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Application guide for power factor testing of power & distribution transformers

Introduction

The transformer is probably one of the most useful electrical devices ever invented. It can raise or lower the voltage or current in an ac circuit, it can isolate circuits from each other, and it can increase or decrease the apparent value of a capacitor, an inductor, or a resistor. Furthermore, the transformer enables us to transmit electrical energy over great distances and to distribute it safely in factories and homes.

Transformers are extensively used in electric power systems to transfer power by electromagnetic induction between circuits at the same frequency, usually with changed values of voltage and current.

Power factor testing is an effective method to detect and help isolate conditions such as moisture, carbonization, contamination in bushings, windings and liquid insulation. In addition to power factor testing, transformer excitation current measurements will help detect winding and core problems.

Definitions

Step-Down Transformer: A transformer in which the power transfer is from the higher voltage source circuit to a lower voltage circuit.

Step-Up transformer: A transformer in which the power transfer is from the lower voltage source circuit to a higher voltage circuit.

Autotransformer: A transformer in which at least two windings have a common section.

Load-Tap-Changing Transformer: A transformer used to vary the voltage, or phase angle, or both, or a regulated circuit in steps by means of a device that connects different taps of tapped winding(s) without interrupting the load.

Excitation Current (No-Load Current): The current which flows in any winding used to excite the transformer when all other windings are open-circuited.

Tap (in a transformer): A connection brought out of a winding at some point between its extremities, to permit changing the voltage, or current, ratio.

Delta Connection: So connected that the windings of a three-phase transformer (or the windings for the same rated voltage of single-phase transformers associated in a three- phase bank) are connected in series to form a closed circuit.

Y (or Wye) Connection: So connected that one end of each of the windings of a polyphase transformer (or of each of the windings for the same rated voltage of single-phase transformers associated in a polyphase bank) is connected to a common point (the neutral point) and other end to its appropriate line terminal.

Zigzag Connection: A polyphase transformer with Y-connected windings, each one of which is made up of parts in which phase-displaced voltages are induced.

Tertiary Winding: The third winding of the transformer and often provides the substation service voltage, or in the case of a wye-wye connected transformer, it prevents severe distortion of the line-to-neutral voltages.

The following equipment and tests will be discussed in this guide:

1. Two-Winding Transformers
2. Three-Winding Transformers
3. Autotransformer
4. Transformer Excitation Current Tests
5. Shunt Reactors
6. Potential Transformers
7. Current Transformers
8. Voltage Regulators
9. Dry-Type Transformers

Two-Winding Transformers

Test Connections

For all transformer testing, including spare transformers, ensure the following safety conditions are observed:

- The transformer must be taken out of service and isolated from the power system.
- Ensure the transformer is properly grounded to the system ground.
- Before applying any voltage on the transformer make sure that all bushing current transformers are shorted out.
- Never perform electrical tests of any kind on a unit under vacuum. Flashovers can occur at voltages as low as 250 volts.
- If the transformer is equipped with a load tap changer, set the unit to some step off of neutral. Some load tap changers are designed with arrester type elements that are not effectively shorted out in the neutral position even with all the bushings shorted.
- Connect a ground wire from the test set to the transformer ground.
- Short all bushings of each winding including the neutral of a wye-connected winding. The neutral ground must also be removed. The shorting wire must not be allowed to sag.
- Refer to section 3, Table 3 in the Delta 2000 manual for test connections and the insulation tested.
- Connect the high voltage lead to the high side bushings for tests 1, 2, and 3. Ensure that the high voltage cable extends out away from the bushing.
- Connect the low voltage lead to the low voltage bushings.
- For tests 5, 6 and 7, connect the high voltage lead from the test set to the low voltage bushings of the transformer and the low voltage lead from the test set to the high voltage bushings. (Note) Test 5, 6 and 7 normally are not conducted unless there appears to be a problem with tests results obtained in tests 1. 2 and 3.
- Individual tests should be performed on each bushing. Bushings equipped with a potential/test tap should have the UST test performed and the GST hot collar test on those without test taps. Transformer windings must remain shorted for all bushing tests. Refer to the APPLICATION GUIDE FOR POWER FACTOR TESTING OF BUSHINGS.
- For transformers that have wye-wye configuration, and the neutrals internally cannot be separated, short the high voltage bushings and the low voltage bushings together and perform a GST test. Test voltage should be suitable for the rating of the low voltage winding.

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Test Procedure

For all power factor testing, the more information you record at the time of testing will ensure the best comparison of results at the next routine test. Test data should be compared to the nameplate data. If nameplate or factory readings are not available, compare the results of prior tests on the same transformer or results of similar tests on similar transformers. If at all possible, power factor and capacitance readings should be taken on new transformers. Field measurements of power-factor and capacitance can differ from measurements made under the controlled conditions in the factory. Therefore, the power-factor and capacitance should be measured at the time of installation and used as a base to compare future measurements. Power factor testing is extremely sensitive to weather conditions. Tests should be conducted in favorable conditions whenever possible. All tests are performed at 2.5kV or 10kV. If these values exceed the rating of the winding, test at or slightly below the rating.

- Follow the test sequence of the Two-Winding Transformers Test Connections in Section 3 Table 3 of the Delta 2000 manual. Tests 1, 2 and 3 can be completed without a lead change. Record the results.
- Test 4 is a calculation subtracting the capacitance and watts results in test 2 from test 1. The results should compare with the UST measurement for the C_{HL} insulation
- Reverse the test leads for tests 5, 6 and 7. Test voltage should be at a level suitable for the secondary winding of the transformer. Record the results.
- Test 8 is a calculation by subtracting test 6 from test 5. Results should compare with the UST measurement in test 7 for the C_{HL} insulation.
- Record all the nameplate information of the transformer.
- Note any special or unusual test connections or conditions.
- Record ambient temperature and relative humidity and a general indication of weather conditions at the time of the test.
- Record actual test voltage, current, watts, power factor and capacitance. Correct current and watts to a standard test voltage such as 2.5kV or 10kV.
- Correct the power factor readings of the transformer to 20^0 C from the top oil temperature. (Refer to the chart for Temperature Correction Factors for Liquids, Transformers, and Regulators, Appendix D in the Delta 2000 manual).
- Identify each set of readings of the transformer bushings with a serial number. Record manufacture, type or model and other nameplate ratings. Especially be aware to record nameplate C_1 capacitance and power factor values if available. Correct the power factor readings on the bushings to 20^0 C using the ambient temperature. (Refer to the chart for Bushing Temperature Correction Factors in Appendix D in the Delta 2000 manual).

Test Results

Power factor results should always be compared to manufacturers' tests, or to prior test results if available. It is impossible to set maximum power factor limits within which all transformers are acceptable, but units with readings above 1% at 20^0C should be investigated. Bushings, if in poor condition, may have their losses masked by normal losses in the winding insulation Therefore, separate tests should be applied to them.

Increased power factor values, in comparison with a previous test or tests on identical apparatus, may indicate some general condition such as contaminated oil. An increase in both power factor and capacitance indicates that contamination is likely to be water. When the insulating liquid is being filtered or otherwise treated,

repeated measurements on windings and liquid will usually show whether good general conditions are being restored.
Oil oxidation and consequent sludging conditions have a marked effect on the power factors of transformer windings. After such a condition has been remedied, (flushing down or other treatment) power factor measurements are valuable in determining if the sludge removal has been effective.

Measurements on individual windings may vary due to differences in insulation materials and arrangements. However, large differences may indicate localized deterioration or damage.

Careful consideration of the measurements on different combinations of windings should show in which particular path the trouble lies; for example, if a measurement between two windings has a high power factor, and the measurements between each winding and ground, with the remaining winding guarded, gives a normal reading, then the trouble lies between the windings, perhaps in an insulating cylinder.

Three-Winding Transformers

Testing of three-winding transformers is performed in the same manor as two-winding transformers with the additional tests of the tertiary winding.

In some cases transformers are constructed so that the interwindings are shielded by a grounded electrostatic shield or a concentric-winding arrangement. This could provide test results that capacitance is almost non-existent or even a negative power factor. The transformer manufacturer should be contacted to verify the existence of a shield or a concentric-winding arrangement.

Refer to the Three-Winding Transformer Test Connections in Section 3 Table 4 of the Delta 2000 manual.

Autotransformers

In the design of an autotransformer, the secondary winding is actually part of the primary winding. For a given power output, an autotransformer is smaller and cheaper than a conventional transformer. This is particularly true if the ratio of the incoming line voltage to outgoing line voltage lies between 0.5 and 2. Generally all three-phase autotransformers have a tertiary winding.

To power factor test the autotransformer, both primary and secondary bushings are shorted together and the tertiary bushings are shorted to each other. The autotransformer is then tested as a two winding transformer. Individual tests should be performed on each bushing if they are equipped with a test tap.

Transformer Excitation Current Tests

Transformer excitation current tests are helpful in determining possible winding or core problems in transformers, even when ratio and winding resistance tests appear normal. Excitation tests should be conducted routinely along with power factor testing.

Test Connections

- Transformer excitation current tests are performed on the high voltage winding to minimize the excitation current. Problems in the low voltage windings will still be detected by this method.
- The secondary windings are left floating with the exception of a wye secondary. In this case the X0 bushing remains grounded as it is in normal service.

- Refer to Section 3 Table 5 for test connections for Single Phase, Three Phase High Side Wye and Three Phase High Side Delta transformers.
- Single Phase: The transformer is energized from the H1-H2 bushings. Test connections can be reversed for additional data, but test results should be the same. H2 may also be designated as H0.
- Wye – Wye: Observe that the ground wire is removed from the H0 bushing for testing, but remains connected on the X0 bushing.

Test Procedure

- Test voltages should be as high as possible without exceeding the rating of the line-to-line voltages on delta connected transformers and line-to-ground on wye connected transformers.
- Test voltage should always be the same as prior tests.
- All transformer excitation current tests are conducted in the UST test mode.
- For routine testing, transformers with load tap changers should have tests performed in at least one raise and one lower position off of neutral. The no-load tap changer should be in the normal in service position.
- For new transformers, excitation tests should be performed in every tap position for both the load and no-load tap changers.
- The more information that is recorded at the time of testing will ensure the best comparison of results at the next routine test.
- Record test voltage and current. Corrections are not applied to transformer excitation current tests.

Test Results

Compare test results to previous tests on the same transformer, or to manufacturers' data if available. Tests can also be compared to similar type units. It is essential that identical test voltages be used for repeat tests on a transformer. Fluctuation in the test voltage will produce inconsistent current readings. Three phase transformers should have the individual windings energized at both ends if the original test appears abnormal. Transformer excitation current tests on the high voltage winding should detect problems in the secondary winding if they exist. Winding resistance testing in addition to the excitation tests could be helpful in isolating either a core or winding defect.

Test results on three phase transformers, especially wye-connected windings, could produce high but similar readings on two phases compared to the third phase. This is the result of the low phase being wound around the center leg of a three-legged core. The reluctance of the magnetic circuit is less for the center leg of the core resulting in a lower charging current.

Shunt Reactors

When electrical energy is transmitted at extra high voltages, special problems arise that require the installation of large compensating devices to regulate the over-voltage conditions and to guarantee stability. Among these devices are shunt reactors. Shunt reactors are composed of a large coil placed inside a tank and immersed in oil. They can be single phase units or three phases in one tank. In both cases each phase has its own neutral bushing.

Test Connections

- For all tests, the line and neutral bushings for corresponding phases must remain shorted.

Test Procedure

- Record test results on the test form for Miscellaneous Equipment Capacitance and Power Factor Tests, located in Appendix C in the Delta 2000 manual.
- Test voltages are at 10kV. If 10kV exceeds the insulation rating, test at or slightly below the insulation rating.
- For single phase units only one overall ground test is performed in the UST mode.

Test Results

Power factor and capacitance results should be recorded in the same manner as for oil filled power transformers. Temperature correction should be to the top oil temperature. Compare test results to previous tests or tests on similar units. Additional bushing tests should be performed if test results are suspect.

Potential Transformers

Potential transformers are installed on power systems for the purpose of stepping down the voltage for the operation of instruments such as voltmeters, wattmeters and relays for various protective purposes. Typically the secondary voltage of potential transformers is 120 volts, so power factor testing is performed on the primary winding.

Potential transformers are typically single phase with either single or two bushing primaries. Single bushing primaries have one end of the high voltage winding connected to ground. Secondary windings are normally three wire and dual identical secondary windings are common.

Test Connections

- Ensure that the potential transformer is disconnected from the primary source before testing begins.
- Remove any fusing on the secondary circuits to prevent any type of back-feeding to the secondary.
- Ground one leg of each secondary winding for all tests on two primary bushing transformers, for dual secondary transformers it is typically X1 and Y1.
- Ensure that the case of the potential transformer is securely grounded to a system ground before testing begins, this also includes testing of spare transformers.

Test Procedure

- Ensure the test set is securely grounded.
- Record all tests results. Power factor tests should be corrected to ambient temperature.
- Compare test results to prior tests on the same or similar equipment.

Current Transformers

Current transformers are used for stepping down primary current for ammeters, wattmeters and for relaying. Typical secondary current rating is 5 amperes.

Current transformers have ratings for high voltage and extra high voltage application. The higher voltage classifications can be oiled filled, dry type or porcelain construction. Current transformers that are donut or window type are normally not tested for power factor.

Tests on two bushing primary currents transformers are performed by shorting the primary winding, grounding all secondary windings and test in the GST mode. Some current transformers in the high voltage classifications have test taps similar to bushings. Tests can be performed on units equipped with a test tap for the C_1 insulation and the C_2 tap insulation. Refer to the application guide for Bushing Testing.

Assure that the unit under test is grounded before testing. Record all test results and correct the power factor readings to the ambient temperature at the time of the test.

Voltage Regulators

Regulators are generally induction or step-by- step. The induction regulator is a special type of transformer, built like an induction motor with a coil-wound secondary, which is used for varying the voltage delivered to a synchronous converter or an ac feeder system.
The step-by-step regulator is a stationary transformer provided with a large number of secondary taps and equipped with a switching mechanism for joining any desired pair of these taps to the delivery circuit.

Voltage regulators may be single or three phase. Single phase regulators consists of three bushings identified as S (Source), L (Load) and SL (Neutral). The windings in the regulator cannot be effectively separated, so one overall power factor test is performed. All the bushings are shorted together and tested in the GST test mode. Tests should be conducted with the tap changer moved to some position off of neutral. Additional Hot Collar tests may be conducted on bushings of suspect units.

Excitation tests may also be performed by energizing terminal L with the high voltage lead and the low voltage lead on SL in the UST position. Terminal S should be left floating.

Power factor results should be corrected to top oil temperature on regulators just taken out of service. Ambient temperature should be used for those that have been out of service for any length of time. Power factor results should be compare to previous tests on the same equipment or similar tests on similar units.

Dry-Type Transformers

Testing Notes

Test voltages should be limited to line-to-ground ratings of the transformer windings. Insulation power factor tests should be made from windings to ground and between windings.

Temperature at the time of testing should be at or near 20^0C. ANSI/IEEE C57.12.91 - 1997 recommends correcting results other than 20^0C. However, there is very little data available for temperature correction of dry-type transformers. Repeat tests should be performed as near as possible, in the same conditions as the original test.

Higher overall power factor results may be expected on dry-type transformers. The majority of test results for PF is found to be below 2.0%, but can range up to 10%. The insulation materials necessary for dry-type construction, must meet the thermal and stress requirements.

If power factor results appear to be unacceptable, an additional test called a Tip-Up Test can be performed if a 10kV test set is used. This test can be performed to evaluate whether moisture or corona is present in the insulation system. The applied test voltage is varied starting at about 1kV and increased in intervals up to 10 kV or the line-to-ground rating of the winding insulation. If the power factor does not change as the test voltage is increased, moisture is suspected to be the probable cause. If the power factor increases as the voltage is increased, carbonization of the insulation or ionization of voids is the cause.

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