)

C_{HL}	1.0%	96% of reported units
C_L	2.0%	90% of reported units
C_H	3.0%	not reported

The above encapsulated type transformer recommendations are for power transformers. One owner commented that 83% of the reported distribution transformers were from one manufacturer and had C_L power factors of nearly 8%.

Winding Temperature Indicators

Test results may be affected by RTD's imbedded in the winding (winding temperature indicators). If the C_{HL} results are higher than anticipated or are negative, the ground lead from the RTD should be disconnected and the unit retested.

ANSI/NETA Recommendations[(2)]

ANSI/NETA standard MTS (Maintenance Testing Specifications) does not have recommendations for the insulation power factor of dry-type transformers.

Problems to Expect

Shermco Industries will test and evaluate dozens of these types of transformers each month. In polling the field service technicians, their experience is summarized concerning dry-type transformers. We encounter three primary types of transformers (based on their primary insulation):

- NOMEX
- Mica
- Epoxy cast coil

The majority of the units tested are the NOMEX insulated type. The Mica insulated ventilated transformers are approximately 6% of the total. With the NOMEX insulated transformers typically have less than 5% power factor, with most units testing between 2 to 3%. Mica insulated transformers can have considerably higher power factors, especially if they have been in a high humidity area and de-energized. In high-humidity areas where the transformer is off-line, initial power factors of up to 20% can be measured. Drying the transformer using heaters can reduce this to 5% or less. Epoxy cast coil transformers generally test well, with most being in line with the Doble recommendations.

Some smaller transformers (and fewer larger ones) may have an electrostatic shield between the high- and low-voltage windings. On transformers with this shield, the C_{HL} test cannot be performed, as the shield is grounded. The tests are limited to performing the C_H and C_L tests. This shield also has caused problems when performing a TTR test using some digital ratiometers, but not when an analog TTR is used.

The capillary tubes used for RTD's can also be a problem with dry-type transformers. If they are held in place by anything but a high-temperature cable tie, there often is a problem. In at least five cases reported to me recently there has been transformer failures due to this tube falling onto the winding and causing a short, as the capillary tubes were held in place with standard nylon cable ties. There have been many more cases where the cable tie was clearly close to failure. Best practice is to replace all cable ties with clamps, eliminating the problem.

Potential insulation power factor problems can be caused by dirt building up between the high- and low-winding at the insulating blocks separating the windings from the frame bottom. The insulation power factor often can be reduced by 50% by a thorough cleaning at this point, Figure 4. Another potential problem is that the leads going from the transformer to the line-side of the switch are often twisted to the extent that they have inadequate clearance between cables. This can cause higher than expected percent power factor readings, and can cause problems when performing an excitation test (getting the leads mixed up).

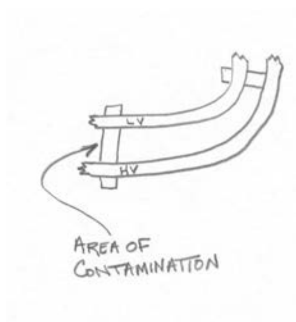


Figure 4
Area of Contamination on Dry-Type Transformers
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Lastly, a good number of transformers have been found with the shipping bolts still in place and secured. This causes high noise and vibration in the unit. Leaving the bolts in place, but loosening them eliminates the noise and vibration while protecting the core from shifting if it ever needs to be relocated.

Summary

AC testing is recommended on large (over 500kVA) transformers to ensure insulation, core integrity and correct ratio and polarity of the winding. AC tests should be considered for dry-type transformers that are power type or feed critical loads. Although there are general recommendations, there have not been an adequate number of test results on a broad sampling to verify the effects of temperature on insulation or to provide definitive values for smaller encapsulated type units. Most of these smaller units are probably adequately tested using megohmmeters and performing PI and/or insulation resistance tests. For larger units, ac tests can provide good insulation grading and help detect any deficiencies, which may affect reliability. The value of the test increases as the size and criticality of the transformer increases.

References

1. "*Power Factor Testing of Dry-Type Power and Distribution Transformers*", E. J. Maritolli and R. Levi, Doble Engineering Company
2. ANSI/NETA MTS-2019, "*Standard for Maintenance Testing Specifications for Electrical Power Equipment and Systems*"