A Guide to Transformer Ratio Measurements

Abstract:

Measuring transformer ratio from one external terminal to another can reveal a great deal of information about the transformer. Transformers are subject to mechanical impact and vibration. Problems or faults occur due to poor design, assembly, handling, poor environments, overloading or poor maintenance. Measuring the polarity and turn ratio of a transformer winding assures that the connections are correct and there are no severe mismatches or opens.

This application note is focusing on using transformer turn ratio measurements for diagnostic purposes. It is not replacing the User Manual for the actual instrument and does not describe the practical operation. Instead this document describes the relevant standards for ratio measurements and how these principles effect the practical testing.

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A Guide to Transformer Ratio Measurements

1 Introduction

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

- To validate design specifications
- To verify quality of manufacturing process
- To establish present condition and condition trend
- To determine if damage has occurred

Deviation of ratio from expected calculated target values may indicate the following:

- Manufacturing defect in winding
  - Improper turns
  - Incorrect polarity
  - Incorrect winding configuration
- Insulation failure
  - Damaged turn-to-turn insulation resulting in shorted windings
  - Major insulation failure: inter-winding or winding-to-ground
- Defective tap-changer
  - Incorrect assembly of winding connections
  - High resistance connections
  - Incorrect tap-changer setting

Transformers are subject to mechanical impact and vibration. Problems or faults occur due to poor design, assembly, handling, poor environments, overloading or poor maintenance. Measuring the polarity and turn ratio of a transformer winding assures that the connections are correct and 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 ratio test.

Regardless of the configuration, star, delta or zig-zag, the measurements are normally made phase to phase and comparisons are made to the estimated ratios defined by the transformer template (voltages and configuration).

This application note is focusing on using transformer turn ratio measurements for diagnostic purposes. It is not replacing the User Manual for the actual instrument and does not describe the practical operation. Instead this document describes the relevant standards for ratio measurements and how these principles effect the practical testing.

2 Standards and definitions

2.1 IEEE standards

Turn-ratio measurements are described in international standards e.g. IEEE C57.12.90 IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers [1] and IEEE Std 62-1995 (to be changed to C57.152) IEEE Guide for Diagnostic Field Testing of Electric Power Apparatus. Part 1: Oil Filled Power Transformers, Regulators, and Reactors [2].

Megger TTR test sets are designed to meet requirements and perform measurements as defined in the standards.

2.2 Definitions

To understand the nature of ratio testing it is important to understand the applicable definitions.

2.2.1 Turn ratio and voltage ratio

The turn ratio of a transformer is the ratio of the number of turns in a higher voltage winding to that in a lower voltage winding. The voltage ratio of a transformer is the ratio of the rms terminal voltage of a higher voltage winding to the rms terminal voltage of a lower voltage winding under specified conditions of load. For all practical purposes, when the transformer is on open circuit, its voltage and turns ratios may be considered equal.

2.2.2 Nameplate voltage and nameplate voltage ratio

Nameplate voltages are defined as the line-to-line/phase-to-phase voltage of the high voltage winding and the line-to-line/phase-to-phase low winding voltage. Nameplate voltage ratio is defined as the line-to-line voltage of the high voltage winding divided by the line-to-line voltage of the low voltage winding.

2.2.3 Definitions summary

The following definitions are used in Megger TTR test instruments:

Transformer nameplate voltage, TNV	Labelled line-to-line voltage for a winding defined on transformer template.
Transformer nameplate ratio, TNR	Ratio between the specific labelled (line-to-line) voltage of a higher voltage winding to a specific labelled (line-to-line) voltage of a lower voltage of the transformer
Transformer voltage ratio, TVR	Ratio between a specific terminal voltage of a higher voltage winding to a specific terminal voltage of a lower voltage winding of the transformer
Transformer turn ratio, TTR	Ratio between the physical number of turns on a specific higher voltage winding to a specific lower voltage winding of the transformer
Measured voltage ratio, MVR	Measured ratio between a specific terminal voltage of a higher voltage winding to a

	specific terminal voltage of a lower voltage winding of the transformer for a specific test setup (without any recalculations)

Table 1. TTR measurement terms and definitions

3 TTR measurements

3.1 Measurement method

The Megger TTR series of instruments determines the transformer turns-ratio using the IEEE C57.12.90 measurement method. The test set outputs an excitation test voltage to the transformer's primary windings and measures the voltage at the corresponding secondary winding. The voltage ratio is displayed and compared with the expected target ratio.

3.2 Measured ratio

Measured voltage ratio is traditionally used in the industry, as well as in Megger instruments, as measured turn ratio. The target ratio, i.e. the expected measured voltage ratio, is calculated from the transformer nameplate ratio and the actual configuration of the transformer. The recalculation factor is pending transformer vector configuration and when applicable also the actual TTR test setup including eventual shorts to create a virtual neutral terminal.

3.2.1 Voltage ratio and nameplate ratio

For single-phase as well as standard 3-phase Yy and Dd transformers, turn ratio/voltage ratio is the same as nameplate ratio. However, for Yd, Dy, some zig-zags and configurations without accessible neutral, voltage ratio is different from nameplate ratio. For recalculation of nameplate ratio to voltage ratio, see Table 2

Transformer configurations/vector groups	TVR recalculation factor, TVR=k*TNR
Dd	1
Dy	√3
Dyn	√3
Dz	1.5
Dzn	1.5
Yd	√3/2
YNd	1/√3
Yy	1
YNy	1
Yyn	1
YNyn	1
Yz	√3/2
YNz	√3/2
Yzn	√3
YNzn	√3
Zd	1
ZNd	2/3

Zy	√3/2
ZNy	1/√3
Zyn	1
ZNyn	1

Table 2. Nameplate ratio to voltage ratio recalculation

3.2.2 Turn ratio and voltage ratio

For most transformer configurations, the transformer turn-ratio is the same as the measured transformer voltage ratio. However, for some configurations the turn-turn ratio is different from the voltage ratio. In case turn-turn ratios are requested, values can be calculated from Megger TTR measured voltage ratios, see Table 3.

Transformer configurations/vector groups	TTR recalculation factor, TTR=k*TVR
Dz	3/2
Yzn	1/2
Yd	2/3
YNzn	1/2
Zd	2/3
ZNy	2
Zy	4/3
ZNy	2

Table 3. Voltage ratio to turn ratio recalculation

3.3 Tap changer ratio measurements

When a transformer has taps for changing its voltage ratio, the turn ratio is based on the number of turns corresponding to the normal rated voltage of the respective windings to which operating and performance characteristics are referred. When the transformer has taps, the turn ratio shall be determined for all taps and for the full winding.

If the transformer has load taps, the turn ratio should be determined for all of these taps with the tap changer for de-energized operation in one specific position such as the nominal or the maximum turns position. In addition, with the load tap changer (LTC) in the neutral position, the turn ratio should be determined for all positions of the tap changer for de-energized operation.

3.4 Tolerances for ratio

3.4.1 IEEE Std C57.12.00-2006 (factory test)

The turn ratios between windings shall be such that, with the transformer at no load and with rated voltage on the winding with the least number of turns, the voltages of all other windings and all tap connections shall be within 0.5% of the nameplate voltages. However, when the volts per turn of the winding exceed 0.5% of the nameplate voltage, the turn ratio of the winding on all tap connections shall be to the nearest turn.

3.4.2 IEEE Std 62-1995 (field testing)

The turn ratio tolerance should be within 0.5% of the nameplate specification for all windings.

From time to time it may be observed that the measured ratios of the outer phases of a three-phase transformer will be slightly different. Unless the differences are >0.5% there is no cause for rejection of this transformer.

Infrequently, it will be found that the ratio will be different from that specified on the transformer nameplate. This condition may occur when a very large transformer is equipped with a low-voltage winding having a relatively small number of turns. In this case, the turn ratio should be expressed to the nearest complete turn.

It should also be noted that transformers with load taps in the low-voltage winding, may not have an equal number of turns between taps due to the overall low number of turns in the low-voltage winding. In such cases, the voltage variation with tap changer operation will not be uniform. All three phases should have the same measured ratio, although it may not be in exact agreement with the nameplate.

4 Transformer turn ratio test sets

4.1 Low voltage ratio measurements

There are a number of Megger turns ratio test sets available. The instruments, when operated as described in the User manual, provide convenient and accurate readings of ratio and phase deviation of power transformers.

4.2 High voltage ratio measurements

Transformer turn ratio may also be measured with a HV tan delta test set such as the Megger Delta. This method will provide good results with power transformers as well as with potential transformers. Higher voltage tests up to 12 kV may be performed. Please consult the user manual of the unit for the exact testing procedure.

5 References

[1] IEEE C57.12.90-2006, IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers.

[2] IEEE 62-1995, IEEE Guide for Diagnostic Field Testing of Electric Power Apparatus - Part 1: Oil Filled Power Transformers, Regulators, and Reactors