6.1.7 Induced voltage test

6.1.7.1 General

The induced test with partial discharge measurement tests the transformer in the normal service condition at a voltage above that which would be seen in service. Partial discharge (PD) measurements made during this test are used to verify that the insulation in the transformer is in an acceptable condition and can withstand normal service conditions. In the factory testing, the induced test is the last dielectric test and is used to ensure that the transformer passed all the other tests and that there are no hidden dielectric problems or failures that were not detected in the previous tests. As such, successfully passing the field induced test gives the user confidence that the transformer can operate in service without a risk of failure.

This test is recommended for such cases as:

- After installation tests when assembled on-site
- on-site test after repair or remanufacture
- for condition assessment
- for failure identification
- when dga results indicate possible PD (H2 gas as indicator)
- if transformer may have been contaminated
- after failure of components (bushings, pumps, tap changers, etc.)
- after possible transportation damage as evidenced by impact recorder readings or diagnostic test (FRA) anomalies.
- when unusual crackling or arcing type sounds are heard from inside the unit.
- When a transformer trips off line, especially when protective equipment (sudden pressure relay, differential relays, etc) have operated.
- When other dielectric test information, such as power factor, DFR, insulation resistance or oil quality indicate a problem.

The induced test is performed at a frequency above the rated frequency in order to prevent over-excitation of the core when voltage above normal is used. The test may be done with a motor-generator set operating at a fixed frequency or with a variable frequency electronic power supply. When a generator is used, it is important to protect the transformer against self-excitation of the generator under the capacitive load from the transformer by the use of reactors and protective gaps during the setup process. When a variable frequency electronic power supply is used, no such protection is needed.

6.1.7.2 Preliminary test procedures

Low-voltage tests (insulation resistance, power factor, ratio, oil dielectric, etc.) should be performed to determine if the insulation of the transformer under test is suitable for

energization. The insulating fluid should be sampled following prescribed procedures (refer to ASTM D 923-9 1) and its total dissolved gas-in-oil level analyzed to ensure that it is acceptable. A moisture content test of the oil should be made to ensure that excessive amounts do not exist. A turns ratio test should be performed to confirm that the transformer's tap changer for de-energized operation is properly positioned and that shorted winding turns do not exist. For the interpretation see table 1.

Table 1—Recommended diagnostic characteristics

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

a) If units are equipped with nitrogen blankets, total dissolved gas should not exceed 1.0 %.

6.1.7.3 Special precautions before test

Every power cable lead, except the cables that will be used to supply the energy from the main power supply, should be disconnected from the bushings before energizing the transformer. Enough clearances should be considered according to the estimated induced voltages at the enhanced level.

Any transformer-mounted surge arresters should be disconnected before energizing the transformer in order to avoid arrester damage and limitation of the test voltages due to arrester operation.

All internal current transformer secondary terminals must be short circuited, and all internal potential transformers must have their secondary winding terminals open circuited for the test.

Corona discharges at the tank of the transformer under test or at nearby grounded or energized objects may not only increase the PD background noise level, but also influence the results of withstand tests. Therefore in preparation for the test, all high-voltage bushings, and in some cases, low voltage bushings of 69 kV and above, should be fitted with corona rings of sufficient size, so as to eliminate all possibilities of air corona discharges. To prevent corona on the ground side, all sharp edges and points on top of and close to the transformer tank should be masked by covering them with corona rings galvanically connected to the tank. All high-voltage bushings should be carefully cleaned and dried. Immediately prior to the test, they should again be wiped dry. No conductive or semiconductive objects should be left ungrounded on the transformer or close to it, as this would produce discharges from floating objects. Therefore, they should either be taken away, when this is possible, or carefully grounded. All current-carrying connections should be very carefully made to ensure good electrical contact as contact arcing may produce unacceptably high PD background noise levels.

Other energized equipment located in close proximity to the transformer being tested, may also contribute to high PD background noise levels. Arrangements may have to be made to de-energize this equipment for the duration of the test.

Caution - prior to subjecting the transformer to the induced test, it is recommended to consult with the original manufacturer to determine if any specific limits on total dissolved gas in oil, particle count or other dielectric values must be met.

6.1.7.4 Power factor pre-test for excitation by M/G sets

After connecting the test set to the transformer under test, a pre-test to determine the power factor at the source should first be performed to ensure that the amount of inductive compensation is sufficient to guarantee that the load on the generator is not capacitive as this could lead to dangerous over voltages due to generator self excitation. To perform this pre-test, a high-voltage bushing of the test transformer should first be temporarily fitted with an external spark gap adjusted to operate at about 50% of the transformer nominal voltage. During this pre-test, the voltage should not be raised above 30% or preferably only at a level high enough to allow fairly accurate power factor measurement. Note that the generator is capable of driving a slightly capacitive load provided that the power margin is sufficient; it is when this margin is exceeded that generator runaway occurs. To be on the safe side, higher than required inductive compensation should first be used and it should be adjusted to a value that will allow the test to be done at full test voltage without exceeding the generator limits as this would cause generator protection tripping. The user should therefore be absolutely sure that the generator has a sufficient power margin to reach the maximum test level without danger of tripping. It is also important that the ratio of the step-up transformer used to match the voltage output of the generator to that of the transformer under test be as close as possible to the required value (optimum adaption). This will ensure maximum power transfer from the generator to the transformer under test. After the pre-test has been performed and the reactive compensation has been adjusted properly, the temporary spark gap should be removed and the voltage can then be taken to the test level.

6.1.7.5 Pre-tests for excitation by Static Frequency Converters (SFC) sets

As there is no danger of self-excitation when using static frequency converters, a special pre-test for checking the power factor is not necessary. In case of small test objects, the test sequence can simply be started after assembly of the temporary test field on-site. But in case of huge test objects the ratio between the available test power and the needed test power should be checked in advance. It has to be taken into account that the transformer under test is a capacitive test object at high frequencies and an inductive one at lower frequencies. At the self-compensation frequency in between the power demand is at its minimum. The SFC set shall be adjusted to that frequency if it is high enough to reach the required test voltage.

NOTE: As a hint, the ratio of the test frequency to the rated frequency of the transformer under test should correspond to the ratio of the test voltage to its rated voltage.

6.1.7.6 Test procedure and acceptance criteria

The test procedures used in the factory induced test with some exceptions may be used as a guide for testing in the field. The exceptions include the tap position, test voltage level and the acceptance criterion. Most often the tap position used in the field test is the normal operating tap. Transformers with all new insulation may be tested at the standard test levels specified for new transformers. For transformers with all or some part of the insulation that is not new, the test levels used are lower, and should be established by agreement between the user, manufacturer and testing company where applicable. ANSI standard C57.12.90 recommends testing transformers with insulation that is not new at no more than 85% of the ANSI test levels. When high PD is present, it may be necessary to limit the voltage to even lower levels than this to prevent damage to the transformer insulation (for example at 110% of nominal voltage). In most instances for transformers with not-new insulation, the enhancement test is omitted and the test is performed at the reduced one-hour ANSI voltage level.

It is recommended to slowly raise the voltage at the beginning of the test and measure the partial discharge at various voltage levels as the voltage is raised. If high PD occurs during this process, steps should be taken to diagnose and correct the cause if possible before raising the voltage in order to prevent flashover either internally or externally due to unforeseen conditions.

PD measurements can also be made on the same levels as the voltage is decreased.
A comparison before and after the withstand level can supply useful information on the insulation condition.

What constitutes an acceptable test is a matter of agreement between the user, manufacturer and test personnel and relies on the experience and judgement of those conducting and observing the test. In general and without other specifications, if the PD levels measured during the test meet the requirements of C57.12.90, the transformer is considered to have passed the test.

Achieving a sufficiently low PD background noise level may be difficult or impossible to obtain on-site. Therefore various steps can be taken to reduce the background noise such as measuring at frequency bands where there is lower background noise, making the PD measuring circuit as compact as possible, reducing grounding loops and other measures for PD noise reduction.

If high PD levels are found during the tests, various diagnostic methods are available to help determine the cause and location of the PD. Some of these methods are:

- Diagnostic step voltage test
- PD phase-resolved pattern diagnosis and comparison to known causes
- Observation of the PD pulse shape with an oscilloscope
- Signal attenuation at various terminals of the transformer. In this case, measurements may be done at terminals not normally required for testing.
- Acoustic PD location
- UHF PD location.