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FEATURE | Power Factor Analysis

ANALYZING POWER FACTOR TEST RESULTS

How industry embraced guidelines can fail the user

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A power factor measurement at line frequency is presently one of the most widely included electrical field tests in the industry and is counted upon to facilitate a routine appraisal of the dielectric well-being of a power asset in the field.

Power factor can be effective in determining, on a general level, whether an insulation system is clean and dry, or conversely, if it is no longer performing its use efficiently or adequately. But does the industry expect too much from this measurement?

Understanding the shortcomings of this diagnostic tool not only answers this question but also, together with the lessons from a sister test (the variable frequency power factor test), shows why the common approach to analyzing power factor test results can lead to poor, resultant decisions and ought to be rethought.

SHORTCOMINGS

The shortcomings of a single, line frequency power factor measurement include:

I AVERAGE CONDITION

A power factor measurement represents the average condition of the total insulation system under test. This power factor measurement deficiency has been resoundingly shouted out for decades. For example, a tester can never be quite sure whether an elevated CHL power factor measurement of 0.6 percent indicates that the interwinding (CHL) insulation system has generally and uniformly become contaminated or whether most of the interwinding system is very healthy barring one localized area of extremely high contamination. The latter is a localized defect and is a more serious condition that typically warrants immediate action, which makes the ability to differentiate between the two (widespread versus localized contamination) vital. You are unable to do this with the power factor measurement. Consequently, users have long been warned of the importance of separating and testing the smallest section of an insulation system possible, so as to minimize an averaging influence in which detail regarding the health of the insulation system becomes lost. The smaller the insulation component tested the more detail that is seen.

II BLIND SPOT

A standard power factor measurement at line frequency (60 Hz) has what equates to a "blind spot". To a long-time subscriber to this methodology, this deficiency is the most disturbing—particularly when you reflect on its far-reaching ramifications. This fact means that an insulation system may be contaminated with moisture, for example, but the level of contamination has not yet been made "visible" whereby the power factor result is affected.

Consequently, the power factor measurement remains unchanged even though moisture contamination (in this example) of the insulation system is increasing. It is not until the degree of contamination advances to a certain level that it then moves into the line of sight of the single, line frequency power factor measurement and is detectable.

III INABILITY TO LABEL THE PROBLEM

When a determination has been made that a system is no longer testing as well, it is impossible to differentiate and characterize these losses, which may indicate moisture, aging, contamination, oil conductivity, or some combination therein.

When the aforementioned shortcomings are considered collectively with the approaches available to analyze power factor test results, the user starts to realize that power factor assessment isn't that straightforward. The tools provided to make the task simpler (guidelines, limits, and a database—between all of which the lines are blurred since limits are derived from a database, and the guidelines are derivatives of limits) can misguide. The result is that the user is ultimately not being served well by the tool in which they have placed so much confidence.

UNDERSTANDING POWER FACTOR

Generally, the power factor is a number that reflects how efficiently the dielectric is fulfilling its purpose of maintaining electrical isolation between points of different potential within an electrical apparatus. Insulation performs this function best when it is clean, dry, and void-free. When insulation becomes contaminated to a large enough degree, the power factor at line frequency responds in turn by changing (normally, increasing). Typically, a smaller power factor (for example, closer to zero) represents an insulation system in better condition.

3 POWER FACTOR ANALYSIS APPROACHES

There are several approaches to analyzing power factor in practice in the industry, and include

ONE: Comparison with benchmark or previous test results (If more than one previous test result is available, trending is possible)

TWO: Comparison to limits or general guidelines

THREE: Comparison to similar apparatus in a database

Notwithstanding the deficiencies of a single, line frequency power factor measurement as a diagnostic tool (see "Three Power Factors" sidebar), which are inescapable despite the analytic approach, the most dependable of these approaches is the first—a comparison with benchmark or previous results, and trending.

When comparing to previous test results, the power factor of an insulation component is not expected to change. A change would warrant additional investigation, first to validate the power factor test result, and if subsequently deemed to be representative of the insulation, to follow with more searching dielectric tests, such as variable frequency power factor or dielectric response measurements. Still, the blind spot exists and you cannot surmise that because the power factor result has not changed from previous, the state of the insulation system has not changed.

The second approach for assessing power factor test results is to apply limits that constitute the general guidelines provided in Table 1. Note that the use and application of these guidelines may result in an inaccurate assessment which leaves us to question whether such guidelines can result in more harm at times than assistance. Those provided in Table 1 are from the IEEE standard 62-1995 – "*IEEE Guide for Diagnostic Field Testing of Electric Power Apparatus - Part 1: Oil Filled Power Transformers, Regulators, and Reactors*"; modifications to this table are anticipated in the future. The standard is published by the Institute of Electrical and Electronics Engineers (IEEE).

As an example of how these general guidelines can fail the user, consider the following example. If an overall power factor measurement for CHL yields a power factor test result of 0.45 percent, by the general industry accepted guidelines this would be considered acceptable. However, if previous test results were available and searched, the user may discover that the transformer had been tested in the preceding year and that this CHL test result was 0.2 percent. Now this most recent test result of 0.45 percent would become cause for great concern.

Procedure	New transformer	Service-aged transformer
Power factor	< 0.5%	< 2.0%
Total dissolved gas*	< 0.5%	< 0.8%
Moisture content	< 10 ppm	< 15 ppm
Turns ratio	Within 0.5% of nameplate	Within 0.5% of nameplate

** If units are equipped with nitrogen blankets, total dissolved gas should not exceed 1.0 percent.*

Table 1: Recommended Diagnostic Characteristics (IEEE Std. 62-1995)

The third approach is to compare the test results to those for similar apparatus as found in a database. It should be noted that a database from which power factor limits as given in Table 1 are incidentally derived is not a consistently reliable tool for evaluation of power factor test results either, particularly because of power factor's blind spot.

For example, we turn to variable frequency power factor, the sister test to a traditional power factor measurement and the tool which exposes the blind spot at 60 Hz (hertz). The variable frequency power factor measurement consists of eight single power factor measurements at discrete frequencies between and including 15 Hz and 400 Hz. The analysis of variable frequency power factor is based heavily on visual analysis. When conductive losses are negligible in a transformer's insulation system, the behavior of power factor versus frequency is such that the power factor is lowest at 15 Hz and progressively increases and is highest at 400 Hz. The resultant curve shape is given in Figure 1.

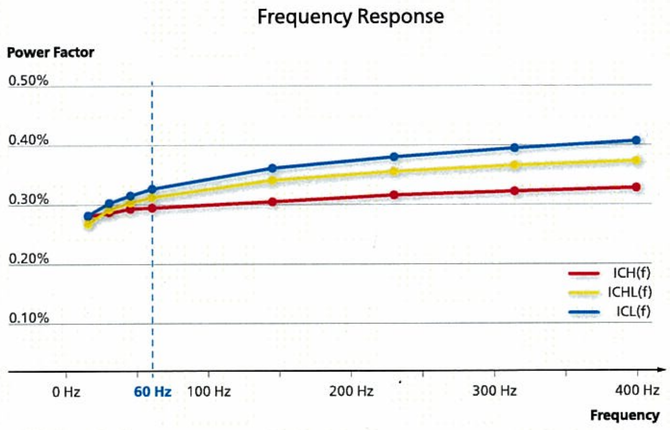

Figure 1: Acceptable variable frequency power factor test results

As an insulation system becomes contaminated with conductive losses, the variable frequency power factor curve shape changes such that it exhibits an upward "fish hook" at the lowest frequencies within the 15 Hz to 400 Hz band. Meanwhile, the line frequency (60 HZ) power factor may not change at all. Figure 2 displays test results that warrant further investigation, and in this example was associated with a transformer that subsequently was determined to have an estimated 3.4 percent water content in paper.

Of particular interest is that the sister transformer to that displayed in Figure 2 was tested as well. Figure 3 provides these test results, in addition to and superimposed on top of those already provided in Figure 2. Although CHL is 0.4 percent for both transformers at 60 Hz, in one case the CHL insulation system is considered to be in acceptable condition (Transformer B with a water content that was subsequently determined to be one percent) and in the other, unacceptable (Transformer A with a water content of 3.4 percent, as stated previously).

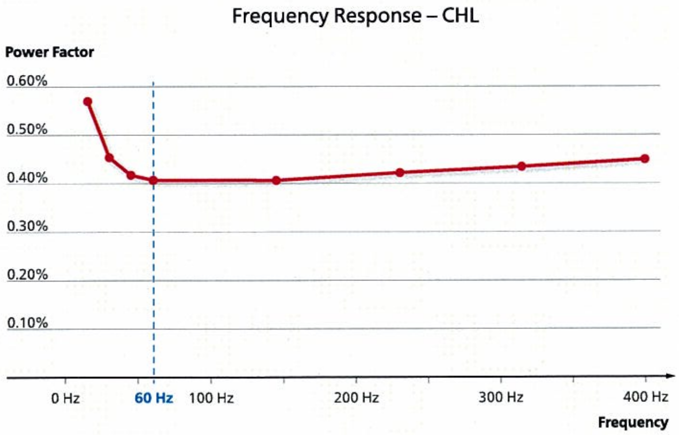

Figure 2: Unacceptable variable frequency power factor test results

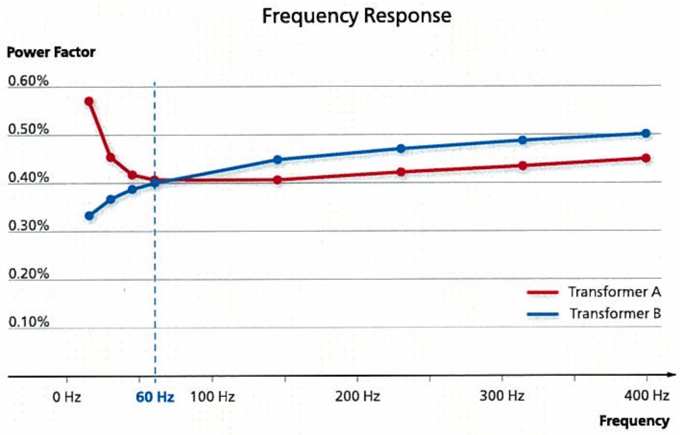

Figure 3: An example of the "blind spot" of a traditional power factor measurement

This is a compelling example that illustrates that although the 60 Hz power factor test results are the same for two separate but similar apparatus, this cannot be interpreted as a reliable indicator that the assets are in the same condition; yet this is the premise upon which the use of a database works.

Therefore, just as it may be misleading to rely on the guidelines provided in Table 1 for an analysis, it may also be misleading to rely on a comparison of power factor results between similar apparatus as a measure to prove that the power factor test result of an apparatus is acceptable.

FAMOUS LAST WORDS

The hope of the foregoing is that it heightens a user's awareness of the pitfalls when analyzing power factor test results. And lest the value of the standard power factor measurement becomes completely minimized, it warrants mention that a strength of the traditional power factor measurement is that it can typically be performed at a notably higher test voltage than that at which variable frequency power factor tests can be performed and some dielectric problems require a higher voltage to expose them. Therefore, the author does not suggest that the power factor diagnostic be usurped by variable power factor measurements but then neither should it stand alone.

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