Three Tips for Reducing Wasted Time When Testing Transformers

Brandon Dupuis
OMICRON electronics Corp. USA
brandon.dupuis@omicronenergy.com

Performing offline electrical tests on transformers can be time-consuming, especially when the field measurements are not captured correctly the first time. This article identifies the electrical transformer tests that test equipment users often struggle to perform efficiently and correctly. Three field testing tips will be provided, to address the transformer tests that are often "time-suckers". By building awareness, test equipment users can better avoid the situations where a significant amount of time is lost due to retesting, troubleshooting, and collaborating with test equipment manufacturers.

1 Review the "Power Factor Checklist" Prior to Testing

Without a doubt, the transformer test that customers most struggle with is the transformer Power Factor test (which includes the Overall test, the Bushing C1 test, and the Bushing C2 test). Unfortunately, the Power Factor test is highly sensitive to the test environment, to the test lead connections, and to the test specimen's earth-ground connection, among other things. Since the Power Factor measurement is highly sensitive, obtaining the correct (that is, the valid) Power Factor measurements in the field is challenging.

The high sensitivity of the Power Factor test is a double-edged sword: on one hand, the high sensitivity makes the Power Factor test a powerful tool for identifying compromised insulation (for example, moisture ingress, contaminated oil, a "bad bushing", etc.). On the other hand, the high sensitivity makes the Power Factor test prone to measurement error.

To prevent wasted time from retesting, troubleshooting, and collaborating with test equipment manufacturers, the following "Power Factor Checklist" should always be reviewed, prior to executing any Power Factor measurement.

- **Are the transformer tanks and the test equipment solidly grounded to earth-ground potential?** Not connecting the test specimen and the test equipment to a solid earth-ground reference is the most common mistake test equipment users make in the field.

- **Are the bushing terminals of the transformer completely disconnected and isolated from all cable, busbar, support insulators, surge arrestors, etc.?**
  When applying a test voltage of 10kV, a minimum clearance of 3 inches should be established (between the terminal(s) that is energized and all other surfaces). Avoid using a rubber blanket, insulated gloves, etc. to isolate the bushing terminals from external surfaces – the best insulator for Power Factor testing is air!

- **Are the surfaces of the bushings dry (and reasonably clean)?**
  Moisture on the surfaces of the bushings can significantly influence a Power Factor measurement. In most cases, using a clean, dry rag to dry the surfaces of the bushings is sufficient. In cases where excessive surface contamination on the bushing surfaces is present, Windex or Collinite may be used to clean the surfaces of the bushings, and thus, may improve the Power Factor measurements.

- **Are the groups of bushing terminals short-circuited together? All primary side (H) bushing terminals must be shorted together, and all secondary side (X) bushing terminals must be shorted together.**
  Always use NON-insulated conductor(s) to short-circuit the bushing terminals together when performing a Power Factor measurement – Do NOT use insulated shorting leads. If insulated conductor(s) are used, then the conductor's insulation can easily become part of the Power Factor insulation measurement. Also, connect the shorting jumpers as tightly as possible from bushing terminal to bushing terminal (in other words, do not let the shorting jumpers sag and/or touch any surface other than the terminal being energized).

- **Remove all in-service grounds from any neutral bushing terminals**
  For example, remove the in-service ground connection from the X0 bushing terminal, if applicable.

- **Place the LTC in any off-neutral tap position**
  Some transformer Load Tap Changers (LTCs) utilize a "tie-in resistor", which has been known to influence the Power Factor measurements, when the transformer is tested in the Neutral tap position. Specifically, Federal Pioneer Electric and Federal Pacific Electric transformers with LTCs have been known to exhibit this behavior.

- **Ensure that the exterior surface of the test equipment's high-voltage cable is not touching any surface of the transformer, at the "far end" where the test-terminal is being energized**
  A conservative approach is to ensure that the last two feet of the far end of the test equipment's high-voltage cable is not touching the transformer tank, the surfaces of the bushings, etc.

- **Be aware that the test environment can significantly influence a Power Factor measurement**
  - Do not Power Factor test in the rain.
  - Avoid testing in high-humidity situations (where excessive moisture is present).
  - Avoid Power Factor testing when the temperature of the transformer oil is below 0°C.
  - Power Factor test after lunch, if possible (which is typically when the least amount of moisture/humidity is present).

The Power Factor Checklist is intended to help test equipment users "get the measurement right first time", which is the most practical strategy to saving wasted time when testing transformers. In conjunction with the Power Factor Checklist, the Variable Frequency Power Factor test can be utilized by test equipment users, to quickly and easily *confirm* that the Power Factor measurements obtained are indeed correct.

2 Identify Incorrect Power Factor Measurements *Before Leaving the Job Site*

One of the most common scenarios we encounter as a test equipment manufacturer is when a customer contacts us to review a set of power transformer test results. Often, the data set is provided *after* the test equipment user has left the job site and returned to the office. Upon reviewing the data, we (OMICRON) frequently identify incorrect Power Factor measurements and recommend that the customer retest in order to obtain the correct results.

Regardless of whether the transformer is still offline or has been re-energized, once this scenario occurs a significant amount of a company's time and resources are/have been wasted. If the crew returns to the field to retest, then time and resources are wasted testing a second time.

If the transformer has already been re-energized, then the company has invested time and resources to obtain invalid test results that cannot be used to assess the condition of the transformer.

To quickly identify and correct “bad” Power Factor measurements *before they leave the job site with the incorrect test results*, test equipment users can utilize the Variable Frequency Power Factor measurement. With a Power Factor measurement at one test voltage and at one test frequency (in other words, with one Power Factor percentage value), it is difficult for the test equipment user to verify that the measurement is even valid; however, invalid measurements often become obvious when the Variable Frequency Power Factor measurement is performed and analyzed.

The Variable Frequency Power Factor test involves performing Power Factor measurements at a series of different test frequencies (for example, 15Hz, 30Hz, 45Hz, 60Hz, 150Hz, 200Hz, 300Hz, and 400Hz). The general guidelines used to assess the Variable Frequency Power Factor test (along with several case studies) are provided in the OMICRON paper titled, “The Value of Performing Power Factor Sweep Measurements on Bushings”.

Consider the bushing C1 Power Factor measurements shown in Figure 1, which were obtained from testing three Lapp POC 138kV bushings. By only analyzing the 10kV-60Hz Power Factor values, it is not obvious that the Power Factor measurements are incorrect; however, notice that the Variable Frequency Power Factor traces for the three bushings are erratic and jagged. In general, jagged frequency sweep traces are indicative of invalid Power Factor measurements. In this case, the customer determined that they did not short-circuit the primary side (H) bushing terminals of the transformer, when the C1 Power Factor measurements were performed on the bushings.

Case Study - Lapp POC 138kV Bushings (1998), Measured Power Factor (10kV-60Hz), Nameplate Power Factor (10kV-60Hz), Variable Frequency Power Factor Traces, Power Factor, Frequency

Case Study - Lapp POC 138kV Bushings (1998)		
	Measured Power Factor (10kV-60Hz)	**Nameplate Power Factor (10kV-60Hz)**
H1	0.36%	0.29%
H2	0.24%	0.23%
H3	0.35%	0.23%

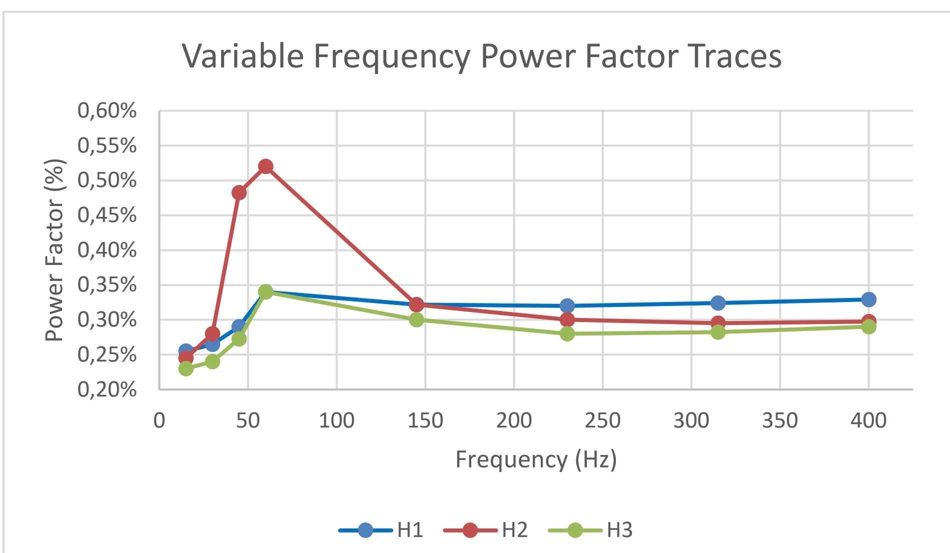

Figure 1 - Variable Frequency Power Factor Results for Three Lapp POC 138kV Bushings

Consider the Overall Power Factor measurements shown in Figure 2, which were performed on a Kuhlman 118kV oil-filled transformer. The 10kV-60Hz Power Factor measurements look “normal” for an oil-filled transformer, but upon reviewing the Variable Frequency Power Factor traces, the customer noticed that the CH frequency sweep trace looked abnormal. Notice that as the test frequency increases, the CH trace approaches 0% Power Factor, and even becomes negative. Negative Power Factor measurements are typically a tell-tale sign of an invalid measurement.

If the test equipment user only had the 10kV-60Hz Power Factor measurements on-hand, then it is conceivable that they would have overlooked the incorrect measurement. In this case, the customer determined that the transformer tank and the test equipment were not connected to a solid earth-ground reference potential.

Overall Power Factor Measurements - Kuhlman 118kV transformer, Measured Power Factor (10kV-60Hz)

Overall Power Factor Measurements - Kuhlman 118kV transformer	
	Measured Power Factor (10kV-60Hz)
CH	0.16%
CHL	0.22%

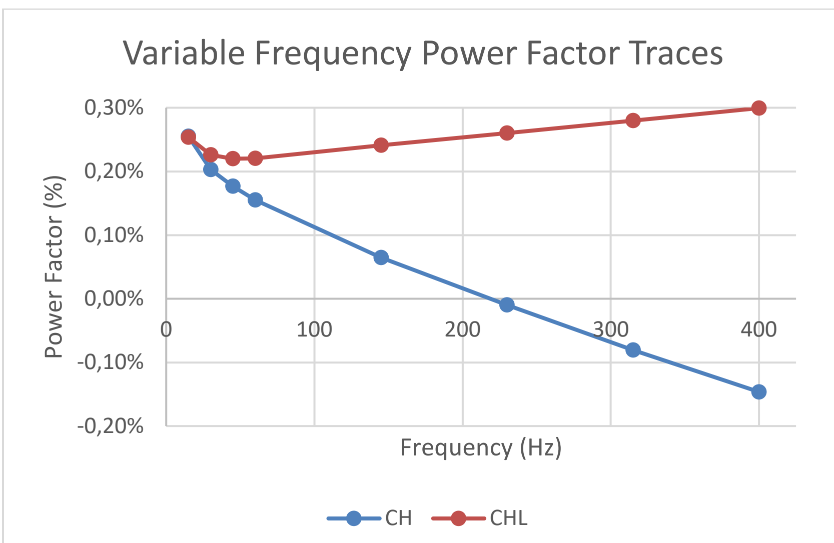

Figure 2 - Variable Frequency Power Factor Results for a Kuhlman 118kV transformer

With the Variable Frequency Power Factor traces on-hand, test equipment users can quickly identify invalid measurements, and can retest *before they leave the job-site with the incorrect test results*.

3 Select the Appropriate Test Current - DC Winding Resistance

The field transformer test that test equipment users most struggle with (other than the Power Factor test) is the DC Winding Resistance test. The DC Winding Resistance test is the offline measurement for identifying bad connections and discontinuities along the current carrying path of a transformer winding [2]. Specifically, the DC Winding Resistance test is an invaluable tool for identifying bad connections associated with tap-changers, which includes both De-Energized Tap Changers (DETCs) and Load Tap Changers (LTCs).

In theory, the DC Winding Resistance test is a simple concept that relies on the fundamental application of Ohm's Law (V = I x R) [2]; however, in practice, obtaining the correct transformer resistance measurements is challenging, because to obtain the correct measurements, the transformer's core must be saturated. The most common mistake that test equipment users make when performing the DC Winding Resistance test, is not waiting long enough for the core to fully saturate (in other words, the resistance measurements are captured “too soon”). Typically, when the resistance measurements are captured “too soon”, the measured resistance values are higher than expected, which makes it appear that there is a bad connection, even when no fault exists.

The best strategy for saturating the transformer core quickly, and in turn, obtaining the correct resistance measurements quickly, is to inject as high a DC current as possible into the winding under test. The higher the injected test current, the faster the transformer core saturates, the faster the test is performed. The following guidelines are intended to assist test equipment users with selecting the appropriate test current for a given winding resistance measurement.

- The lower the resistance of the winding under test, the higher the test current should be.
- Typically, when testing winding resistances greater than 100mΩ, a test current in the range of 5-10A is sufficient – most resistance measurements performed on the primary side (H) winding of a transformer have resistance values greater than 100mΩ.
- Typically, when testing winding resistances less than 100mΩ, a test current in the range of 20-30A is ideal – most resistance measurements performed on the secondary side (X) winding of a transformer have resistance values less than 100mΩ.
- Load Tap Changers (LTCs) in North America are most often applied to the secondary side (X) winding of a transformer. In cases where the LTC is located on the secondary side, a test equipment user often has anywhere from 57-99 resistance measurements to obtain (that are often well below 100mΩ in magnitude). In these cases, it is important that a sizeable test current (for example, 20-30A) is available to the test equipment user, so that they may perform the lengthy test sequence as quickly, and accurately, as possible.
- The test current should not exceed 10% of the rating of the winding under test.
- The test current multiplied by the resistance (of the winding under test) should not exceed the maximum compliance voltage rating of the test instrument’s DC current source – In general, the more power (VA) the test instrument’s DC current source is rated for, the higher the test current that can be injected into a given winding, the faster the DC Winding Resistance test can be performed.

To summarize, test equipment users often attempt to apply the same magnitude of test current for both the DC Winding Resistance H and DC Winding Resistance X tests; however, since the magnitude of winding resistance is often significantly different when comparing the DC Winding Resistance H and DC Winding Resistance X tests, it is conceivable that two different test currents (one for the primary side test, and one for the secondary side test) should be applied when performing both tests. The most common mistake made is NOT injecting enough current when performing the DC Winding Resistance X test, which often leads to a lengthier core saturation time, and inaccurate measurements (especially when an LTC is involved).

Again, the best way to reduce wasted time when testing transformers, is to get the measurement right first time.

4 References

[1] B. Dupuis, „The Value of Performing Power Factor Sweep Measurements on Bushings“

- Transformer Technology Magazine - The Value of Power Factor Sweep Measurements - April 2019
- NETA World Magazine Spring 2019 - The Value of Performing Power Factor Sweep Measurements

[2] C. L. Sweetser, „Obstacles Associated with Winding Resistance Measurements of Power Transformers“ NETA Powertest Conference 2013

Biography

Brandon Dupuis received a B.S. Electrical Engineering degree from the University of Maine. He joined OMICRON electronics Corp, in 2013, where he presently holds the position of Regional

Application Specialist for transformer testing. Brandon’s focus is currently on standard and advanced electrical diagnostics for power transformers and circuit breakers for the North American region. Presently, Brandon is a well-known OMICRON instructor teaching electrical transformer diagnostic testing theory, application, and test result analysis, which includes both presentations and hands-on training. Brandon is an active member of the IEEE/PES Transformers Committee.

OMICRON is an international company serving the electrical power industry with innovative testing and diagnostic solutions. The application of OMICRON products allows users to assess the condition of the primary and secondary equipment on their systems with complete confidence. Services offered in the area of consulting, commissioning, testing, diagnosis and training make the product range complete.

Customers in more than 160 countries rely on the company's ability to supply leading-edge technology of excellent quality. Service centers on all continents provide a broad base of knowledge and extraordinary customer support. All of this together with our strong network of sales partners is what has made our company a market leader in the electrical power industry.

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