IEEE PC57.12.90/special
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IEEE Draft Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers

9.5 Zero-phase-sequence impedance

9.5.1 Zero-phase-sequence impedance tests of three-phase transformers

The zero-phase-sequence impedance characteristics of three-phase transformers depend upon the winding connections and, in some cases, upon the core construction. Zero-phase-sequence impedance tests described in this standard apply only to transformers having one or more windings with a physical neutral brought out for external connection. In all tests, one such winding shall be excited at rated frequency between the neutral and the three line terminals connected together. External connection of other windings shall be as described in zero-phase-sequence impedance for various transformer connections. Transformers with connections other than as described in zero-phase-sequence impedance shall be tested as determined by the individuals responsible for design and application.

The excitation voltage and current shall be established as follows:

a) If no delta connection is present on the transformer and the transformer is a three leg core design, there is a risk of excessive tank wall heating due to the return flux from the core going into the tank wall. To avoid this, the applied voltage should be such that the current is no more than 20% of the base rating of the winding being excited. This applies to both open-circuit tests and short-circuit tests as described in section 9.5.3.

   If the transformer is a five leg core or a shell form design the zero-sequence impedance is equal to the positive sequence impedance and the zero-sequence test is generally not needed. However, should the test be done, the applied voltage should not exceed 30% of the rated line-to-neutral voltage of the winding being energized for the open-circuit test, and the phase current should not exceed ~~its~~ the base rated value of the winding being excited for the short-circuit test.

b) If a delta connection is present, the applied voltage should be such that the base rated phase current of any delta winding is not exceeded.

The percent excitation voltage at which the tests are made shall be shown on the test report. The time duration of the test shall be such that the thermal limits of any of the transformer parts are not exceeded.

Single-phase measurements of excitation voltage, total current, and power shall be similar to those described in 9.3. The zero-phase-sequence impedance, in percent, on kilovoltampere base of excited winding for the test connection is as follows in Equation (21):

$$Z_0(\%) = 300\left(\frac{E}{E_r} \times \frac{I_r}{I}\right) \tag{21}$$

where

Z_0 is the zero sequence impedance, in percent, on kilovoltampere base of excited winding for the test connection
E is measured excitation voltage (V)
E_r is rated phase-to-neutral voltage of excited winding (V)
I is measured total input current flowing in the three parallel-connected phases (A)
I_r is rated current per phase of the excited windings (A)

9.5.2 Transformers with one neutral externally available, excluding transformers with interconnected windings

The zero-phase sequence network, given the external characteristics for transformers of this type, is shown in Figure 24. Winding 1 has the available neutral, whereas windings 2, 3, and so forth do not.

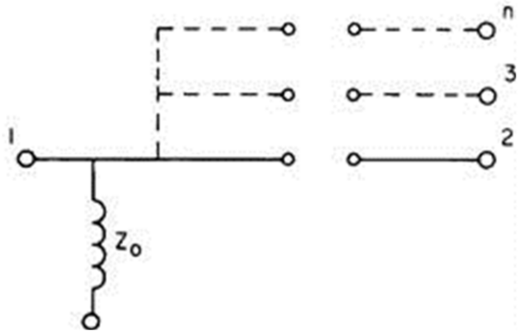

Figure 24 – Equivalent zero-phase-sequence network for transformers with one externally available neutral

A zero-sequence test shall be made on the winding with the available neutral. A single-phase voltage shall be applied between the three shorted line terminals and neutral. The external terminals of all other windings may be open-circuited or shorted and grounded.

The term “interconnected windings” shall be interpreted to mean windings in which one or more electrical phases are linked by more than one magnetic phase.

9.5.3 Transformers with two neutrals externally available, excluding transformers with interconnected windings

The zero-phase sequence network, given the external characteristics for transformers of this type, is shown in Figure 25. Windings 1 and 2 have the externally available neutrals while windings 3, 4, and so forth do not. The diagram is drawn for the case of 0° phase shift between windings 1 and 2.

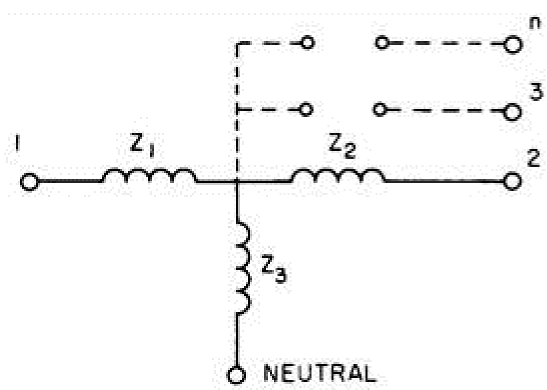

Figure 25 – Equivalent zero-phase-sequence network for transformer with two externally available neutrals and 0° phase shift between windings 1 and 2

NOTE – Applies also to auto transformers. For wye-wye transformers or autotransformers without a delta tertiary: For 5 leg core form and for shell form transformers, Z3 is very large and the zero sequence impedance is equal to the positive sequence impedance For three leg core form transformers, the Z3 value is typically 5-10 times the Z12 measured value due to the "phantom delta" effect of the tank and/or tank wall shielding. The Z3 value should be taken into account in short circuit calculations involving the zero sequence impedance. Measurements may be made at different current levels to establish the non-linear curve for all four different measurements.

Four tests may be made to determine the zero-phase-sequence equivalent network, one of which is redundant.

a) *Test 1*. Apply a single-phase voltage to winding 1 between the shorted line terminals of winding 1 and its neutral. All other windings are open-circuited. The measured zero-phase-sequence impedance is represented by Z_1N_o.

b) *Test 2*. Apply a single-phase voltage to winding 1 between the shorted line terminals of winding 1 and its neutral. Short the line terminals and neutral of winding 2. All other windings ~~may~~ shall be open-circuited ~~or shorted~~. The measured zero-sequence impedance is represented by Z_1N_s.

c) *Test 3*. Apply a single-phase voltage to winding 2 between the shorted line terminals of winding 2 and its neutral. All other windings are open-circuited. The measured zero-phase-sequence impedance is represented by Z_2N_o.

d) *Test 4*. Apply a single-phase voltage to winding 2 between the shorted line terminals of winding 2 and its neutral. Short the line terminals and neutral of winding 1. All other windings ~~may~~ shall be open-circuited ~~or shorted~~. The measured zero-phase-sequence impedance is represented by Z_2N_s.

Test 4 and Test 2 are redundant, and Test 4 need not be performed. If performed, however, it may be used as a check. All measured zero-phase-sequence impedances should be expressed in percent and placed on a common kilovoltampere base. The constants in the equivalent circuit are as shown in Equation (22) through Equation (24):

$$Z_3 = +\sqrt{Z_{2N_o}(Z_{1N_o} - Z_{1N_s})} = +\sqrt{Z_{1N_o}(Z_{2N_o} - Z_{2N_s})} \quad (22)$$

$$Z_2 = Z_{2N_o} - Z_3 \quad (23)$$

$$Z_1 = Z_{1N_o} - Z_3 \quad (24)$$

NOTE—These equations involve complex numbers. The plus sign before the radical in Equation (22) is appropriate for most common cases in which windings 1 and 2 are physically adjacent in the design, and no delta winding (3, 4, etc.) is interleaved with them. A minus sign may be appropriate when a delta winding (3 or 4) is physically located within or between windings 1 and 2. The correctness of the sign can be checked by comparison with design calculations of zero-sequence impedance.

If Z_{1N_o} and Z_{2N_o} approach infinity, then Z_3 approaches infinity, and the equivalent circuit is that shown in Figure 26.

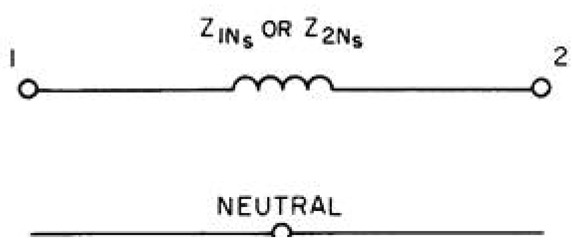

Figure 26 – Equivalent zero-phase-sequence network for transformers with two externally available neutrals and 0° phase shift if Z_{1No} and Z_{2No} approach infinity

In the case of wye-wye connected transformers, the zero-sequence impedance, in general, is a nonlinear function of the applied voltage, which in turn may require more than one set of measurements to characterize the nonlinear behavior.

9.5.4 Autotransformers

The tests and equivalent circuits of 9.5.2 and 9.5.3 apply equally well for autotransformer connections, except that the externally available neutral of a common winding shall be considered as two externally available neutrals, one for the common winding and one for the series-common combination.