Frequency domain spectroscopy of current transformers can now be achieved by using the right test equipment

Introduction

Frequency domain spectroscopy (FDS) is an invaluable tool for determining the moisture content of the solid insulation in combined oil-paper insulation systems. In particular, work carried out in North America and Europe has verified the effectiveness of FDS as way of determining the moisture content in instrument transformers and, more specifically, in high voltage current transformers (CTs). This article describes FDS testing of CTs. It includes configuration data and a step-by-step test procedure using the Megger IDAX300 test set.

The dynamic properties of dielectric materials can be measured in the time and/or frequency domain. The fundamentals of dielectric response functions and the theory of dynamic properties of dielectrics are well described in several publications and, in particular, in a very detailed way in two articles by W S Zeangl, which appeared in the IEEE Electrical Insulation Magazine Vol. 19, 2003.

The traditional dissipation factor testing technique allows identification of the deterioration process of the insulation by measuring the changes in the dielectric properties of the tested unit. This approach involves measurements of capacitance and dielectric loss quantified by the loss or dissipation factor. This type of testing is part of many manufacturing quality control procedures but it is normally carried out at power frequency only. With FDS, however, a wide frequency range from 0.001 to 1000 Hz is used, and this allows the determination of the moisture content in the solid insulation.

Water significantly accelerates the ageing of cellulose. Oil analyses by means of Karl Fischer titration (KFT) have traditionally been used for the evaluation of moisture content, assuming existence of equilibrium in distribution of moisture between oil and paper/pressboard. In reality, the analysis only reflects the moisture percentage in the liquid insulation and equilibrium curves are required to estimate water content in the cellulose insulation. The equilibrium curves are a useful reference but their reliability is still a topic of discussion. Moreover, continual sampling for DGA and water content analysis is not recommended for CTs due to the small volume of dielectric oil they contain. “A chain is no stronger than its weakest link”.[1868 L. Stephen in Cornhill Mag. XVII. 295]

Failure of a substation-type oil-immersed CT can lead to a high-energy release and thermal runaway, very possibly ending in an explosion (see Figure 1). Because of the difference in thermal expansion ratio between the metallic housing of the CT and the relatively fragile porcelain insulator, mechanical stress builds up, resulting in a blast where fragments from the porcelain insulator may reach up to 50 m from the location of the unit. Loss of this important device results in phase to ground fault that will trip the substation, shut down operation and possibly affect other electrical components in the vicinity.

In some applications, the core housing can accommodate up to six independent multi-ratio cores feeding protection relays, or cores feeding a combination of relays and meters, requiring up to 30 secondary leads. More details of the construction of oil-immersed CTs can be found on manufacturers’ websites and literature.

A very real concern

The issue of exploding CTs is currently a very real concern as, in Europe and North America, there have recently been several catastrophic failures of hermetically sealed units in sub-station applications. Initial investigations carried out on CTs similar to those that have failed, using dissolved gas analysis (DGA), have revealed that the failures are due to moisture ingress, and that many CTs still in service are at risk of similar failures. Regular CT testing is, therefore, increasingly seen as essential but, as has already been noted, tests that involve oil sampling, which includes DGA testing, cannot be used regularly on CTs because of the small volume of oil they contain. FDS testing, which eliminates entirely the need for oil sampling, is therefore establishing itself as the preferred approach.

Performing FDS tests on an oil-immersed current transformers

First make a visual inspection of the unit and its surroundings. Ensure that local safety procedures (tag-out/lock-out) have been observed and that the test area is properly identified and is free of obstacles on emergency evacuation paths. The procedure for testing a HV CT uses the same configuration as that used to perform power factor/dissipation factor tests. Thus, the unit must be isolated from the power system (primary as well as secondary winding) and discharged. If the test is to be performed after a through fault, it must also be demagnetized. As a general rule, when a series of tests is to be carried out on an HV CT, DC tests should be performed last. With a clear area of operation established, confirm that good connections have been made to the unit under test (UUT), to the substation's ground system, and from the test instrument to the same grounding point. Typically, the ground terminal of the test equipment is connected to the same ground terminal on the secondary box of the CT. The CT is tested using the standard method. This implies energizing the primary winding and measuring the secondary connected to ground.

Current transformers belong to the group of electrical apparatus dedicated for the protection of electrical systems and measurement of control parameters, although they are not protected themselves. Every time the Technical Support Group carries out a Substation Best Practices Seminar, one of the questions we ask the audience is: "How often do you test your CTs?" and the answer is usually close to never. Let's summarize several examples of testing CTs and determining the moisture concentration of the units.

Factory samples

In North and South America brand new CTs were tested, some in the factory and others at the end-user's facility. The S shape curve is similar to those obtained from power transformers.

The information gathered during the test was sent to MODS, Megger's proprietary software algorithm created as a result of co-operative research with a number of large transformer manufacturer's around the world.

Something to note and take into account when analysing moisture concentration on CTs is that there are no spacers physically in the unit and therefore the Y% value is set to zero. Because this is brand new oil, the conductivity was found to be very low but the moisture concentration (2.4%) is higher than would normally be seen on power transformers. In a similar procedure, another sample unit was tested after passing all acceptance factory tests and the shape of the curve was mainly influenced by the cellulose part of the insulation and the numbers obtained after analysis using MODS confirm similar geometry, similar quality of the liquid insulation but a lower moisture concentration compared with the previous specimen.

It is not possible here to include all the different tests used to validate the application on CTs, but it is the intention of this article to look at the most informative results, so as to provide the reader with enough guidelines to recognize and understand the results of the DFR technique as applied to CT testing.

Sample units 1 and 2 are from the same manufacturer and have a similar voltage rating. They were tested under factory conditions.

For the next example, Sample Unit 3 was acquired by the end-user and stored as a spare. The end-user requested that the unit should be tested to verify the quality of the insulation of the CT prior to bringing it on-line.

The shape of the curve was similar to those observed previously, but there were not enough data points for a more accurate analysis.

Now let's look in the opposite direction. An operational CT (Sample Unit 4) with over 5 years of service was contaminated by opening it in the field and changing the seal on one of the high current terminals. This operation allowed ingress of moisture, leading to the results shown below.

Looking in detail at the shape of the curve, it is clear that the effect of the contamination is that the power factor value at lower frequencies tends to unity, specifically in the region where solid insulation has the largest influence. There are two important things to highlight. The first is a similar geometrical characteristic with a lower X% (barriers) due to possible insulation degradation. Second is a high moisture concentration together with high oil conductivity. This means that the unit was not only contaminated with external moisture but also carbonic by products were dissolved in the oil and therefore increased its conductivity. This unit was removed from service and sent to dry-out and internal inspection. In summary, experience of using DFR (Dielectric Frequency Response) using a Megger IDAX300 tester on oil-immersed current transformers has provided the following guidelines:

GST measurements are recommended as first choice since many CT's do not have a test tap. (UST measurements should be used if the CT does have a test tap/F-tap) GST measurements can be performed on all types of CT but have the disadvantage of being more sensitive to noise/interference and also to leakage currents on the outside of the unit. The normal procedure to prevent this is to make sure the unit is dry and cleaned before the test. Recording ambient temperature and humidity is always recommended. Measuring GST guard using a conductive collar strap can reduce leakage currents due to dirt and/or condensing water on the outside enclosure of the tested device.

- **The conductivity of the oil reflects the degree of concentration of contaminating by-products, which are usually a result of solid and liquid insulation degradation. The oil conductivity in a brand new current transformer is typically close to the 1.00E-14 range.**
- **A conductivity value above 5.00E-11 is an indication of aged oil and conductive sediments, possibly resulting from overheating of the solid insulation.**
- **Moisture analysis of cellulose is temperature dependent. It is important to correctly estimate the test object's temperature. Refer to the manufacturer's manual for the heat run test analysis, as this should provide information about the expected temperature at certain load levels. Best practice is to allow cooling to a stable temperature prior to running the test.**
- **Current transformers are available in different types and constructions, but they normally have an oil level gauge. This should be used to confirm that the oil level in the tank is correct.**
- **The range of frequencies needed to obtain an accurate estimate of moisture concentration is from 1000 Hz to at least 1 mHz.**
- **Compared to moisture assessment in oil-immersed power transformers, moisture estimation in CTs is a relatively new application. However the basic theories on insulation modelling are well proven and there is no reason to believe that this application should be significantly different from the power transformer application.**

Classification

A classification guideline based on analysis of measurements on numerous current transformers in various conditions has been established. Significantly aged units had moisture contents of more than 4% (sometimes considerably higher). The following table could be used as a reference/benchmark when classifying current transformers (head-type) by moisture content.

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ABSTRACT: FDS testing of high voltage CTs is now well-established. It is essential to avoid potentially lethal situations where transformers might explode. Close analysis of the moisture content is a critical step in avoiding catastrophe, and correctly setting up the test equipment is consequently vital.

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