

An Electrical Test Procedure for Determination of Copper Sulfide Contamination in Transformer Windings

Lance R. Lewand, Doble Engineering Company

INTRODUCTION

Over the past several years there has been much work performed to determine if an oil has corrosive sulfur present. This includes methods to determine if the corrosive sulfur will react with copper to form deposits in the paper insulation and the tendency of some oils to become corrosive with time and temperature.

To date, oil tests can only provide information about the characteristics of the oil itself and not if the windings of the transformer have been compromised in any way through deposition of copper sulfide on the conductor or the paper insulation surrounding that conductor. As copper sulfide contamination in the windings may lead to the failure (due to compromised insulation) of the transformer, it is very important that the condition of the winding can be evaluated in some manner.

Doble embarked on a research program to determine which electrical tests, if any, could be used to determine if copper sulfide contamination existed in the winding. Various techniques such as DFR (dielectric frequency response), SFRA (sweep frequency response analysis), leakage reactance, and normal power factor measurements were employed but did not yield satisfactory results or information that could be used as a diagnostic.

On-line partial discharge testing may also not prove useful or successful in alerting of an impending failure. This is due to the fact that many of the failures do not exhibit the gassing involved in an incipient-fault condition. For example, during review of several failure investigations, samples taken for DGA shortly before failure (in one case the day before) exhibited a gassing profile that was the same as previous samples and showed no increase in combustible gases associated with partial discharge.

Copper sulfide contamination in a transformer is very localized in a majority of the failures that have been reviewed. As such the test technique would have to stress the winding to a point where that localized contamination would be revealed as a deviation from a normal value usually obtained when compared to a non-contaminated winding. Continued research clearly showed that a variation of the Doble power factor tip-up test employing test voltages above 10 kV and up to 35 kV yielded very discerning results when copper sulfide was present both in research samples and in actual transformers. This test was termed the “high-voltage power factor tip-up test.”

What is the High-Voltage Power Factor Tip-Up Test?

If the measured power factor increases as the applied voltage is increased then this is what is referred to as power factor tip-up. Experience has shown that transformers with good insulation do not experience tip-up. Normal power factor tip-up testing is usually

performed between 2 and 10 kV. Why the test is important in this situation is because moisture and polar byproducts do not influence tip-up. Rather, tip-up is caused by discharge, partial discharge activity or from the resulting byproducts and conductive material such as fine metal debris and copper sulfide. This makes it an excellent tool for determination of conductive contamination in a winding.

Laboratory studies under controlled conditions clearly showed that power factor tip-up testing was the best indicator as well as the most sensitive and distinctive for copper sulfide contamination. The more serious the deposition the higher the power factor and the tip-up. Refer to Figure 1.

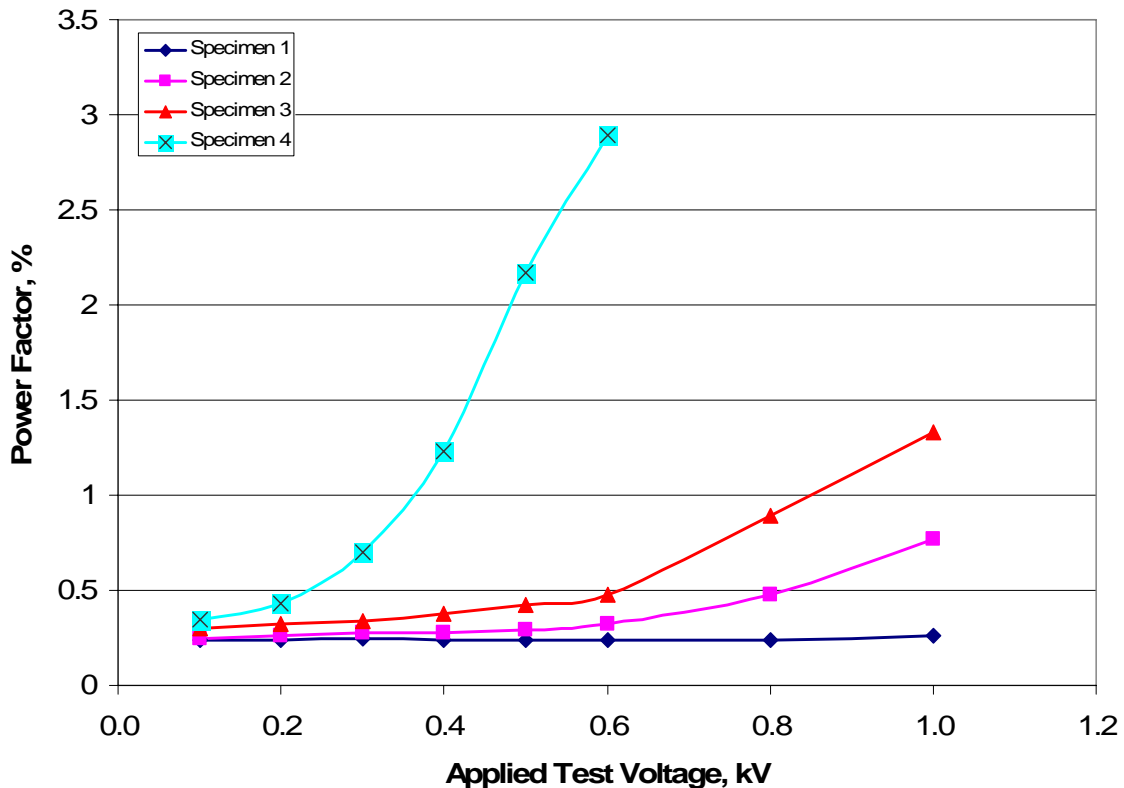


FIGURE 1

As shown in Figure 1, insulating paper contaminated with varying amounts of copper sulfide did not require >10kV to show the effects of copper sulfide contamination in the power factor tip-up test. The blue line represents a non-contaminated paper and as such shows a straight line with increasing voltage. Specimens 2 through 4 show an increase in power factor with an increase in voltage. The amount of power factor increase (tip-up) is directly related to the amount of copper sulfide contamination present as specimen 4 has the most contamination, followed by Specimen 3 and then Specimen 2 which is contaminated but has the least amount.

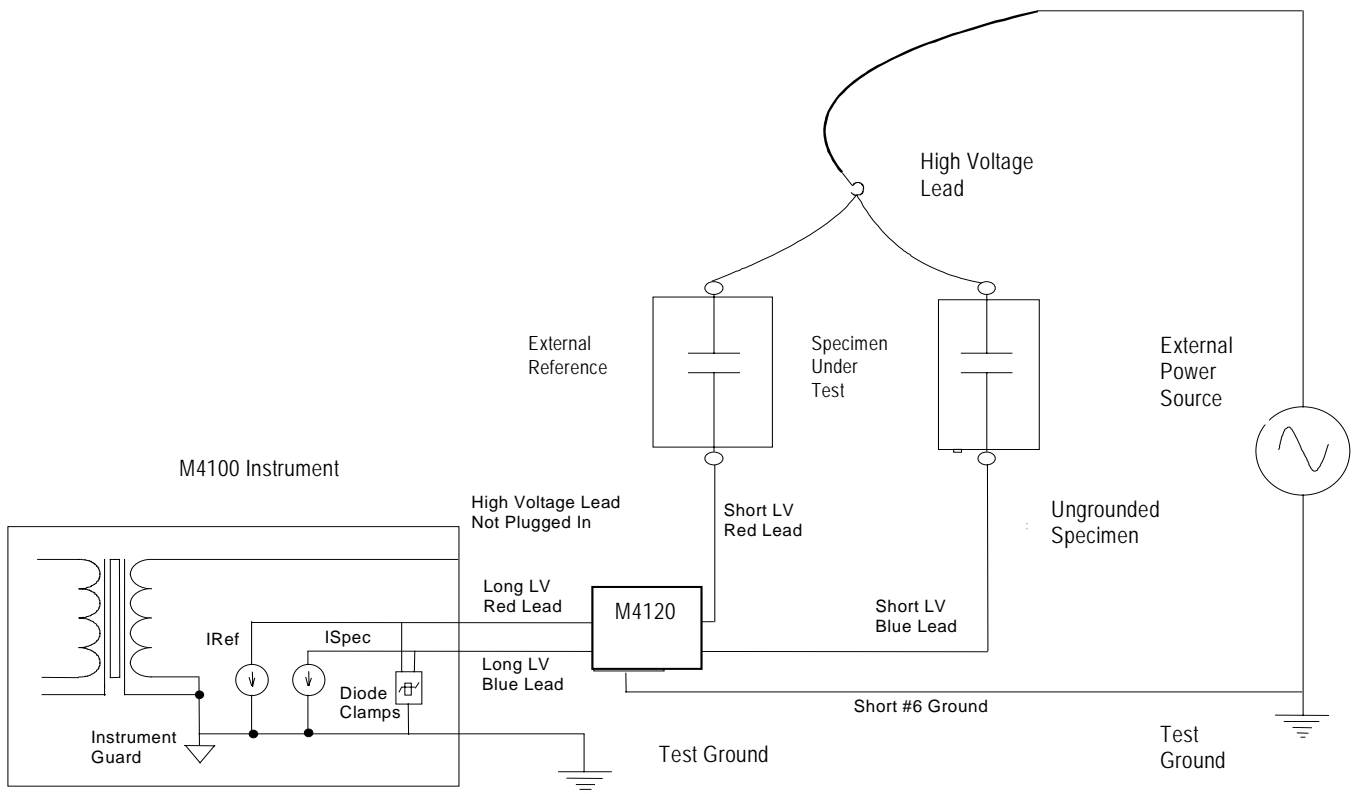
In experiments involving parts of the contaminated windings, transformers and reactors themselves, the necessary voltage to achieve power factor tip-up was always above 10 kV and up to about 30 kV depending upon the apparatus and the configuration.

How is High Voltage Power Factor Tip-Up Performed?

This measurement is made through the use of several pieces of instrumentation. The use of the Doble M4100 (power factor measurement system) or other types of measurement bridges are required and serves solely as the measurement instrument and operates in conjunction with an external reference and power supplies:

- The external reference, typically a capacitor, provides the means for M4100 measurement to measure the test voltage. The M4100 monitors the voltage, displays the test potential and uses the voltage as the reference in calculating the real and reactive components of the measured current.
- The external power supply, usually a step-up transformer, provides the test potential. If tests are to be performed in the Grounded Specimen Mode (GST), the power supply should be designed to allow for its losses to be guarded away. To prevent the losses associated with the power supply from affecting the GST measurement, the guard plain of the power supply must remain isolated from ground and connected to the guard point on the M4100.

Figure 3 is a schematic of a connection diagram that Doble uses to carry out the measurement. In all cases the specimen under test (transformer, reactor, etc.) must be disconnected and isolated from the electrical system.



**TEST SETUP WITH M4120 EXTERNAL REFERENCE MODULE
FIGURE 3**

CONCLUSION

Transformers that are suspected of being contaminated with corrosive sulfur should be subjected to the oil tests as indicated in previous articles. In addition, the condition of the winding (which is the limiting factor in terms of copper sulfide contamination) can be determined by the use of the high voltage power factor tip-up test. (Doble can provide an application note that describes the specifics of the test using the Doble M 4100 instrumentation). After the connections are made on the transformer, the test is easy to perform and only takes a few hours. In addition, there is no requirement of modeling the transformer. The test results are easily defined and will provide information on whether or not conductive contamination such as copper sulfide is present and provide a relative indication on the severity of the contamination.