Stator Winding Hipot (High Potential) Testing

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Abstract: **Over-potential or hipot tests are frequently applied to machine stator windings to assure that the electrical insulation in windings is fit for service. However, several questions are frequently raised: When should a hipot test be applied? Which hipot test should be applied? What should be the hipot test levels? Does hipot test damage a good winding? To answer these questions, a comprehensive review of literature was done and industry experts were surveyed for their views and experience under an EPRI sponsored project. The results are summarized in this paper. The questions are answered using the information from the literature review and the survey responses.**

INTRODUCTION

Hipot or over-potential tests are generally performed to assure that the winding insulation has a minimum level of electrical strength to survive electrical stresses in normal service. Hipot tests may be performed with any of three types of voltages: AC at the power frequency, DC, and very low frequency (VLF) at 0.1 Hz. Several questions have been frequently raised by test users. When should a hipot test be applied? Which hipot test should be applied? What should be the hipot test levels? Does hipot test damage a good winding? To answer these questions, a comprehensive review of literature was done and industry experts were surveyed for their views and experience under an EPRI sponsored project. The work was done first in 2000 and then updated again in 2007 to assess any change in industry attitudes. The findings from 2000 work were published in a report [1] and summarized in a 2001 paper [2]. The detailed results from the work in 2007 are given in a report [3]. This paper summarizes the important findings from the later work and may be considered an update to the 2001 paper [2].

VARIOUS HIPOT TESTS

Hipot tests are performed with three different types of voltages. The AC hipot tests at the line frequency are described in ANSI/IEEE standard C50.10-1990 and other standards [4-6]. The VLF (very low frequency) hipot test is performed at 0.1 Hz in accordance with IEEE Std. 433 [7]. In both cases the voltage is increased slowly (in about 1 minute or less) to the specified hipot test level, and then maintained at that level for one minute.

DC hipot tests described in IEEE Std. 95 [8] may be either a conventional hipot test or a controlled hipot test. In the conventional test the DC voltage is increased slowly from zero or some other low value to the specified hipot voltage, and then maintained at that level for one to ten minutes. In a controlled DC hipot test the voltage is either increased in a series of steps or ramped up to the maximum test level. There are two variations of the stepped DC hipot test: uniform-time voltage step method, the graded-time voltage step method [8]. The measured current is plotted against the applied voltage as the test progresses. Abnormalities or deviations in the current vs voltage plot may indicate insulation problems. The test also serves as a proof test (similar to AC test), if the insulation system withstands the prescribed hipot test voltage.

The hipot test level is (2E+1) kV for the power frequency AC test [4], 1.63 (2E+1) kV for 0.1 Hz test [7], and 1.7 (2E+1) kV for DC test [8] for new stator windings with rated line-to-line voltage E.

SURVEY DETAILS

The survey questionnaire in 2007 was similar to the one in 2000 with few minor changes and was sent to EPRI contacts. Twenty-nine (29) {*compared to 44 in 2000}* responses were received from 26 utilities (19 in North America), 2 service companies, and 1 OEM. The detailed survey results are given in an EPRI report [3]. The main findings from the survey are summarized below. Where necessary for comparison, the results from 2000 survey are given in *{italics}*. Note that one respondent corresponds to 3.4 *% {2.3 %}* of all respondents.

SURVEY RESULTS

Use of Hipot Tests: Responses are given in Table 1. In 2007 survey the new coils and windings were separated. All respondents use hipot test for new coils, windings, and rewinds. Hipot as one of several maintenance tests is used by 76 *% {100%}* of respondents; the 2007 response seems to be more realistic as many utilities use no hipot tests on machines in service. No respondent uses hipot test as the only maintenance or diagnostic test.

Which Hipot Test Used: As shown in Table 2, the use of hipot test was separated in 2007 for new machines and maintenance. Also the DC step tests were separated into uniform (*u*) or graded (*g*) steps. For new machines the use of AC hipot at line frequency is almost universal. Both AC and DC hipot tests are used for maintenance, the DC test being somewhat preferred. Both conventional and step DC tests are used. The

use of DC ramp test is limited to very few utilities. The VLF test at 0.1 Hz is rarely used.

Table 1. Use of Hipot Tests

Use/specify hipot for	2000	2007
Acceptance - new coils and windings	100 %	100 % *(windings)* 100 % *(coils)*
Acceptance - rewinds	100 %	100 %
Maintenance (as one of many tests)	100 %	76 %
Maintenance (as only test)	0 %	0 %

Table 2. Which Hipot Test Used?

Test	2000	*2007 new machine*	*2007 Maintenance*
AC line	59%	90%	41%
VLF 0.1 Hz	5%	3%	0
DC (all)	93%	76% (*both*)	
- conventional	64%	38%	41%
- step	59%	31% *(u)* 7% *(g)*	45% *(u)* 21% *(g)*
- ramp	14%	10%	17%

Reasons to Prefer AC Hipot Test: The main reasons to prefer the AC test are the similarity of the test stress to that in service, the belief that AC tests are better in detecting defects, and availability of AC supply (Table 3). Other reasons are short time for test and between successive tests (no need to drain residual charge), OEM/insurance requirements, no need for a thorough dry out, and convenient application with other diagnostic tests (dissipation factor, PD etc). Only the DC test is used by 10 % respondents.

Table 3. Reasons to Prefer AC Hipot Test

Reason	2000	2007
Stress similar	52%	62%
AC supply available	11%	24%
AC hipot better	25%	45%
Short test time	na	10%
Other*	23%	31%
Use DC test		10%

*OEM, insurance, no thorough dry out required

Reasons to Prefer DC Hipot Test: The main reasons are the availability of cheap and small DC power supplies, possibility of aborting test on warning before a damaging failure, and diagnostic information in controlled tests (Table 4). Note that 24 % of the respondents use only AC tests.

Table 4. Reasons to Prefer DC Hipot Test

Reason	2000	2007
DC supply small/cheap	52%	45%
DC hipot better	5%	7%
DC • failure warning	61%	48%
DC• diagnostic info	na	*31%*
*other	36%	0
Use AC		24%

*Supply available, trending, less damaging

AC Hipot Test Level: Most respondents use 2E+1 kV AC for new machines and coils. Many OEMs often use AC voltages 5 - 15 % higher than 2E+1 kV for new machines and 10 to 90 % higher than 2E+1 kV for new coils. Most respondents use 60 to 80 % of 2E+1 kV voltage for maintenance tests. However, four *{two}* respondents used voltage as low as 1.0 to 1.1 E kV for old machines.

DC Hipot Test Level: DC voltages from √2 (2E+1) kV to 1.7(2E+1) kV are used for new machines and coils in almost all cases, and 57 to 80 % of 1.7(2E+1) kV for maintenance tests in most cases. However, voltages 1.25 E, 1.7E, 1.13E, and 25μA leakage current limit are also reported for maintenance tests by individual respondents.

Type of DC Hipot Ttest Used: About half of the respondents use conventional DC hipot test with highest voltage held for 1 minute in most cases, and 5 - 10 minutes in few cases (Table 5). Step tests (with uniform and graded steps) are also used by almost 50 % of the respondents as described in IEEE Std 95 [8]. Only 21 % *{14%}* respondents use ramp test at 1 to 3 kV/min rate. Many respondents use more than one type of DC hipot tests.

Table 5. Type of DC Hipot Test Used

DC hipot type	2000	2007
Conventional -1 min	45 %	41 %
5 -10min	5 %	10 %
Ramp 1-3 kV/min	14 %	21 %
Step test	50 %	*U 48%* *G 21%*

Which Hipot at What Level Used for Green coils? To this new question posed in the 2007 survey, 86 % of respondents left it to the vendor or gave no response. Few other responses were unrealistic, indicating either poor understanding of the question or the poor language of the question.

Hipot Test for Water-Cooled Machines: This new question in the 2007 survey got no response from 34 % respondents. AC hipot tests at E to 1.5E is used by 27%, DC hipot tests at 1.25 E to 1.7(2E+1) by 27%, and 'either of AC or DC test' by 10%. 10% of respondents specify dry and/ or drained condition and one specifies wet/dry. 10% use AC hipot with other (PD, C, dissipation factor) tests. Also three respondents specifically mention 'as recommended by manufacturer', which in our opinion is extremely important.

Comments from Hipot Test Experience: Many different comments, as detailed in [2], were received including these important ones: (a) Hipot tests fail marginal, not good windings; (b) Hipot failures near the neutral end do occur; (c) Managers are often reluctant to approve a hipot test; (d) AC tests better detect defects, and used for water cooled machines; (e) DC tests give prior warning of failure, may fail windings without warning, are time consuming, give questionable trending, are not good for epoxy-mica system; (f) A hipot test is more useful when performed with IR, PD, DF tests.

Suggestions for Further R &D: Many divergent suggestions directly or indirectly repeated questions asked earlier. Few respondents saw need for further R&D. Many respondents asked: how to convince managers when seeking approval for a hipot test?

ANSWERS TO IMPORTANT QUESTIONS

The project's objective was to answer some important questions on the use of hipot tests frequently raised by utility engineers. Answers to these questions are given using the findings from the survey and a comprehensive review of existing literature.

Do Hipot Tests Damage a Good Winding?

The answer is NO to this question raised often by managers, who have to approve the hipot tests. Maintenance hipot tests do not introduce any significant degradation in a machine with good insulation system. Machines, which failed a hipot test, have always been found to have a poor insulation system in an examination following the failure.

Theoretically, the insulation in a good machine should not suffer any detectable degradation during a hipot test [9, 10]. Coils and bars used in machines should have the capability to pass a voltage endurance test [IEEE Std 1043]. For example, a 13.8 kV winding coil passes the endurance test for 400 hours at 30 kV at about 100 C without failure. If a 400-hour test at 30 kV and 100 C represents 25 years or more life in service, then an AC hipot test for 1 minute at 29 kV (2E+1 kV) at room temperature 30 C ages the insulation by nine (9) hours using IEEE Standard 930 for the relationship between voltage stress level and insulation life.

In experiments on 90 coil groups, Sedding et al [11] found that the AC breakdown voltages for sets of coil groups, which had been subjected to 5 AC or 5 DC hipot tests, were no different than those for the set of coil groups not subjected to any hipot tests. This shows empirically that the hipot tests do not damage an otherwise good insulation system.

When to Apply (or not Apply) Hipot Tests?

New windings: For new windings (also coils), the hipot tests are and should be used universally as acceptance and quality assurance tests. Generally AC hipot tests are used with other diagnostic tests such as insulation resistance (IR), polarization index (PI), dissipation factor (DF), and/or partial discharges (PD).

Windings in service: To reduce the risk of a costly forced outage, a regular maintenance program, including hipot tests, is necessary. The winding may be tested during maintenance outages often every 3 to 6 years and somewhat longer for large generators.

As stated above, a hipot test does not degrade an otherwise good winding. There is a finite risk that a marginal winding, which would have hopefully operated for some more time, may be punctured in the hipot test. For example, a winding with poor coils near the neutral end may operate for many years, but it may fail a hipot test. It will require immediate repairs or replacement. This risk can be minimized (but not eliminated) by using the DC ramp or step test and other diagnostic tests (IR, PI, PD, DF), which may detect insulation problems without a puncture during the test.

Maintenance hipot tests require a management decision. The choice is between the failure of a marginal winding during the off-line hipot test and an in-service failure sometime later with a costly forced outage. The decision depends on factors like the criticality of machine application (to production, safety, environment, or otherwise), the redundancy in the plant for operation with a failed machine, the availability of a spare machine for quick replacement, and the insurance implications.

Which (AC or DC) Hipot is Better?

The stress distribution in the insulation in operating machines is more similar to that in AC hipot tests than in DC hipot tests. But DC supplies are smaller and cheaper than AC supplies required for hipoting large machines.

The controversy about the relative efficacy of DC and AC hipot tests for detecting insulation weaknesses has continued for many years [12, 13]. Relative merits of AC and DC hipot tests applied to stator windings are discussed in detail in IEEE Std. 95 [8] and briefly in references [9, 10, 12].

AC tests are better in detecting defects in slot sections while DC hipot tests are better in detecting defects in endwindings [8 - 10]. But some defects in endwindings, which may fail in DC hipot tests, may never fail under operating AC stress [8].

For new machines and coils, AC hipot tests are and should be preferred, as done by all OEMs and most utilities responding to the survey.

For the maintenance purpose, AC hipot tests should be preferred and should be performed with other diagnostic tests (IR, PI, DF, PD) for the following reasons.

From the survey, more respondents believe that AC hipot test is better in detecting winding defects than DC hipot test. There has been an increase in the relative use of AC hipot tests. DC hipot tests and AC hipot tests were used by 93 % and 59 % of respondents in 2000 survey, and by 76 % and 90 % of respondents in 2007 survey, respectively. Also the fear of more damage to core in a failure by AC hipot test than by DC hipot test is unwarranted; experts have never experienced significant core damage from an AC hipot test failure [9].

A sudden increase or knee in the current vs voltage plot in controlled voltage DC hipot tests may sometimes provide a prior warning of an impending failure. This is not always true, even less true for modern epoxy-mica insulation [survey and reference 14]. Some authors [15, 16] report that 'snaking' in the current vs. voltage plots in DC ramp test detects defects (voids and delaminations) in the insulation. However, this appears to be controversial at present and is not confirmed in other tests [17].

Of course performing a DC hipot test is better than no test. If problems in endwindings are indicated by the past history of a machine, both AC and DC hipot tests may be made. For large machines, where an adequate AC supply may not be available, DC hipot test should be performed.

For water-cooled machines, AC (line frequency or 0.1 Hz) hipot tests are preferred. DC hipot tests should not be applied without thorough drying, as was clear from the survey.

Only a couple of utilities appear to have used the VLF test in past, and that was many years ago, mainly because of poor quality of VLF power supplies then available. A recent paper [18] finds that VLF hipot tests with the better quality power supplies now available may be as effective as the 60 Hz AC hipot tests or DC hipot tests. However, this should be investigated further.

What Should Be The Hipot Test Levels?

For new machines and coils everybody appears to be using 2E+1 kV rms AC, or 1.7 (2E+1) kV DC, or 1.63 (2E+1) kV at 0.1 Hz. OEMs may be using somewhat higher voltages on new windings or new coils.

For maintenance tests, most respondents use a hipot test level around 60 to 80 % of the value for new machines. This appears to be an appropriate choice. For older machines with poor insulation (indicated by other tests like PD, IR, PI, DF), the test levels may be towards the lower end of the range.

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