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A Guide to Transformer Winding Resistance Measurements

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Abstract: Measuring a transformer's DC resistance from one external terminal to another can reveal a great deal of information about the transformer. In addition to the obvious faulted winding (i.e., an open winding or shorted turn), more subtle problems can be detected. The DC current, in addition to flowing through the winding, must also flow through the off-load ratio adjusting switch (RA switch), the on-load ratio adjusting switch (load tap changer or LTC), as well as numerous welded and mechanical connections. Hence, the integrity of all these components can be verified.

Authors note: Specific aspects of safety are addressed herein; however comprehensive procedures are not detailed. It is assumed the operator has sufficient knowledge of electrical theory and safe working practices to use the test instrument in a safe and responsible manner.

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1 Introduction

1.1 General

This application note is focusing on using winding resistance measurements (WRM) for diagnostic purposes. The intention of this reference manual – application guide is to guide the operator in the appropriate method of making winding resistance measurements on power transformers and assist in the interpretation of test results obtained. It is not a complete step-by-step procedure for performing tests and is not replacing the user manual for the actual instrument. Before performing any test with an instrument, read the user manual and observe all safety precautions indicated.

1.2 Winding resistance measurements (WRM)

Winding resistance measurements in transformers are of fundamental importance for the following purposes:

- Calculations of the I2R component of conductor losses.
- Calculation of winding temperature at the end of a temperature test cycle.
- As a diagnostic tool for assessing possible damage in the field.

Transformers are subject to vibration. Problems or faults occur due to poor design, assembly, handling, poor environments, overloading or poor maintenance. Measuring the resistance of the windings assures that the connections are correct and the resistance measurements indicate that there are no severe mismatches or opens. Many transformers have taps built into them. These taps allow the ratio to be increased or decreased by fractions of a percent. If any of the ratio changes involve a mechanical movement of a contact from one position to another, these tap changes should also be checked during a winding resistance test.

Regardless of the configuration, either star or delta, the measurements are normally made phase to phase and comparisons are made to determine if the readings are comparable. If all readings are within one percent of each other, then they are acceptable. Keep in mind that the purpose of the test is not to duplicate the readings of the manufactured device, which was tested in the factory under controlled conditions and perhaps at other temperatures.

2 Winding Resistance Measurements – When?

2.1 At Installation

Risk of damage is significant whenever a transformer is moved. This is inherent to the typical transformer design and modes of transportation employed. Damage can also occur during unloading and assembly. The damage will often involve a current carrying component such as the LTC, RA switch or a connector. Damage to such components may result in a change to the DC resistance measured through them. Hence, it is recommended that the DC resistance be measured on all on-load and off-load taps prior to energizing.

If the transformer is new, the resistance test also serves as a verification of the manufacturers work. Installation measurements should be filed for future reference

2.2 At Routine (scheduled) Transformer Maintenance

Routine maintenance is performed to verify operating integrity and to assure reliability. Tests are performed to detect incipient problems. What kind of problems will the resistance test detect?

2.2.1 Ratio Adjusting Switch (ratio adjusting off-load tap changer)

Contact pressure is usually obtained through the use of springs. In time, metal fatigue will result in lower contact pressure. Oxygen and fault gases (if they exist) will attack the contact surfaces.

Additionally, mechanical damage resulting in poor contact pressure is not uncommon. (E.g. A misaligned switch handle linkage may result in switch damage when operated). Such problems will affect the DC resistance measured through the RA switch and may be detected.

2.2.2 Load Tap Changer

The LTC contains the majority of the contacts and connections in the transformer. It is one of few non static devices in the transformer and is required to transfer load current several thousand times a year. Hence, it demands special consideration during routine maintenance.

In addition to detecting problems associated with high resistance contacts and connectors, the Megger winding tester will also detect open circuits (drop-out test). LTCs transfer load current. An open circuit would likely result in catastrophic failure. On installation and after maintenance it is certainly prudent to verify operating integrity by checking for open circuits. LTC maintenance often involves considerable disassembly and the test will provide confidence in the reassembly.

It is recommended DC resistance measurements be made on all on-load and off-load taps to detect problems and verify operating integrity of the RA switch and LTC.

2.3 At Unscheduled Maintenance/Troubleshooting

Unscheduled Maintenance generally occurs following a system event. The objectives of unscheduled maintenance are:

- To detect damage to the transformer.
- To determine if corrective action is necessary.
- To establish priority of corrective action.
- To determine if it is safe to re-energize.

Many transformer faults or problems will cause a change in the DC resistance measured from the bushings (shorted turns, open turns, poor joints or contacts). Hence, the information derived from the resistance test is very useful in analyzing faults or problems complimenting information derived from other diagnostic tests such as FRA, DFR, power factor and other measurements. The winding

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resistance test is particularly useful in isolating the location of a fault or problem and assessing the severity of the damage.

2.4 At Internal Transformer Inspections

Internal inspections are expensive due primarily to the cost of oil processing. When such opportunities do present themselves the inspection should be planned and thorough. Prior to dumping the oil, all possible diagnostic tests including the resistance test should be performed.

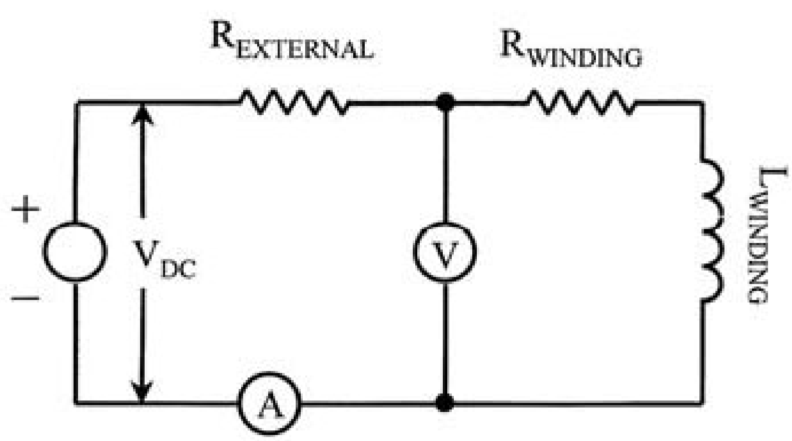
3 Test Equipment

Prior to modern digital electronic equipment, the Kelvin Bridge was used. Batteries, switches, galvanometers, ammeters and slide-wire adjustments were used to obtain resistance measurements. Current regulators were constructed and inserted between the battery and the bridge. Input voltage to the regulator of 12 volts dc from an automobile storage battery provided output currents variable in steps which matched the maximum current rating of the bridge on the ranges most used on transformers. The current regulator increased both speed and accuracy of the bridge readings. The approximate 11 volt availability was used to speed up the initial current build-up and tapered off to about 5 volts just before the selected current was reached and regulation started. When the regulation began, the current was essentially constant in spite of the inductance of the windings and fluctuation of the battery voltage or lead resistance.

The testing times have been greatly reduced using modern microprocessor based test equipment. Direct readings are available from digital meters and on some testers like the Megger MTO series, two measurement channels are available allowing two resistance measurements at the same time.

4 Measurement principle

Winding resistance is measured with the following setup;



A DC test current is injected across the measured winding (-s), the voltage drop as well as the test current is measured and the resistance is calculated.

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For purely resistive objects the measurement is trivial and very easy to perform. However, when the measurement circuit is highly inductive, the so called “simple application” may become rather complex. The mathematical expressions, where U is Voltage, R is resistance, I is current, Φ is flux, L is inductance and t is the time, to describe the measurement are;

$$U = R \times I + \frac{d\phi(I,t)}{dt} \qquad L(I,t) = \frac{\phi(I,t)}{I}$$

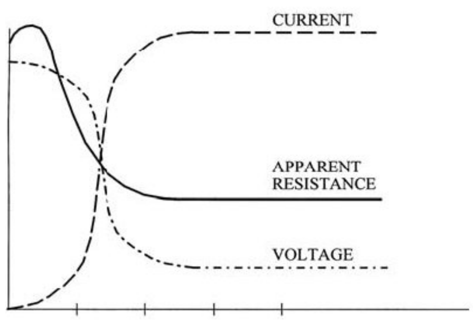
$$U = R \times I + \frac{d[L(I,t) \times I(t)]}{dt}$$

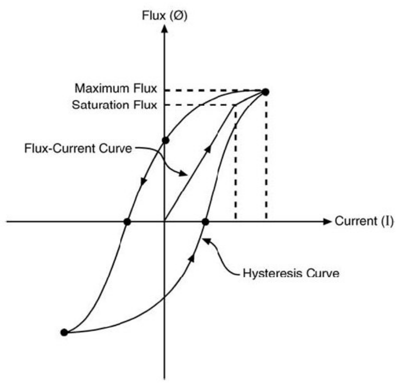
$$U = R \times I + L \times \frac{\partial I(t)}{\partial t} + I \times \frac{\partial L(t)}{\partial t}$$

Where the first term is the winding resistance R times the current I, i.e. what we want to measure. The second term is the voltage caused by change of current, i.e. the Ldi/dt term, and the third term is caused by change of inductance with time; the magnetic properties of the core does not only depends on current level and history (hysteresis), it also depends on time.

The second “error” term, inductance x change of current, is well known and the solution to this issue is to keep the test current constant over time. The third “error” term, current x inductance change, is much more difficult to reduce or compensate for. In practice the only way is to wait for the inductance change to stabilize. This third term in the equation is what may cause very long measurement time to perform WRM on large LV delta configured windings, see section 7 and 8.3.

The time-variable parameters in the winding resistance measurement are described in the following diagrams.





To the left: Illustration of Voltage, Current and Apparent resistance as function of time. To the right: A typical hysteresis curve for a magnetic material, e.g. transformer core. The Inductance L is proportional to the slope of the curve when current is changed

Generally, to minimize influence of above described physics; avoid low flux densities in legs involved in measurement and try to reach saturation flux in the core. As a rule of thumb, saturation is achieved at around 1% of the rated current of the winding.

5 Safety Considerations

While performing winding resistance tests, hazardous voltages could appear on the terminals of the transformer under test and/or the test equipment if appropriate safety precautions are not observed. There are two sources to consider; AC induction from surrounding energized conductors, and the DC test current.

5.1 AC Induction

When a transformer is located in an A-C switch yard in close proximity to energized conductors it is quite probable that electrostatic charge would be induced onto a floating winding. This hazard can be eliminated by simply tying all windings to ground. However, to perform a winding resistance test, only one terminal of any winding can be tied to ground. Grounding a second terminal will short that winding under test and would probably result in measuring the resistance of the ground loop. Two grounds on a winding which is not under test will create a closed loop inductor. Because all windings of a transformer are magnetically coupled, the DC test current will continually circulate within the closed loop inductor (the shorted winding). The instrument display would probably not stabilize and accurate measurements would not be possible.

It does not matter which terminal is grounded as long there is only one terminal of each winding tied to ground. When test leads are moved to subsequent phases or windings on the transformer it is not necessary to move the ground connections. Ensure the winding is grounded prior to connecting the current and potential test leads, and when disconnecting leads, remove the ground last.

5.2 DC Test Current

Should the test circuit become open while DC current is flowing, hazardous voltages (possibly resulting in flash over) will occur. Care must be taken to ensure the test circuit does not accidentally become open:

- Ensure the test leads are securely attached to the winding’s terminals.
- Do not operate any instrument control which would open the measured circuit while DC current is flowing. Discharge the winding first.
- Do not disconnect any test leads while DC current is floating. Ensure the winding is discharged first.
- When terminating the test, wait until the discharge indicator on the Megger winding tester goes off before removing the current leads. When testing larger transformers it may take 30 seconds or more to discharge the winding. If a longer time (30 second plus) is required to charge a winding when the current is initiated a corresponding longer time will be required to discharge the winding.

5.3 Summary of Safety Precautions

Ensure all transformer windings and the test instrument chassis are grounded prior to connecting the test leads.

Take appropriate precautions to ensure the test circuit is not open while DC (test) current is flowing.

Failure to take appropriate precautions can result in hazardous potentials which could be harmful to both personnel and test equipment. It should be noted that the transformer windings are essentially large inductors. The higher the voltage produced and the larger the (MVA) capacity, the higher the induction and hence the potential hazard.

6 Selecting the Proper Current Range

- Always try to saturate the core. This happens typically when the test current is about 1% of rated current
- Never exceed 10% of rated current. This could cause erroneous readings due to heating of the winding
- Typical test currents are from about 0.1% to a few percent of rated current
- If test current is too low, measured resistance is not consistent (pending magnetic status before the test is started) and a specific winding will have different readings when measured from time to time

Note: If MTO indicates input voltage overload or does not charge the transformer with the selected test current, you have selected a test current > 10%. Select next lower current range and restart.

7 Measurements

Wait until the display has stabilized prior to recording resistance values. Generally, readings on a star-configured transformer should stabilize in 10-30 seconds after the test current has stabilized. However, the time required for readings to stabilize will vary based on the rating of the transformer, the winding configuration, and the current output selected. On large transformers with high inductance windings it could take a minutes for readings to stabilize.

For large transformers with LV delta configuration, magnetization and getting stable readings can take substantially longer time (see Figure 4), sometimes as long as 30-60 minutes. If the readings don't stabilize close to expected value within a reasonable measurement time, check leads, connections and instrument. It may be necessary to inject current on HV and LV windings simultaneously (recommended!), see example in Figure 3-6 and table 1.

- Read and record the winding temperature
- Record measurements as read. Do not correct for temperature.
- Do not calculate individual winding values for delta connected transformers.
- Record the selected DC test current
- Record unit of measure (ohms or milli-ohms).
- Review test data. Investigate and explain all discrepancies.

As a general rule, the first measurement made is repeated at the end of the test. Consistent first and last readings give credibility to all measurements. Whenever an unexpected measurement is obtained both the test method and procedure are questionable. If the measurement can be repeated the doubt is removed. In situations where time is of concern, the repeat measurement can be omitted if all measurements are consistent.

Always check the winding schematic on the nameplate, and trace the current path(s) through the windings. The nameplate vector representative may be misleading. Also, check the location of grounds on the windings and ensure the grounds do not shunt the DC test current.

When a winding has both an RA switch (ratio adjusting off-load tap changer) and an LTC (load tap changer) take measurements as follows:

- With the LTC on neutral, measure resistance on all off-load taps.
- With the RA switch on nominal /rated tap, measure resistance on all on-load taps.

7.1 RA Switch Measurements

The recommended procedure for testing RA switches is as follows:

- Prior to moving the RA switch, measure the resistance on the as-found tap. Note: This measurement is particularly useful when investigating problems.
- Exercise the switch by operating it a half dozen times through full range. This will remove surface oxidization. See “Interpretation of Measurements – Confusion Factors”.
- Measure and record the resistance on all off-load taps.
- Set the RA switch to the left tap and take one final measurement to ensure good contact. Do not move the RA switch after this final measurement has been made.

7.2 LTC Measurements

“As-found” measurements are performed for diagnostic purposes in routine and non- routine situations. “As-left” measurements are performed to verify operating integrity following work on the LTC. The resistance test on a transformer with an LTC is time consuming; hence the value of the “as-found” test in each particular situation should be evaluated. Consider maintenance history and design. Certainly, if the proposed work involves an internal inspection (main tank) or a problem is suspected the “as-found” test should be performed.

Prior to taking “as-left” measurements, exercise the LTC. Operating the LTC through its full range of taps two to six times should remove the surface oxidation.

When testing windings with LTCs, be sure to use tap-changer setup/sequential testing on the instrument so the measurement value of each tap is stored separately. The current generator is on throughout the test sequence while changing from tap to tap.

Measure and save the resistance for the first tap. Operate LTC. Measure for the second tap and save the resistance value. Operate LTC. Measure resistance for the third tap etc.

Should the LTC open the circuit and cause current interruption, the Megger MTO will automatically indicate open connection and if the interruption is longer than about 10 ms, the unit will stop and go into its discharge cycle. This gives the operator a clear indication by a panel light of a possible fault within the tap changer. Such transformers should not be returned to service as catastrophic failure would be possible.

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8 Connections

8.1 General

Prior to connecting the instrument leads to the transformer, all transformer windings must be grounded. See Safety Considerations. Make connections in the following order:

1. Ensure windings terminals are not shorted together and tie to ground (the transformer tank) one terminal of the transformer winding to be tested. Note: It does not matter which terminal is grounded (a line terminal or neutral) as long as only one terminal on each winding is grounded.
2. Ensure the instrument's power switch is in the off position and connect it to the mains supply. Note: The instrument's chassis is grounded through the supply cable to the station service. (On occasion it has not been possible to stabilize the measurement when the instrument's chassis ground was not connected to the same ground point as the winding (i.e., the transformer tank) This problem is most likely to occur when the station service ground is not bonded to the transformer tank and is easily remedied by connecting a jumper between the instrument chassis and the transformer tank.)
3. Connect the test leads to the instrument.
4. Connect the test leads to the transformer winding. The potential leads must be connected between the current leads or use kelvin clips. Do not clip the potential leads to the current leads. Observe polarity.
5. Upon completion of the test, ensure the winding is discharged before disconnecting any test leads. Remove the ground from the transformer winding last.

Caution: Do not open the test circuit in any way (i.e. disconnecting test leads, or operating the current selector switch) while DC current is flowing. Hazardous voltages (probably resulting in flash-over) will occur.

Note: A three phase test set will make suitable connections to the windings by internally switching the measuring leads.

8.2 Star/Wye Windings

Refer to figures 1-3 and Table 1. Measuring two windings simultaneously is possible if a suitable common test current can be selected. Take resistance measurements with the indicated connections.

Connecting the test equipment as per figure 3 is the preferred method because it allows the operator to measure two phases simultaneously. Compared to measuring each phase individually there is a significant time savings particularly when measuring a winding with an LTC.

If time is of concern the last test set up, which is a repeat of the first, may be omitted if all measurements are consistent when comparing one phase to the next or the previous tests.

8.3 Delta Windings

Refer to Figures 1-2 and Table 1. If there is a delta configured LV, always try to inject test current in HV and LV simultaneously (and measure two windings). This will magnetize the core more efficiently and shorten the time to get stable readings. If single-injection single-channel measurement is chosen, please note that the time for stabilization on larger transformers may be long!

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Take a resistance measurement with the indicated connections. Again, if time is of concern the last test set up, which is a repeat of the first, may be omitted if all measurements are consistent when comparing one phase to the next or to the previous tests.

9 Interpretation of Measurements

Measurements are evaluated by:

- Comparing to original factory measurements
- Comparing to previous field measurements
- Comparing one phase to another

Phase to phase comparisons will usually suffice. The industry standard (factory) permits a maximum difference of 0.5% from the average of the three phase windings. Field readings may vary slightly more than this due to the many variables. If all readings are within 1% of each other, then they are acceptable.

Comparing absolute resistance values in the field with factory values may be difficult due to the problem of exactly estimating the winding temperature. Values within 5% are normally acceptable.

Variation from one phase to another or inconsistent measurements can be indicative of many different problems:

- Shorted turns
- Open turns
- Defective ratio adjusting (RA) switch or LTC
- Poor connections (brazed or mechanical)

The winding resistance test is very useful in identifying and isolating the location of suspected problems.

9.1 Confusion Factors

Apparent problems (i.e., inconsistent measurements or variations between phases) can also be the result of a number of factors which are not indicative of problems at all. Failure to recognize these factors when evaluating test data can result in confusion and possibly unwarranted concern.

9.1.1 Temperature change

The DC resistance of a conductor (hence winding) will vary as its temperature changes, for copper windings 0.39% per degree C. This is generally not a significant consideration when comparing one phase to another of a power transformer. Loading of power transformers is generally balanced, hence temperatures should be very familiar. However, when comparing to factory measurements or previous field measurements small but consistent changes should be expected. In addition to loading, temperature variations (likewise resistance variations) can be due to:

- Cooling or warming of the transformer during test. It is not uncommon for one to two hours to pass between taking a first and last measurement when testing a large power transformer with

an LTC. A transformer which has been on-load can have a significant temperature change in the first few hours off-load.
- Selecting a too high test current. When measuring the DC resistance of smaller transformers, care should be exercised to ensure that the test current does not cause heating in the winding. The test current should not exceed 10 percent of the winding's rating.

9.1.2 Contact oxidization

The dissolved gases in transformer oil will attack the contact surfaces of the RA switch and LTC. The problem is more prevalent in older transformers and heavily loaded transformers. Higher resistance measurements will be noticed on taps which are not used. (Typically a load tap-changer installed on a sub-transmission system will only operate on 25-50 per cent of its taps.) This apparent problem can be rectified by merely exercising the switch. The design of most LTC and RA switch contacts incorporate a wiping action which will remove the surface oxidization. Hence, operating the switch through its full range 2 to 6 times will remove the surface oxidization.

A potential transformer installed in one phase could become part of the measured circuit and affect the measured DC resistance of that phase.

A two winding CT installed in one phase would have a similar effect. Usually a donut bushing type CT is used in power transformers. However, on rare occasions an in-line two winding CT may be encountered.

9.1.3 A measuring error

There are many possibilities:

- A wrong connection or poor connection
- A defective instrument or one requiring calibration
- An operating error
- A recording error
- Ambiguous or poorly defined test data

There is often more than one way to measure the resistance of a transformer winding (e.g., line terminal or line neutral). Typically, field measurements are taken from external bushing terminals. Shop or factor measurements are not limited to the bushing terminals.

Additionally, internal winding connections can be opened (e.g. opening the corner of a delta) making measurements possible which are not practical in the field**.** Details of test set ups and connections are as often omitted in test reports which can lead to confusion when comparing test data.

9.2 How Bad is Bad?

When a higher than expected measurement is encountered what does it mean? Is failure imminent? Can the transformer be returned to service? Is corrective action needed? To answer these questions more information along with some analytical thinking is usually required.

- Firstly, have the confusion factors been eliminated?

- Secondly, what are the circumstances which initiated the resistance test? Was it routine maintenance or did a system event (e.g. lightning or through fault) result in a forced outage?
- Is other information available? Maintenance history? Loading? DGA? Capacitance bridge? Excitation current? If not, do the circumstances warrant performing additional tests?
- Consider the transformer schematic. What components are in the circuit being measured? Has the location of the higher resistance been isolated? See "Isolating Problems".
- How much heat is being generated by the higher resistance? This can be calculated (I2R) using the rated full load current. Is this sufficient heat to generate fault gases and possibly result in catastrophic failure? This will depend on the rate at which heat is being generated and dissipated. Consider the mass of the connector or contact involved, the size of the conductor, and its location with respect to the flow of the cooling medium and the general efficiency of the transformer design.

10 Isolating Problems

The resistance test is particularly useful in isolating the location of suspected problems. In addition to isolating a problem to a particular phase of winding, more subtle conclusions can be drawn. Consider the transformer schematic (nameplate). What components are in the test circuit? Is there an RA switch, LTC, diverter isolating switch, link board connectors, etc.? By merely examining the test data, problems can often be isolated to specific components. Consider:

10.1 RA Switch

In which position does the higher resistance measurement occur? Are repeat measurements (after moving the RA switch) identical to the first measurement or do they change.

10.2 LTC

The current carrying components of the typical LTC are the steps switches, reversing switch and diverter switches. Carefully examine the test data looking for the following observations:

10.3 Step Switch Observation

A higher resistance measurement occurring on a particular tap position both boost and buck (e.g., both +1 and -1, +2 and -2, etc.)

The above observation would indicate a problem with a particular step switch. Each step switch is in the circuit twice, once in the boost direction and once in the buck direction.

10.4 Reversing Switch Observation

All boost or buck measurements on a phase are quantitatively and consistently higher than measurements in the opposite direction or other phases.

The reversing switch has two positions, buck and boost, and operates only when the LTC travels through neutral to positions +1 and -1 the resistance measured through a poor reversing switch contact would likely change.

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10.5 Diverter Switch Observation

All odd step or all even step measurements in both the buck and boost direction are high. There are two diverter switches. One is in the current circuit for all odd steps and the other for all even steps.

The foregoing discussion is only typical. LTC designs vary. To draw a conclusion based on resistance measurements, the specific LTC schematic must be examined to identify the components which are being measured on each step. This information is usually available on the transformer nameplate.

10.6 Contacts vs. Connectors or Joints

Is the higher resistance measurement consistent and stable when the RA switch or LTC is operated? Generally inconsistent measurements are indicative of contact problems while a consistent and stable high measurement would point to joint or connector.

11 Limitations

The transformer resistance test has several limitations which should be recognized when performing the test and interpreting data:

The information obtained from winding resistance measurements on delta connected windings is somewhat limited. Measuring from the corners of a closed delta the circuit is two windings in series, in parallel with the third winding (see figure 4).

The individual winding resistances can be calculated; however this is a long tedious computation and is generally of little value and not recommended. Comparison of one “phase” to another will usually suffice for most purposes. Additionally, since there are two parallel paths, an open circuit (drop out) test does not mean too much. However, the test is still recommended.

The resistance of the transformer’s winding can limit the effectiveness of the test in detecting problems. The lower the resistance of a winding the more sensitive the test is with respect to detecting problems. Windings with high DC resistance will mask problems.

It is not possible on some transformer designs to check the LTC using the resistance test (e.g., series winding). The circuit between external terminals simply excludes the LTC. On such units the resistance test is of no value in verifying the operating integrity of the LTC. If the LTC selector switch is in the main tank (i.e., same tank as windings) and cannot be physically inspected it is recommended that samples for DGA be taken as part of routine LTC maintenance.

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12 Figures and Tables

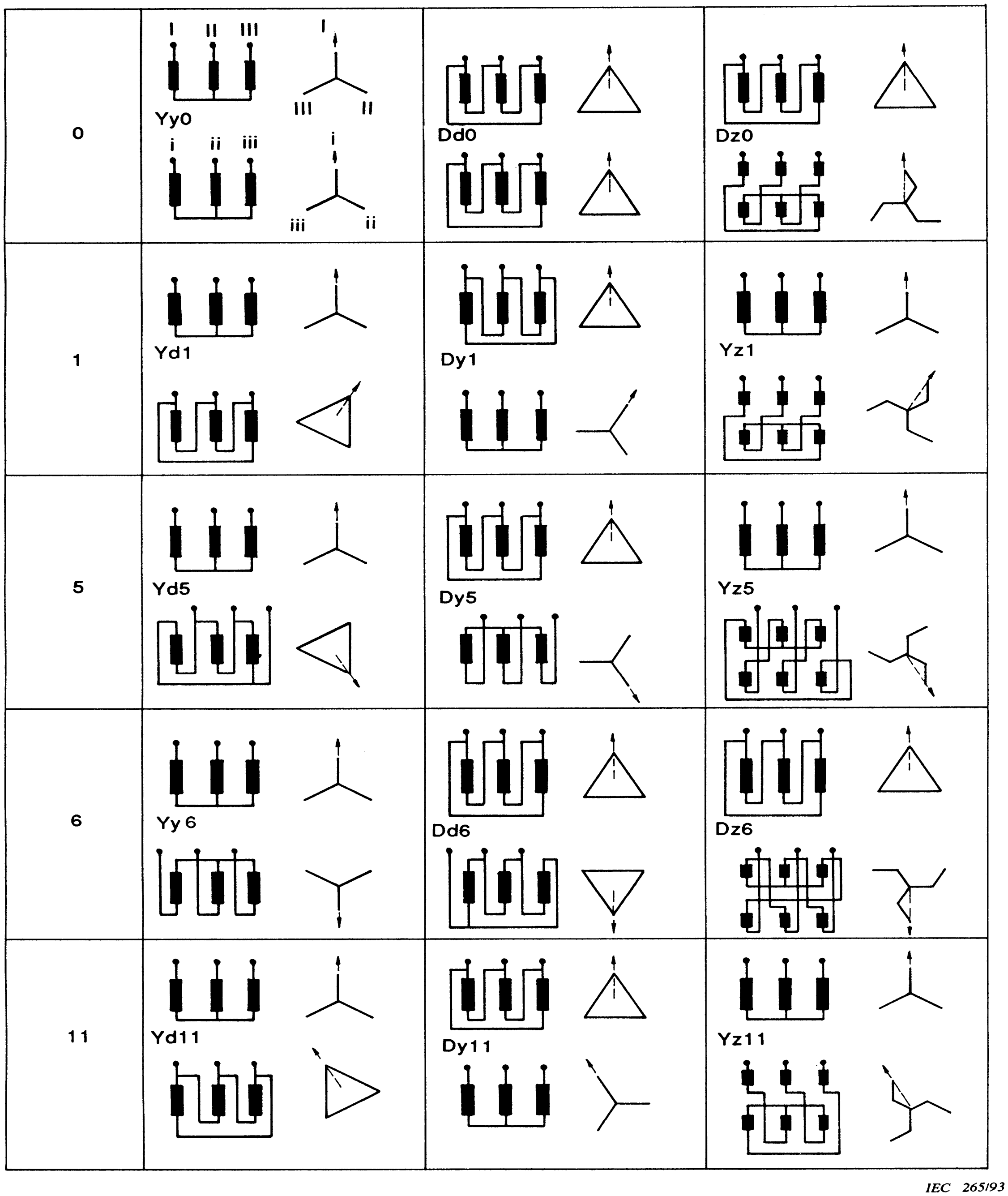

Figure 1. Common 3-phase Transformer Connections

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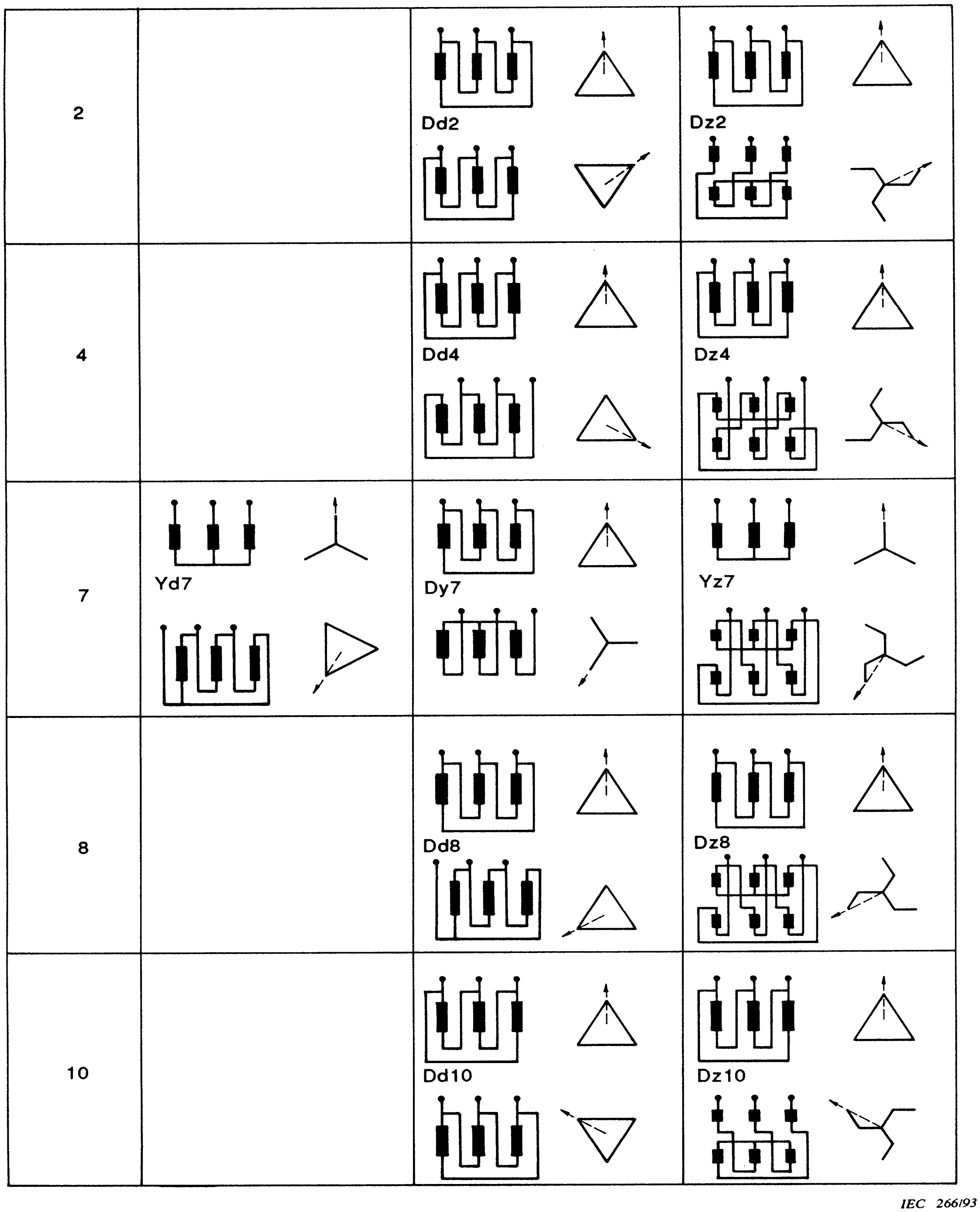

Figure 2. Alternative 3-phase Transformer Connections

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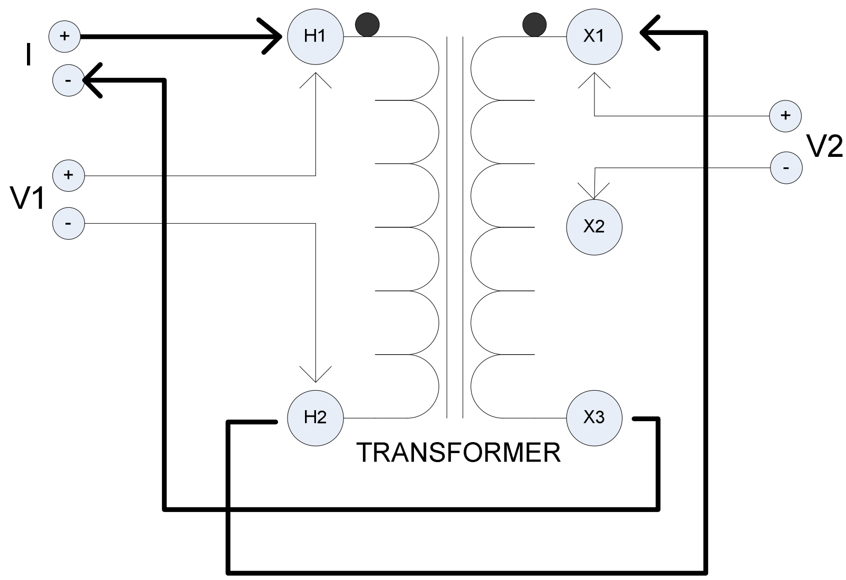

Figure 3. Measuring two windings simultaneously

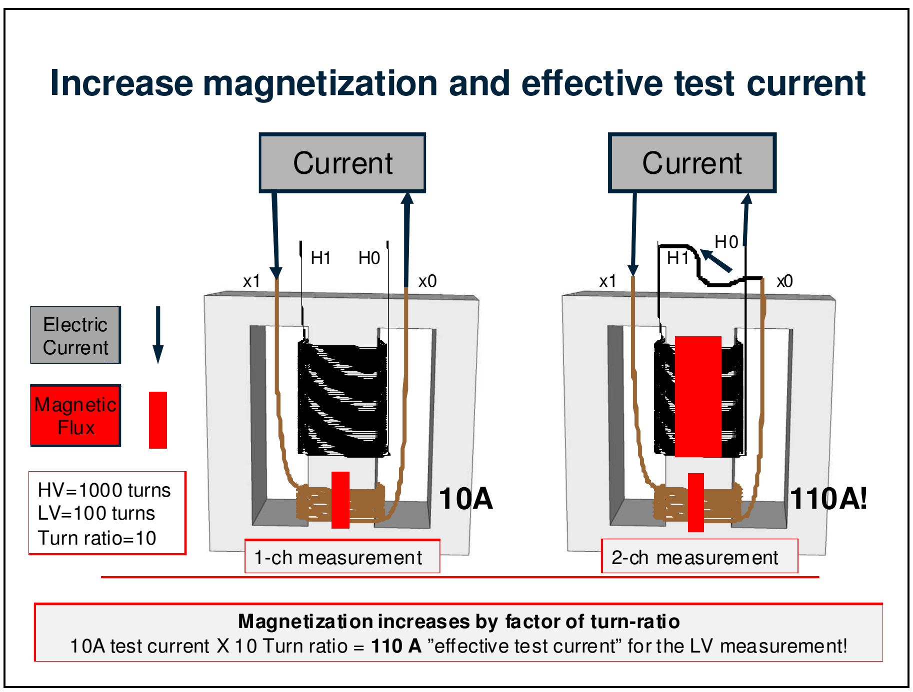

Figure 4. Amplification of magnetic flux by dual injection technique

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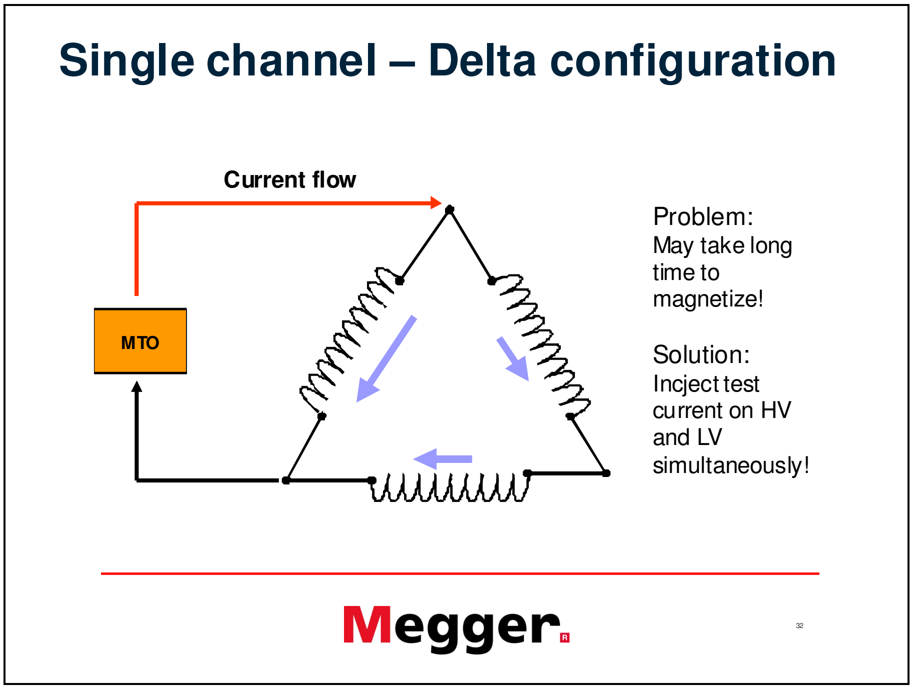

Figure 5. Closed delta winding

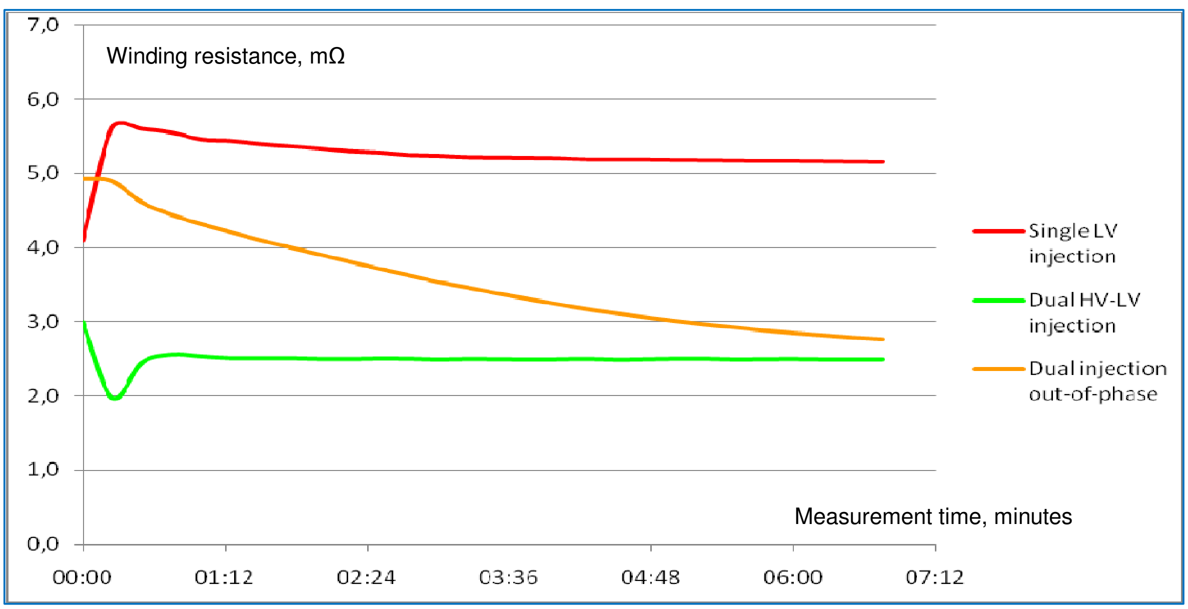

Figure 6. WRM on 200 MVA Ynd11 LV winding with different current injection techniques

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Table 1. Transformer Connection Schemes for 2-ch measurements

EXAMPLES ON TRANSFORMER CONNECTION SCHEMES FOR INJECTING TEST CURRENT AND MEASURING TWO WINDINGS SIMULTANEOUSLY

Vector Group	Measurement setup						
	Current Connections			Meas ch 1		Meas ch 2	
	+ Current	Jumper	- Current	+	-	+	-
Dd0	H1	H3-X1	X3	H1	H3	X1	X3
	H2	H1-X2	X1	H2	H1	X2	X1
	H3	H2-X3	X2	H3	H2	X3	X2
Dyn7	H1	H3-X0	X1	H1	H3	X0	X1
	H2	H1-X0	X2	H2	H1	X0	X2
	H3	H2-X0	X3	H3	H2	X0	X3
Dyn1	H1	H3-X1	X0	H1	H3	X1	X0
	H2	H1-X2	X0	H2	H1	X2	X0
	H3	H2-X3	X0	H3	H2	X3	X0
YNyn0	H1	H0-X1	X0	H1	H0	X1	X0
	H2	H0-X2	X0	H2	H0	X2	X0
	H3	H0-X3	X0	H3	H0	X3	X0
Ynd1	H1	H0-X1	X2	H1	H0	X1	X2
	H2	H0-X2	X3	H2	H0	X2	X3
	H3	H0-X3	X1	H3	H0	X3	X1
Dy1	H1	H3-X1	X2	H1	H3	X3	X2
	H2	H1-X2	X3	H2	H1	X1	X3
	H3	H2-X3	X1	H3	H2	X2	X1
YNd7	H1	H0-X2	X1	H1	H0	X2	X1
	H2	H0-X3	X2	H2	H0	X3	X2
	H3	H0-X1	X3	H3	H0	X1	X3
Dyn5	H1	H2-X0	X1	H1	H2	X0	X1
	H2	H3-X0	X2	H2	H3	X0	X2
	H3	H1-X0	X3	H3	H1	X0	X3
Dy11	H1	H3-X1	X3	H1	H3	X1	X3
	H2	H1-X2	X1	H2	H1	X2	X1
	H3	H2-X3	X2	H3	H2	X3	X2
Dyn11	H1	H2-X1	X0	H1	H2	X1	X0
	H2	H3-X2	X0	H2	H3	X2	X0
	H3	H1-X3	X0	H3	H1	X3	X0

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