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Field Measurement of Transmission Cable Dissipation Factor

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Abstract

This presentation describes instrumentation that has been developed to measure the dissipation factor of in-service transmission cables. Measurement experience to date is also presented.

1. Background

Insulation dissipation factor or *Tan δ* measurements are the primary quality control measurement for oil impregnated paper insulation. Basically, it measures the dielectric losses in the cable system. This measurement is a routine factory test for all production cables[1],[2] and has also been used for long term qualification testing to determine the amount of deterioration of oil impregnated cable insulation. If there are irreversible increases in the cable insulation dissipation factor, then either the insulation has been contaminated or aging of the cable insulation has occurred.

There are two primary reasons why cable insulation dissipation factor measurements are not made on transmission cables after they are installed in the field. First, it is necessary to be able to "collect" the cable charging current and force it to flow through a dissipation factor measurement instrument. Since pipe-type cables and other transmission cables are grounded at more than one place it is not practical to "lift the grounds" and connect them to an instrument. An EPRI developed instrument[3] solves this problem by measuring the current that flows into the cable at the terminations by means of a fiber optic cable link. The second problem in making dissipation factor measurements on transmission cables is that it takes a large power supply to energize the cable -- even at several kV. The EPRI instrument uses the power system to energize the cable - from one end.

2. Dissipation (Tan δ) Measurements

Dissipation factor is defined as the ratio of the real power generated by losses in a dielectric divided by the total voltage applied to the dielectric times the magnitude of the current flowing through it .

Dissipation factor measurements are also called *Tan δ* measurements in International Electrotechnical Commission (IEC) and other test standards. This is because the dissipation factor is numerically equal to the tangent of the angle (δ) between the current flowing through a dielectric and a quadrature current that would flow through a loss free capacitor (see Figure 1).

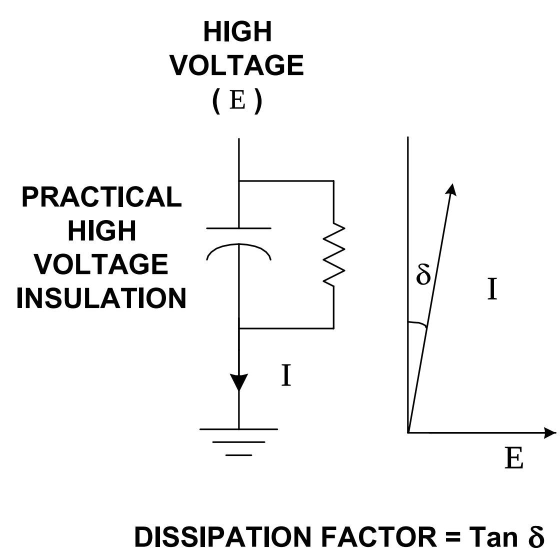

Figure 1. Phase relationship of currents in insulation

The losses in the capacitor (represented by the parallel resistor) are caused by dielectric polarization losses, conductance of the insulation, and partial discharges in some cases.

Tan δ measurement are normally made in high voltage testing laboratories using a transformer ratio-arm bridge shown in Figure 2.

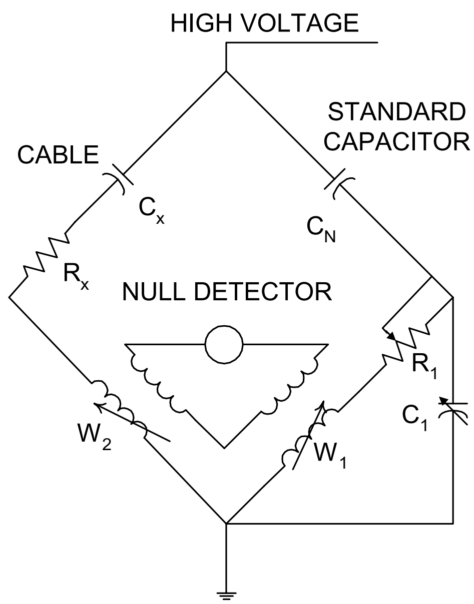

Figure 2: Transformer Ratio-Arm Bridge

With the transformer ratio-arm bridge the phase angle of the quadrature current flowing through a compressed gas standard capacitor, C_N, is shifted by means of the potentiometer, R_1, until it is in phase with the current flowing through the cable insulation I_x. When the bridge is balanced, *Tan* δ is numerically equal to the product $R_1\ \omega\ C_1$ (where ω is the angular frequency of the test voltage).

There are two difficulties in using the transformer ratio-arm bridge (Figure 2) to measure the dissipation factor of in-service transmission cables. These are:

1. In most cases it is not practical to collect all of the cable charging current and force it through a bridge circuit.
2. Compressed gas standard capacitors used in laboratory measurements are large and difficult to transport in the field.

3. EPRI Tan δ Measurement Equipment

The Electric Power Research Institute (EPRI) funded research to develop equipment suitable for measuring the dissipation factor of in-service transmission cables. This was accomplished as follows.

- A low inductance shunt is placed in series with the cable transmission cable (Figure 3) to create a voltage signal that is in phase with the cable charging current.

Figure 3: Current shunt and fiber optic link.

- This signal is transmitted to a device at ground potential via a voltage to frequency converter and a fiber optic data link.
- A precision frequency to current converter is then used to create a scaled analog of the cable charging current at ground level.
- The recreated, scaled cable charging is then fed into a conventional transformer ratio-arm bridge to measure the phase angle between the cable charging current and the charging current in the standard capacitor.

- A relatively compact and rugged high voltage standard capacitor (Figure 4) with polypropylene insulation is used in place of the usual compressed gas standard capacitor.

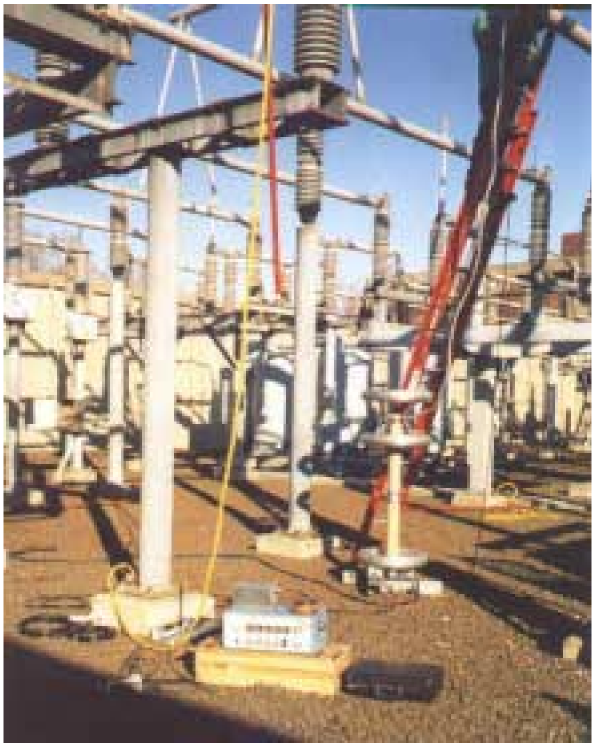

Figure 4: Standard capacitor and bridge

Figure 5 shows a schematic of the circuit used to make rated-voltage, field dissipation factor measurements on transmission cables.

The following corrections must be made to the dissipation factor measured by the transformer ratio-arm bridge at ground level.

- The polypropylene standard capacitor has a low, but not negligible, dissipation factor. Therefore, the bridge readings must be adjusted to take this into account.
- The electronics in the charging current isolation system also introduce a small, but constant, phase shift that must be taken into account.
- The transmission cable is not a lumped capacitor as shown schematically in Figure 5. Adjustments must be made to account for the losses in the cable conductor created by the cable charging current .

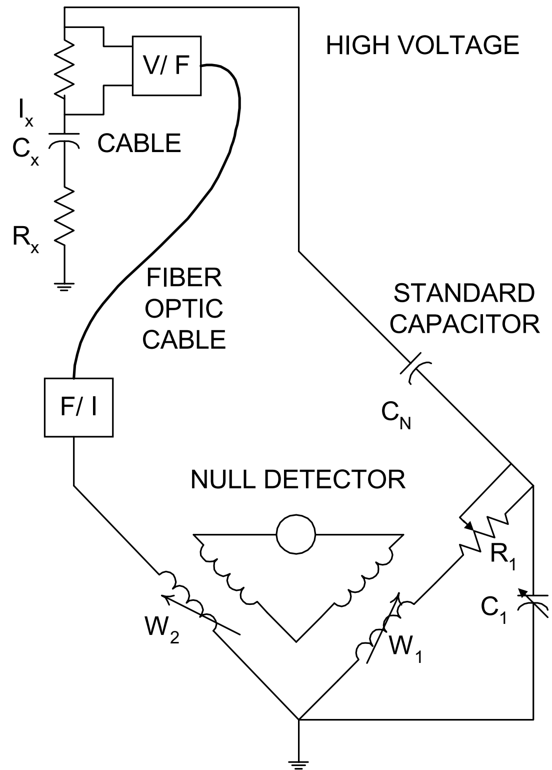

Figure 5: Modified bridge for field measurements

4. Applicability To Transmission Cables

Although the EPRI instrumentation can be used to perform dissipation factor measurements on any type of cable, it was primarily developed for cables with oil-impregnated paper insulation because of the following reasons.

- It is well known that cellulose insulation deteriorates with time and elevated operating temperature. This is primarily due to the fact that moisture is produced by deterioration of the cellulose component of the insulation. The moisture, in turn, results in a general increase in dielectric losses.
- Dielectric losses in XLPE transmission cables are very low and failures are usually the result of very localized discharges. The dissipation factor measurement is not well suited for detecting localized problems.

5. Measurement Procedure

The transmission cable must be energized from one end only during the measurements. This is because the instrument measures the losses in the cable insulation, and the only way of doing this is to disconnect an energized cable from the rest of the power system and to very accurately measure the angle between the cable charging current and voltage. It is also standard measurement procedure to disconnect any surge arrestors at the “far” end of the cable circuit; however, losses in surge arrestors are negligible in most cases.

5. Interpretation Of Measurement Results

Insulation dissipation factor measurements give an indication of the average condition of the cable high voltage insulation for the entire length of cable that is being measured. Dissipation factor measurements will not detect very localized problems in a cable system. Also, the dissipation factor of oil impregnated paper varies somewhat with temperature. Therefore, like many other diagnostic tests, a single measurement will not yield a good indication of whether a cable feeder is good or bad unless the condition of the cable is very bad or the temperature is known along its length. Since the temperature of the cable along the length of the circuit is usually not known, the measurements have to repeated at different times to determine if there is a trend of increasing dissipation factor.

5. Measurement Objectives and Experience

Dissipation factor measurements have been made on numerous transmission cable circuits using the instrumentation shown in Figures 4 and 5 for the following reasons.

There are numerous pipe-type and self-contained fluid-filled (SCFF) transmission cables in North America that have exceeded their planned 40-year service life. Many of the electric utilities that own these older transmission cables are faced with the question of whether or not these cables are near the end of their service life. If they are, then plans and financing must be set in place for their replacement. Since insulation dissipation factor of oil-impregnated paper insulation increases with thermal aging, it is one of the most suitable, non-destructive, measurements to determine loss-of-life of the cable insulation. This being the case, the EPRI developed dissipation factor instrumentation has been used in numerous cases as a tool to estimate the remaining life of older pipe-type and SCFF cable systems. In almost all cases the dissipation factor measurements have indicated that these cables have not deteriorated significantly over 40 years (or more) of operation.

Field dissipation factor measurements have also been used to assess the condition of pipe-type and SCFF cables after major repairs. There are several cases where cable systems have been mechanically damaged and repaired. Dissipation factor measurements were then made to detect if a significant amount of moisture has entered the high voltage insulation as a result of the damage to the cable.

In one incident fluid pressure had been lost in one hydraulic section of a 115 kV SCFF cable system, and there was concern that continued operation with little or no pressure may have resulted in damage to the cable. Dissipation factor measurements indicated that there was no significant damage to the high voltage insulation. This conclusion was based on comparison with previous dissipation factor measurements and by comparing the dissipation factor with other cable sections. The cable system was placed back in services and it has operated without incident for several years since that time.

In another incident dielectric fluid samples from a relatively old 230 kV SCFF cable system indicated that the dissipation factor was well above acceptable limits. This utility replaced the dielectric fluid but was concerned that the cable insulation may have deteriorated as a result of exposure to the contaminated dielectric fluid. Dissipation factor measurements confirmed that dielectric losses in the high voltage insulation had increased significantly since it was manufactured. The utility used the measured dissipation factor to reassess the ampacity or book rating of the circuit. The measurements also revealed that the dissipation factor in one phase was significantly higher than the other two. A fault occurred in the phase with the high dissipation factor several months after the dissipation factor measurements were made.

6 Conclusions

Field dissipation factor measurement for oil-impregnated paper transmission cables is a useful tool to access the general condition of the high voltage insulation. However, since it measures the average dielectric losses of the entire length of the cable system, it may not detect localized problems.

It is a tools to assess whether or not there has been generalized deterioration of the high voltage insulation.

Although the dissipation factor measurement equipment described in this presentation was developed for transmission cables, it is believed that it would also be a useful diagnostic tool for distribution class PILC cables.

References

/1/ AEIC CS7, *Specifications for Paper-Insulated Cables, High Pressure Pipe-Type*, Association of Edison Illuminating Companies.

/2/ AEIC CS4, *Specifications for Impregnated-Paper Insulated Low, and Medium Pressure, Self-Contained Liquid Filled Cables*, Association of Edison Illuminating Companies.

/3/ EPRI TR-102449, "Field Measurement of Cable Dissipation Factor", Electric Power Research Institute, Palo Alto, CA, May 19