

APPLICATION NOTE

Transformer testing for the 21st century

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Fundamentally, transformers are simple devices. Two coils of wire – the windings – are wound together on an iron core. One coil – the primary – is connected to a power source, while the other coil – the secondary – provides power to a load. Energy transfer occurs via magnetic induction. The more turns there are in a winding, the greater its impedance, and the higher the voltage generated across it.

As nothing is free in nature, the higher voltage is achieved at the cost of current. If the secondary has more turns than the primary, voltage is increased but the current is reduced. Since most transformers are categorised in terms of voltage, this is a step-up transformer. Conversely, if the secondary has fewer turns than the primary, the voltage is reduced and the current increased. This is a step-down transformer.

As they have no moving parts to wear out, transformers can operate reliably for many years. Even so, they are not perfect; they can and do break down. Breakdowns can have catastrophic consequences both in terms of cost and disruption, so, as far as possible, they must be prevented. Turn ratio testing is an effective method for detecting and addressing impending failures.

A direct relationship exists between the voltage ratio of the transformer and the number of turns in the primary and secondary windings. This relationship is expressed by:

$$\frac{V_P}{V_S} = \frac{N_P}{N_S}$$

where V_P = primary voltage, V_S = secondary voltage, N_P = number of primary turns, and N_S = number of secondary turns. Standard notation designates the high-voltage winding H and its terminations H1 and H2. The low-voltage winding is designated X with terminations X1 and X2. The source voltage can be connected to either set of terminals, depending on whether the transformer is step-up or step-down.

This fundamental relationship is the basis for turns ratio testing, which is one of the most effective methods of testing, evaluating, and maintaining transformers. When a transformer is in service, many factors can damage or cause deterioration of the insulation around the windings, leading to short circuits between turns, which allow current to flow directly from one turn to the next. This effectively reduces the number of

turns and alters the turns ratio. Because of this, periodically measuring turns ratio provides a valuable indicator of the overall health of the transformer and alerts the maintenance program of issues in time to head off serious consequences. A transformer will tolerate a limited amount of insulation deterioration, but it is a predictor of ultimate failure. This is reflected in ANSI Standard C57.12, which specifies that the measured turns ratio should be within 0.5% of rating.

Changes in the turns ratio affect the output voltage of a transformer, but direct measurement of the output voltage is often difficult and dangerous. In addition, such measurements are unlikely to be accurate enough to allow precise calculation of the turns ratio. Furthermore, variations in the source voltage could produce erroneous results. Therefore, voltage measurement for turn ratio calculation must be performed using a dedicated instrument designed to offer requisite performance characteristics and sensitivity.

A traditional hand-cranked turns ratio tester (TTR) is a reference transformer modified to be balanced against a load (the transformer under test). It measures the balanced voltages very accurately and calculates the ratio. The voltage ratio under no-load (balanced) conditions is equal to the turns ratio. To meet the ANSI standard, the tester must measure voltage to 0.1% accuracy or better, which is hardly attainable with a common voltmeter. Turns ratio testing is performed on de-energized transformers with the tester providing the test current. The reference transformer and the transformer under test are connected in parallel and balanced so that there is zero circulating current and voltage and no burden on either transformer.



Traditional TTRs were fairly large pieces of equipment, typically weighing around 10 kg (20 lbs) and carried by a shoulder strap. They were constructed for hard usage and often powered by a hand crank. Decade knobs required the operator to manually balance the load using analog meters, an exercise that could be tedious. Test results were fairly limited in the amount of information they provided. Modern advances in microcircuitry have notably simplified and improved on the traditional labor-intensive routines for transformer turns ratio testing. Some old-format testing may still be required for the most demanding jobs, but taking advantage of modern instruments can save considerable time and effort while increasing accuracy, reliability, and safety.

Modern TTRs can now be handheld instruments. They include battery-powered single-phase models that are quick and convenient to operate, working at up to 250 V AC induced with 0.05% accuracy. They can be used on single- and three-phase distribution, power and instrument transformers for ratio, polarity, and verification. Dedicated instructions guide users through three-phase setup and testing, guarding against operator error. The operator is not required to know the test voltage, as modern instruments use single-phase step-up ratio technologies to overcome voltage dependence when testing large transformers. The risk of operator error is further reduced by color-coded leads and customizable on-screen vectors and voltages to match the transformer's nameplate.



Typical built-in capabilities include full-color displays, replacing the old analog meter guesswork. Pass/fail ratio evaluation, auto saving of results, customizable vector list and asset nameplate, and simulation mode software provide the operator with additional diagnostic help. Powered by AA NiMH batteries, a modern tester can perform up to 1000 tests on a single charge. Recharging batteries is a simple process, using the built-in USB-C connector and any standard USB wall charger. Modern testers also provide go/no-go short circuit and open circuit identification, as well as inductance, short circuit impedance and reactance measurement. Additive/subtractive polarity designation, excitation current display and phase deviation determination further aid the operator in analysis, diagnosis, and evaluation.

Safety is always a paramount consideration. A modern tester will perform safety checks before applying full test voltage, and CE certification to IEC 61010 provides dependable and demonstrable assurance.

In addition to their main function of measuring turns ratio, full-featured modern testers can identify loose connections, turn-to-turn shorts, winding deformation, core problems, tap changer contact problems, and broken strands. Phase angle deviation, the phase relationship between in-phase vectors of the high side and low side windings, informs the operator about the quality of core and winding. When the transformer

is functioning properly, it should exhibit very low values ($<0.1^\circ$) of phase angle deviation, but problems like shorted turns and damaged or distorted core produce noticeable increases.

For three-phase transformers, sophisticated testers can now provide phase-by-phase connection instructions on their display. Internal shorting and lead compensation mean that connection requirements for short circuit impedance tests are the same as for all other tests, so that only one ladder climb is needed.

Taking full advantage of 21st century developments in microcircuitry, TTRs can now alleviate much of the physically taxing nature of 20th century turns ratio testing while virtually eliminating the common sources of operator error. Results are readily stored, reproduced, and transferred, making a once potentially taxing and error-prone chore a streamlined and welcome addition to the critical electrical equipment maintenance portfolio.