MODERN METHODS of TESTING RELAYING CTs.

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RESUME:

The principles of a test set operating on direct current and providing information on the alternating current performance of relaying current transformers is described. The portable test set operates according to traditional physical principles of electricity and magnetism. The unique feature of the test set is its ability to separate the eddy current losses from the hysteresis losses, thus being extra sensitive to CT problems, such as shorted turns.

INTRODUCTION.

The reliability of the electric power system depends, in part, on the proper operation of the protective relay systems. The proper operation of any relaying scheme, in turn, relies on the proper voltage and current signals applied to it. This paper discusses the test that should be carried out on current transformers in order to verify their performance and assure the proper operation of the protection relaying scheme.

Unlike metering current transformers that operate over a specified range of current and can be readily tested for their accuracy, relaying current transformers operate in the current overload range and cannot be readily tested for their performance. As the test set up for testing of relaying current transformers is very extensive it is practical only in factories or test laboratories. The testing of relaying CTs at site, prior to commissioning of any protective relaying system must rely on other than over current test which will lead one to believe that the CT is of desired characteristics and in good operating condition.

Test that have been used for this application include: ratio, polarity, secondary winding resistance, excitation current and loss and insulation resistance. A normal procedure would also require the CT to be demagnetized prior to being connected into service.

REASONS for TESTING.

The reasons for testing the CTs should be obvious. Reviewing some of the reasons we have:

The ratio - if the ratio of the CT is not correct in a differential protection scheme then the scheme will be tripping incorrectly. If it is used in a line protection scheme then the reach of the relay will not be shorter or longer than what is expected.

The polarity – if connected with incorrect polarity, the protection scheme will trip immediately upon energization. In a line protection scheme, the protection will be looking in the opposite direction than expected.

The secondary winding resistance - is part of the burden on the CT. By measuring it, we not only determine the internal burden of the CT, but are also checking the continuity of the circuitry. A CT with inadequate accuracy, or one that is overburdened, will not be able to drive the secondary current through the relays of the protection scheme. The same applies to a damaged core or shorted turns.

Insulation resistance – checks that there are no unwanted grounds on the CT and that its winding and wiring insulation is adequate to withstand the voltage that may be developed across the winding during a fault condition.

Excitation current and power loss – allows one to determine the relaying accuracy of the CT as well as to check for any problems with the CT, such as shorted turns, damaged core and the like.

TRADITIONAL INSTRUMENTATION.

The traditional instrumentation for conducting all of these tests consisted of many individual pieces of equipment.

For determining the ratio and polarity – a ratio meter of some description would be used. For measuring the continuity and winding resistance – a bridge of some description, or a low resistance ohmmeter would be used.

The excitation test is the most complex one as it requires a variable source of voltage capable of delivering substantial current (VA), a voltmeter, an ammeter and a wattmeter of suitable range. This instrumentation was especially cumbersome as ranges of current from milliamperes to amperes and voltages from a few volts to hundreds of volts had to be accommodated.

A 500/1000 volt insulation tester was required to measure the insulation resistance of the CT secondary winding.

The demagnetizing would be typically carried out as part of the excitation test, using the same equipment.

The advent of modern digital test equipment reduced the number of individual instruments as a digital voltmeter or ammeter would cover a wide range, thus multiple voltmeters and ammeters would not be required.

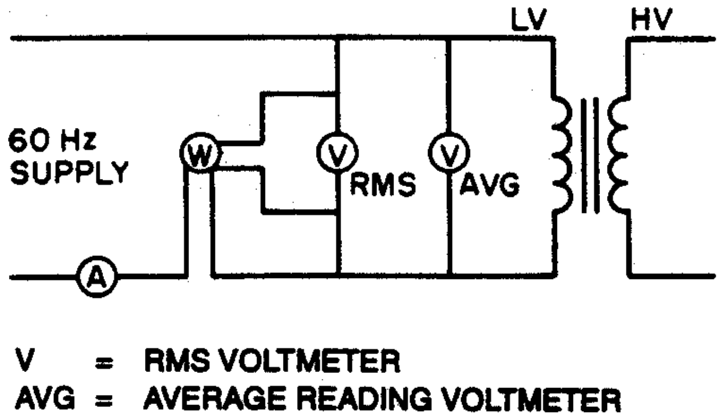

Figure 1. Setup for measuring excitation characteristics of CTs according to ANSI C57.13.

THE TESING PROCEDURE.

Traditionally, the resistance is conducted first, then the ratio and polarity test, followed by the excitation test. The reason for this particular sequence is that the resistance test would magnetize the core of the CT while the excitation test would demagnetize the core.

The testing usually does not present much of a problem except for the excitation test. Here one experiences a lack of appropriate instrumentation – such a “flux voltmeters” as well as low current and low voltage wattmeter. As the CT contains a magnetic core, the test is subject to influences that will depend on the test frequency and the harmonic distortion of the test voltage. As the magnetic core is not linear, the test results will also depend on the excitation source, especially on its output impedance.

The result of all of this is that it is rather difficult to conduct an excitation test over the required range and then to compare it to previous tests, such as those from the factory. As the excitation sources are different and the instrumentation is not identical, the results are typically not comparable but questionable.

ALTERNATE TEST METHODS.

Perhaps the main problem with testing the relaying performance of a CT is the lack of appropriate instrumentation for testing the characteristics of the magnetic core of the CT. The typical tests with rms responding voltmeters and ammeters is accurate only under sinusoidal excitation conditions. It can be shown that if the excitation testing was done using a “flux voltmeter” and a “peak reading” ammeter, then the test results would be independent of harmonic distortion in the excitation source, thus they would always be comparable – as long as the test frequency would be maintained. As neither flux voltmeters nor peak reading ammeters are readily available, they are not specified in typical standards or test guides.

Realizing that we have a non-linear magnetic element in the CT, we should tailor the test method to deal properly with the magnetic element, especially with its non-linearity. The test method presented here plays special attention to the characteristics of the magnetic core. The method determines the characteristics of the CT core using direct current and then converts this characteristics to current and voltage values.

THE THEORY.

Going back to physics and lessons in electricity and magnetism in particular, we know that the voltage developed in a coil is proportional to the “rate of change of magnetic flux”, or e = dÔ/dt.

Intergrating both sides of this equation with respect to time, we have the integral of ‘e’ being proportional to ‘Ô’, the flux in the core. The integral of ‘e’ is the area under the excitation voltage curve. With the vertical dimension being voltage and the horizontal dimension being time, the unit of flux (Ô) becomes “volt-seconds”. Herein lies the problem with the repeatability of typical excitation tests, as it is not the test voltage, but the “integral” of the test voltage that is proportional to magnetic flux (also the magnetizing current).

Knowing that the application of “volt-seconds” to the magnetic structure of the CT will result in a flux (Ô) in the core and a certain magnetizing current to be drawn, we can chose to apply these “volt-seconds” by other means than a voltage at the power frequency of 50 or 60 Hertz. A test at 50 Hz applies many repetitive cycles of relatively high voltage (V) but applies them for a very short time – namely 10 milliseconds. One could choose to test the CT at one-tenth the frequency (5 Hz) by applying only one-tenth the voltage (V/10), wherein the “volt-seconds” would be applied over a period of 100 milliseconds. One could even chose to test the CT at one-hundredth the frequency (0.5 Hz), by applying one-hundredth the voltage (V/100), wherein the “volt-seconds” would be applied over a 1 second period. One could even apply a DC voltage “V” for a period of time “s”, which would apply the required “volt-seconds” (Vs) for testing the CT.

The above justification indicates that one does not need to apply a power frequency voltage to test the performance of a relaying current transformer. With appropriate instrumentation the test could be performed using direct current excitation of the CT.

THE MODERN TEST EQUIPMENT.

The aim of the development of modern test equipment for relaying CTs has been to design a piece of test equipment that would provide reliable and repeatable test results for all the required quantities. This meant that the equipment's test results must not only be repeatable but also should not be affected by line frequency or distortion. The test results must be but also comparable to the test results using "ideal test equipment".

It was realized very early in the development that to make it reliable and repeatable, the test would have to be conducted using direct current excitation, as alternating current excitation was subject to errors due to frequency and waveform distortion (harmonic distortion). Furthermore, it was very apparent from the beginning that power requirement for testing with direct current was very low, say 1 to 10 watts, whereas testing with alternating current required power in the vicinity of 1kVA. This reduction of power requirement makes it possible to make the relaying CT test set portable. A further advantage of direct current excitation is its safety. A CT with a knee-point of thousands of volts can be safely tested using low voltage.

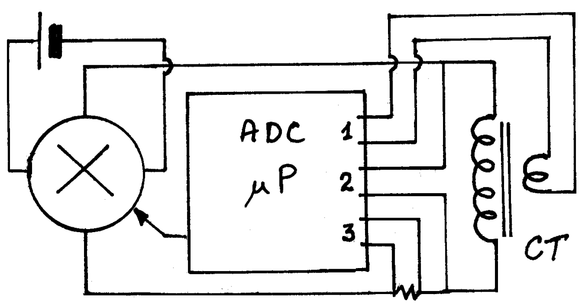

Figure 2. Basic diagram of the Relaying CT Test Set.

Thus, a CT Saturation Test Set was designed using a microprocessor, a multi-chanel analog to digital converter, some controls and an operator interface. The excitation test was programmed as per the outline under the "excitation tests', below. In addition to the excitation test, the microprocessor was programmed to conduct the following tests:

The ratio and polarity of the CT would be made be exciting the secondary of the CT with a square waveform of 12 volts peak. The frequency of this waveform would be variable, so that even CTs with very low knee-point voltages could be tested. By measuring the applied voltage and the polarity and magnitude of the voltage induced on the primary, the ratio and polarity of the CT would be accurately determined.

The secondary winding resistance would be measured once the CT was saturated and drawing current. By measuring the voltage drop across the secondary winding and knowing the test current, the secondary winding resistance would be determined.

The insulation resistance of the winding would be determined by applying a test voltage of 500 volts and the winding's leakage current to ground would be measured.

The excitation current and power loss would be measured by conducting a series of tests on the CT that are similar to the "Epstein Frame Test". As the core in the CT is not a "sample", but is typically a complete toroid, it does not require an Epstein Frame arrangement, but can be tested using a test popularly referred to as the "Rowland Ring Test".

The conventional method of conducting the Rowland Ring Test is identical to that of the Epstein Frame Test, namely a known current is applied to the test winding while the voltage across the winding is integrated using a ballistic galvanometer. As the ballistic galvanometer integrates the applied voltage, its calibration is in volt-seconds or similar units. In the modified Rowland Ring Test used in the test set, a fixed voltage is applied to the winding while the voltage across the winding and the current through the winding are measured at precise intervals. The measuring intervals are very short, typically in the microsecond range. By integrating the applied voltage during the saturation process the magnetic flux in the core can be calculated. By using proper scaling factors, the magnetic field can be converted to voltage and then plotted against exciting current. Two graphs can be plotted from the results. One graph would be that of rms voltage at a frequency "f" (assuming sinusoidal excitation) against rms current. The other graph would be of flux voltage against peak current. The second graph is actually a plot of many "end points" of individual hysteresis loops. A more precise explanation of the process is provided below.

THE EXCITATION TEST.

The excitation characteristics curve is plotted using anywhere from 20 to 40 points. Each point on the curve is the result of calculations based on one "hysteresis loop".

Thus, to accomplish this, 20 to 40 hysteresis loops, each consisting of 200 to 800 readings of excitation voltage and current are taken. The voltage readings are integrated over the test period to provide a measure of voltage, while an rms calculation is performed of the current readings to provide an rms value of the excitation current. The same 200 to 800 readings are used to calculate the excitation volt amperes, power loss and excitation power factor for each hysteresis loop.

The excitation test is conducted starting with the largest hysteresis loop, the loop using the highest current. The applied volt-seconds and thus the excitation current are slowly decreased for each successive hysteresis loop until the applied volt-seconds are only a few percent of the saturation volt-seconds.

Conducting the hysteresis loop test with direct current allows one to calculate the residual magnetism in the core. This measurement can be conducted ONLY ONCE, as the core is demagnetized during the test.

It should be noted that this process not only provides the 20 to 40 points for the excitation curve, but at the same time the CT core is demagnetized, leaving typically less than 3% remanence.

Thus the excitation test is conducted with direct current using an automated Rowland Ring Method, and the results are used to calculate the rms voltage and rms current at any prescribed frequency. These dc test results can be converted into ac excitation values for frequencies of 25, 50, 60 Hz or other frequencies.

INTERESTING MODIFICATIONS.

Most professionals dealing with electricity and magnetism know that losses in magnetic materials comprise of two components, namely “Hysteresis Loss” and “Eddy Current Loss”. Once the discussed test equipment was operational, it was soon realized that by modifying the Rowland Ring Test sequence, it would be as possible to measure these two loss components separately. As is known, this is the first time that separate measurements of hysteresis losses and eddy current losses have been possible by any instrument.

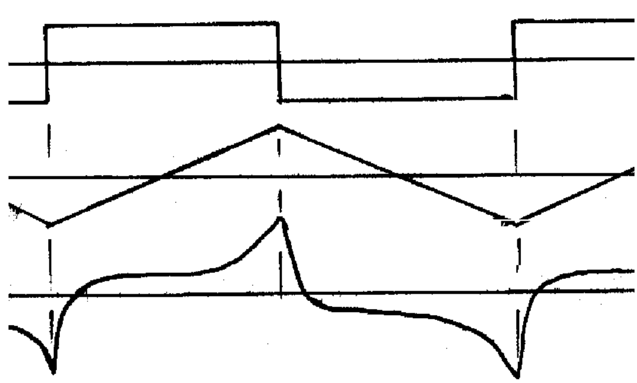

Figure 3. Conventional method of conducting a Rowland Ring Test.

Top – applied voltage – (+) & (—).
Center – Flux in CT core (volt-seconds).
Bottom - Exciting current.

The separate measurements of hysteresis and eddy current losses are important as they can identify problems with current transformers. Whereas hysteresis and eddy current losses are characteristics of the core material, an increase in eddy current losses are indicative of shorts on the core including shorted turns on the winding or shorted turns due to defective mounting arrangements.

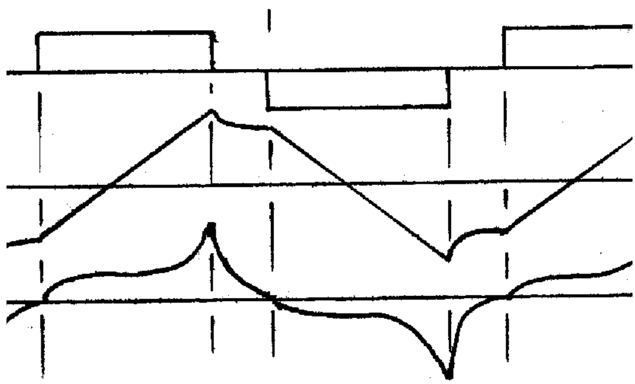

Figure 4. Modified method of conducting a Rowland Ring Test.
Top - Applied voltage – (+), (0), (—), (0).
Center - Flux in CT core (volt-seconds).
Bottom – Exciting current.

CONCLUSIONS

A project to develop a "relaying CT test set" resulted in not only a test set that provides all the measurements required by typical standards, such as ANSI C57.13, but also provides valuable addition information. The instrument provides a measure of residual magnetism in the CT core, automatically demagnetizes the core and can distinguish between hysteresis and eddy current losses in the transformer. Although applied to current transformers, the principles employed here can be equally applied to large power transformers.

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