Transformer Turn Ratio Testing

In their basic conception, transformers are simple devices. Two coils of insulated wire are wound in close proximity on an iron core. Also referred to as “windings,” one is connected to a power source, such as the utility or a generator, and is designated the “primary.” The other provides power, “transformed” in some manner, to the load, and is designated the “secondary.” Energy transfer from one to the other is through magnetic induction. The more “turns” there are to the winding, the more impedance it offers, and hence the higher the voltage that is generated across it, but at the cost of current. If the secondary has more turns than the primary, voltage is increased relative to the primary while current is less. This is called a “step up” transformer. Conversely, fewer windings in the secondary create a “step down” transformer of lower voltage, but higher current.

Offering “no moving parts”, as an old advertising ploy used to proclaim, such a device can, and does, run for years and years. But no device is perfect, and transformers can, and do, break down, sometimes catastrophically. Such failures can produce fires causing enormous damage, even to millions of dollars. An important diagnostic method of testing transformers to detect impending breakdown is called turns ratio testing.

A direct relationship exists between the number of turns and the voltage ratio of the primary to the secondary, and 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. Additional standard notation is to indicate the high-voltage winding with “H”, and the terminations accordingly as H₁ and H₂. The low-voltage winding is commonly noted “X”, with the terminations designated 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.” As a simple example, if the transformer had 480 turns on the high-voltage side and 240 on the low, and a 480 V source connected to “H,” the output would be 240 V, and the transformer a “step
down.” If the input were 100 A, the output would be 200. The high-voltage winding would, in this case, be the primary. But if the same source was connected to the X side, the transformer would now output 960 V but only 50 A for 200A from the source, and the low-voltage winding would be the primary. In the first case, turns ratio would be expressed as 2:1, and in the second, 1:2.

This fundamental relationship is the basis for one of the most effective methods of testing, evaluating, and maintaining transformers in working condition. The method is called turns ratio testing. In service, the insulation around windings can become damaged or deteriorated, from an array of causes including spikes, surges, contamination, faults, shipping damage, and others. Insulation damage can result in shorts between turns, effectively reducing the number of turns and altering turns ratio to some value deviating from nameplate rating. It is this change in turns ratio that is measured and utilized as an electrical maintenance tool. The extent of deviation from nameplate ratio is a direct indication of winding deterioration. A transformer will tolerate a limited amount of such deterioration, but it’s a blueprint for ultimate failure. Accordingly, the ANSI Standard C57.12 specifies that turns ratio be no more than 0.5% from rating.

Direct measurement of output voltage might seem a ready solution, but doesn’t work in practice. Live voltage measurement is difficult and potentially dangerous, and cannot be performed with the accuracy and sensitivity necessary to make an exacting calculation of turns ratio. Furthermore, any such crudely determined ratio error could be produced by disturbances to the source voltage, rather than deterioration of turns. Voltage measurement is the key to turn ratio calculation, but it must be performed by a dedicated turns ratio tester designed with requisite performance characteristics and sensitivity.

A turns ratio tester is essentially a reference transformer modified to be balanced against a load (the transformer under test), measure the balanced voltages to high accuracy, and calculate the resultant ratio. The voltage ratio at “no load” (balanced) condition is for practical purposes the turns ratio. In order to conform to the above-mentioned standard, the tester should be able to measure voltage to 0.1% accuracy, which is hardly attainable with a common voltmeter across live output! Turns ratio testing is performed on de-energized transformers, with the tester providing the test current. The reference transformer and test transformer are connected in parallel, excited, and balanced so that there is zero circulating current, without burden on either transformer.

A major source of measurement error is primary impedance drop from magnetizing current. This can be minimized by excitation at a fraction of rated voltage. The tester should be able to measure “no load” voltage ratio with little excitation voltage. Testers typically operate at around 8 V, and may have multiple test voltages down to a fraction of a volt. A sophisticated tester will limit excitation current to some appropriate level (an example being 100 mA), then autorange to lower test voltages to prevent exceeding the limit. For the higher demands of three-phase transformers, test voltages up to 100 V are available.

Precise measurement is further implemented by various design techniques, including applying excitation voltage to the low side, and by a reference transformer with an alloy core of high permeability and an exciting winding of low resistance. By exciting the low voltage winding, required excitation power, exciting losses, and voltage drop in the winding are low, facilitating high measurement accuracy. Older models, many still in use today, employed magnetic operation through a vibrating reed. As it vibrates, the reed contacts the poles of a double-pole, double-throw switch, rectifying the signal to dc. The operator balances a series of windings on the reference transformer until no current flows. At this point, there is no deflection of the null detector, and turns ratio is read by the settings of the decade dials.

Reeds have sensitivity issues on both ends of the scale, thereby circumscribing their use. If the operation was step-down, by applying excitation to the high-volt-
age winding, the resultant voltage might be too low to accurately measure. An amplifier would be required in order to cover a practical range. The reverse configuration, exciting the low voltage winding, enables the tester to be smaller, lighter, and easier for field use. Later designs substitute a synchronous rectifier for the vibrating reed. Turns ratios of 0.001 to 130 are typical, but the higher ratios of large transformers could not be tested by this basic technique. Other techniques, employing line voltage and capacitor banks, were used, but these methods were potentially dangerous and destructive. High voltage transformers could be “cascaded” through a series of step-downs, but this required tedious hand calculations, and suffered loss of accuracy. The heightened sensitivity of microprocessor technology now enables transformers of all ratios to be measured directly, with ranges to values of 45,000.

Low-end ranges to 0.001 facilitate measurements in conformance with the ANSI accuracy requirement mentioned above. With this degree of sensitivity, low test voltages can be applied to the high voltage winding, with the commensurately lower output voltages accurately measurable. This reversal of configuration eliminates the problem of dangerous voltages generated by the earlier step-up configuration.

Success of the operation depends as much on the operator’s knowledge and available information on the transformer’s wiring diagram as it does on the capabilities of the tester. Figs. 1-3 show typical setups, for a single-phase transformer, a voltage regulator, and a distribution transformer, respectively. Current transformers (CTs) present a particular challenge. CTs are used to measure the current in a phase. One of their main uses is at the transfer of ownership of electricity. Toroidal CTs in this application have windings along the entire circumference of the core. Most CTs have ratios less than 1000:1. Frequently, they are used in a “cascading mode”; that is, the current in the main is too high to measure accurately with only one CT. A winding of the first CT will pass through the core of the second CT. The output of the second CT is sufficiently low to be measured directly. The ratios of both cascading CTs need to be measured accurately in order to determine the actual current in the main.

Low voltage testers are ideally suited for this application because they avoid saturating the core. To measure, one of the X leads makes a complete loop through the toroid to contact the other X lead. If the opening is not large enough, a wire can be substituted, making one full loop, with the X leads connected across the ends (Fig. 4). The H leads are connected to the output terminals of the CT, and the measurement taken. Low-voltage testers are requisite because the low winding resistance of CTs would cause the core to saturate at higher test voltages.

Two corollary functions frequently performed are excitation current measurement and phase displacement (polarity). Excitation current is the current the tester applies through one winding in order to generate voltage across the other. Its measurement helps detect shorted turns or unequal number of turns connected in parallel, and provides information about the condition of the core. Unwanted circulating currents, unintentional grounds, or incipient short circuits can affect the exciting current. Identification of normal (in phase) and reverse polarity determines proper connection within a power network.

With recent improvements in technology, the benefits of turns ratio testing may now be applied to all transformers, even of the highest ratios, with convenient, portable testers affording light weight, enhanced safety, and maximum accuracy.

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