

IEEE Recommend Practice for Routine Impulse Test for Distribution Transformers

Sponsor

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Abstract: General test procedures for performing routine quality control test that is suitable for high-volume, production line testing. Transformer connections, test methods, circuit configurations and failure detection methods are addressed. This recommended practice covers liquid-immersed, single-and three-phase distribution transformers.

Keywords: distribution transformers, routine impulse test, production line testing

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Introduction

(This introduction is not part of IEEE Std C57.138, IEEE Recommended Practice for Routine Impulse Test for Distribution Transformers.)

William P. Lidinsky, Chair*
Tony Jeffree, Chair, Network Management Task Group*

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IEEE Recommended Practice for Routine Impulse Test for Distribution Transformers

1. Overview

1.1 Scope

This recommended practice covers routine impulse tests performed on distribution transformers, as required in IEEE Std C57.12.00-1993, and described in subclause 10.4 of IEEE Std C57.12.90-1993.

Distribution transformers covered by this recommended practice are liquid-immersed, single- and three-phase overhead-type up to 500 kVA; single-phase pad-mounted compartmental-type and underground-type up to 167 kVA; three-phase pad-mounted compartmental-type and underground-type up to 2500 kVA. These transformers are covered by IEEE Std C57.12.20-1988 through IEEE Std C57.12.26-1992.

This recommended practice covers only those aspects of impulse testing that are specific to routine testing of distribution transformers. For more thorough coverage of impulse testing of transformers in general, the IEEE Guide for Transformer Impulse Tests, IEEE Std C57.98-1993, should be consulted.

1.2 Purpose

This recommended practice is to assist manufacturers of distribution transformers in the setup and operation of a routine impulse test, and to assist distribution transformer users and purchasers in understanding the routine impulse test and how it differs from design tests.

2. References

When the following ANSI/IEEE standards and guides referred to in this recommended practice are superseded by a general revision approved by the American National Standards Institute, the latest revision shall apply.

This recommended practice shall be used in conjunction with the following publications:

IEEE Std 4-1995, IEEE Standard Techniques for High-Voltage Testing.¹

¹IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

IEEE Std 1122-1987, IEEE Standard for Digital Recorders for Measurements in High-Voltage Impulse Tests.

IEEE Std C57.12.00-1993, IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers.

IEEE Std C57.12.20-1988, Requirements for Overhead-Type Distribution Transformers, 500 kVA and Smaller: High Voltage 34 500 Volts and Below; Low Voltage 7970/13 800 Y Volts and Below.

IEEE Std C57.12.22-1989, American National Standard for Transformers—Pad-Mounted, Compartmental-Type, Self-Cooled, Three-Phase Distribution Transformers with High-Voltage Bushings, 2500 kVA and Smaller: High Voltage, 34 500 Grd Y/19 920 Volts and Below; Low Voltage, 480 Volts and Below—Requirements.

IEEE Std C57.12.23-1992, IEEE Standard for Transformers—Underground-Type, Self-Cooled, Single-Phase Distribution Transformers with Separable, Insulated, High-Voltage Connectors; High Voltage (24 940 Grd Y/14 400 Volts and Below) and Low Voltage (240/120 V; 167 kVA and Smaller).

IEEE Std C57.12.25-1990, American National Standard for Transformers—Pad-Mounted, Compartmental-Type, Self-Cooled, Single-Phase Distribution Transformers with Separable Insulated High-Voltage Connectors: High Voltage, 34 500 Grd Y/19 920 Volts and Below; Low Voltage, 240/120 Volts; 167 kVA and Smaller—Requirements.

IEEE Std C57.12.26-1992, IEEE Standard for Pad-Mounted, Compartmental-Type, Self-Cooled, Three-Phase Distribution Transformers for Use with Separable Insulated High-Voltage Connectors (34 500 Grd Y/19 920 Volts and Below; 2500 kVA and Smaller).

IEEE Std C57.12.90-1993, IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers and IEEE Guide for Short Circuit Testing of Distribution and Power Transformers.

IEEE Std C57.98-1993, IEEE Guide for Transformer Impulse Tests.

3. General test procedures

For information on the correct test sequence when impulse voltage tests are to be performed, refer to IEEE Std C57.12.90-1993.

The routine impulse test normally consists of one reduced and one full-wave impulse, or two full-wave impulses. The full-wave impulses are at a crest voltage equal to the rated BIL of the terminal being tested. Chopped wave tests are not included in the routine test. Each line terminal of a winding rated above 600 V that is brought out through a suitable bushing is to be tested. For transformers that have two or more windings rated above 600 V, all line terminals of each such winding are to be tested. Neutral terminals, and terminals of windings rated 600 V and below, are not to be tested in the routine impulse test.

4. Fault detection methods

Routine impulse testing of distribution transformers as specified in IEEE Std C57.12.90-1993, subclause 10.4 requires that the test equipment demonstrate the ability to detect a single-turn fault. A typical fault can be simulated by placing a shorted turn of wire around the core leg and over the coil of a core and coil assembly. Methods of providing such detection sensitivity are discussed in the sections that follow and in the Annex that accompanies this document.

5. Circuits for routine impulse testing

This test is normally performed on the production line as part of the routine quality control tests. As such, the routine impulse test may be performed on a large number of transformers using a test with automated failure detection. The failure detection system must be sensitive enough to detect all failures, including a single-turn fault.

For a general description of the routine impulse test circuit see the lightning impulse test circuit described in IEEE Std C57.98-1993. Subclause 5.2 of this document describes the recommended circuit hook-ups for various test pieces.

5.1 Impulse wave shape

The impulse wave shape to be used for routine impulse testing of distribution transformers is the ANSI/IEEE standard $1.2 \times 50 \mu\text{s}$ full-wave lightning impulse described in IEEE Std 4-1995 and IEEE Std C57.98-1993. Descriptions of approved techniques and equipment for measurement of the applied impulse wave can also be found in IEEE Std C57.98-1993.

5.1.1 Test voltages

The full-wave impulses shall have a crest value equal to the rated BIL of the terminal being tested. The reduced full-wave impulses shall have crest values equal to 50%–70% of rated BIL.

5.1.2 Tolerances

Tolerances for impulse test voltages and wave shapes are given in ANSI/IEEE Std C57.12.90-1993. It must be noted, however, that it is sometimes not practical to make circuit modifications to achieve a wave shape within tolerance for every transformer being tested. If the impulse equipment is sized to test the required range of transformers and the wave shaping circuit is designed to produce a standard impulse on an average transformer, the test circuit will generally be adequate for making a valid routine impulse test on the full range of transformers.

Every effort should be made to ensure that the applied wave shape complies with the standard in the area of the voltage peak. That is, oscillations on the voltage peak should be no greater than 5% of the crest voltage. If the frequency of those oscillations is greater than 0.5 MHz or the duration of overshoot is less than $1 \mu\text{s}$, the peak voltage value is determined from a mean curve through the oscillation(s). (Refer to IEEE Std 4-1995.)

5.1.3 Effects of impulse generator loading

The impulse equipment used for routine impulse tests on distribution transformers must satisfy a different set of requirements than equipment used for design impulse testing in laboratory environments. Due to the large number of tests that must be performed on a typical production line, impulse circuit parameters can not be modified for each test by changing component values or circuit connections. The impulse circuit, as indicated by Figure 1, should be designed such that it will supply the proper impulse wave shape for all units to be tested without the need to make changes. Depending on the mix of units to be tested on a single production line, such a design may be difficult or uneconomical to achieve. A few guidelines on impulse circuit design for production line testing are given in the following paragraphs.

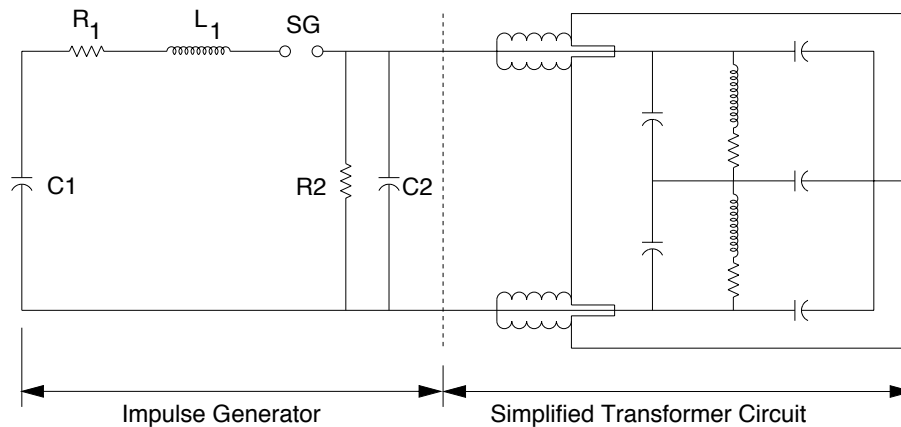


Figure 1—Typical lightning impulse circuit

A large majority of distribution transformers presently produced have a fairly high impedance at the primary terminals when excited by impulse frequencies. As a result the load presented to the impulse generator when performing routine impulse tests on distribution transformers often has only a small effect on the voltage wave shape produced by a well-designed impulse generator. Some transformers however will have a large effect, especially on an impulse generator whose design was not carefully considered.

To provide a more consistent “time to half value” one can use larger stage capacitors and lower value parallel or tail resistors. At the same time, a reduction in the value of front or series resistors will reduce the wave shape distorting effects of variations in load current. Be aware however that reducing the value of front resistors will also reduce front time and may increase oscillations near the wave crest.

As load capacitance changes, so does the impulse front time, often making it difficult to obtain the specified value. The front time is generally determined by the impulse circuit inductances and the RC time constant formed by the front resistors and the circuit capacitances. The two capacitances having the greatest effect are the preload or wave shaping capacitor (C2 in Figure 1), and the effective load capacitance. Since the preload capacitor is in parallel with the load, using a preload capacitance that is much greater than the capacitance of the load reduces the sensitivity of front time to changes in load capacitance. The stage capacitance is in series with the load and preload capacitances and is typically much larger than the preload capacitance. As such, the choice of stage capacitance usually has little effect on front time. Lead inductances and internal generator inductances can, when large enough, have a significant effect on front time. For this and other reasons it is always a good idea to keep all series inductances as low as possible through the use of low-inductive components and short testing leads.

Using good grounding practices also improves the consistency of impulse wave shape and amplitude. For a general discussion on recommended grounding techniques, see section 5 of IEEE Std C57.98-1993.

5.2 Transformer connections

The required connections for routine impulse tests on distribution transformers are defined in subclause 10.4 of IEEE Std C57.12.90-1993. The impulse is applied to one end of a high-voltage winding while the other end of the same winding is connected to ground through a low-impedance shunt or wide-band current transformer. All other windings, the tank and the core are grounded in a likewise manner. A typical connection meeting these requirements is shown in Figure 2. It should be noted that in Figure 2 only one terminal of the non-impulsed winding is connected to ground. The single ground connection to the non-impulsed windings enhances fault detection sensitivity. However, the voltage to ground on any non-tested terminal should not be

allowed to exceed 80% of the applicable BIL. Recommended connections for various types of transformers and a few special considerations are provided in the following paragraphs. The voltage divider and oscilloscope connection as shown in Figure 2 was omitted for clarity in Figure 3 through Figure 20.

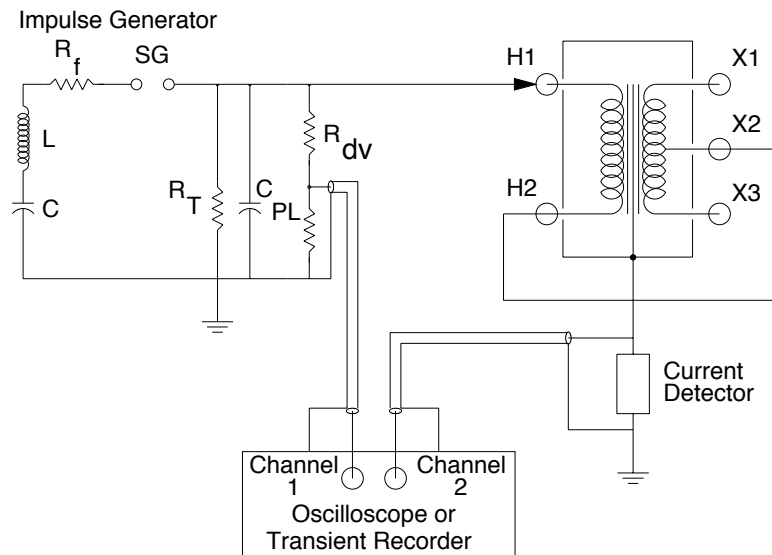


Figure 2—Typical transformer connection for routine impulse testing

5.2.1 Improved fault detection sensitivity

It is generally accepted that one of the more difficult transformer impulse failures to detect is a single shorted turn near the grounded end of a high-voltage, low-kVA, wire-wound primary coil. This type of coil design combines many turns, low volts per turn, and small gauge wire, which are all factors that reduce fault detection sensitivity. Tests on these and other similar units have shown that the sensitivity of the fault detection circuitry to staged faults of this type is increased whenever the tank and one terminal of all non-impulsed windings are connected directly to ground, rather than through the current detector. Routing the tank and low-voltage winding currents through the current detector simply dilutes the fault detection information. A typical connection for greater detector sensitivity during routine impulse tests on distribution transformers is shown in Figure 3.

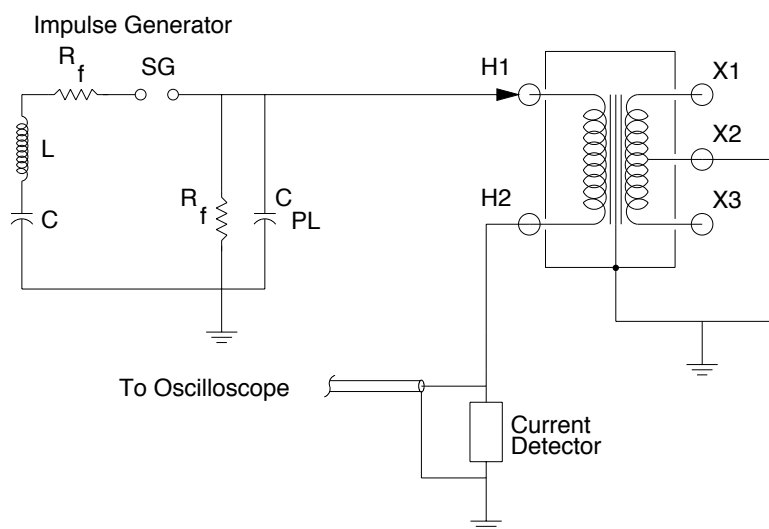


Figure 3—Maximum sensitivity connection

5.2.2 Special cases for single-phase distribution transformers

There are several winding connections for single-phase distribution transformers that require different impulse test connections.

5.2.2.1 Single high-voltage bushing

Figure 4 shows the recommended connection for routine impulse testing of units with one end of the primary or high-voltage winding connected to the tank. The connection for this type unit has the slight disadvantage of routing the tank current through the current detector.

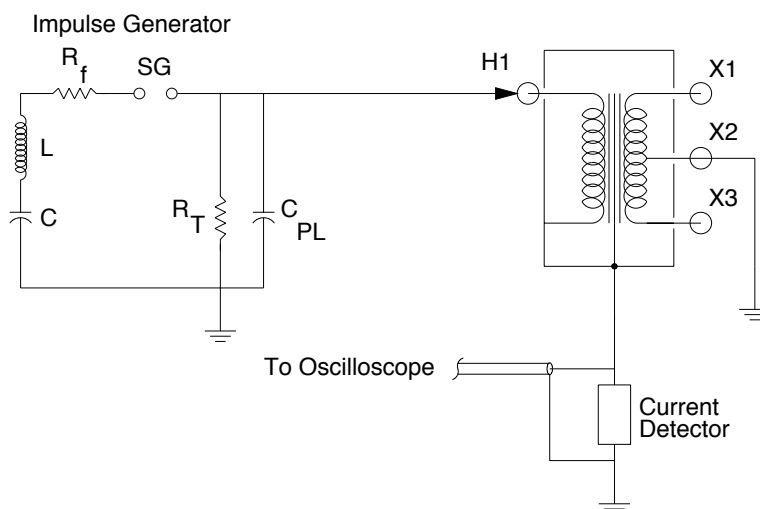


Figure 4—Connection for single HV bushing

5.2.2.2 Internal ground on low-voltage winding

An internal ground on the low-voltage winding reduces the number of external connections required to perform a routine impulse test. See Figure 5 for connection diagram. The connection that should be used for a unit with an internal ground connection on both the low-voltage and high-voltage windings is shown in Figure 6. This connection is much like that shown in Figure 2 except that several external connections are replaced by internal connections.

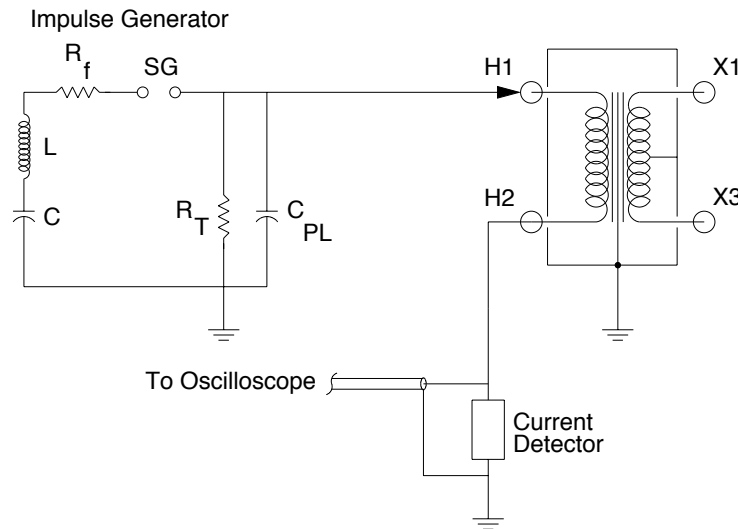


Figure 5—Connections for internally grounded neutral terminal

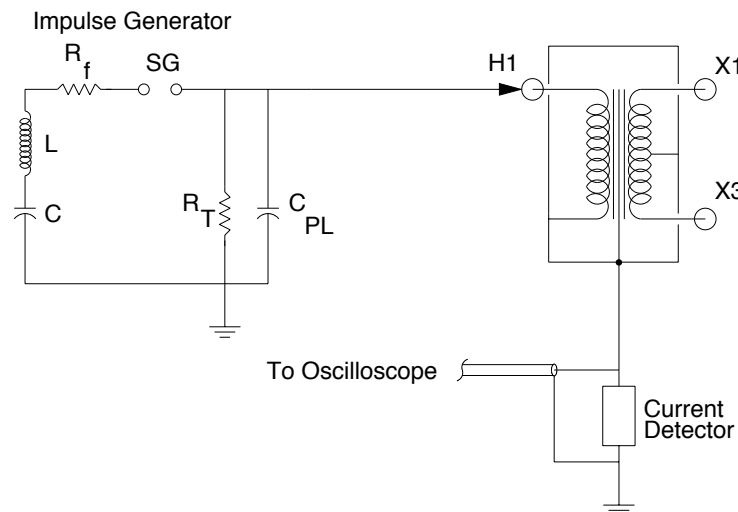


Figure 6—Connections for internally grounded H2 and X2

5.2.2.3 Two low-voltage terminals

On units with only two low-voltage terminals, one end of the winding should be directly connected to ground. Figure 7 shows the recommended connection. For low-voltage windings rated 600 V or below,

either end of the winding may be grounded. Step-down or Intertie units having secondary voltages greater than 600 V may require special consideration when grounding two terminal windings (refer to Subclause 5.2.4 of this document for details).

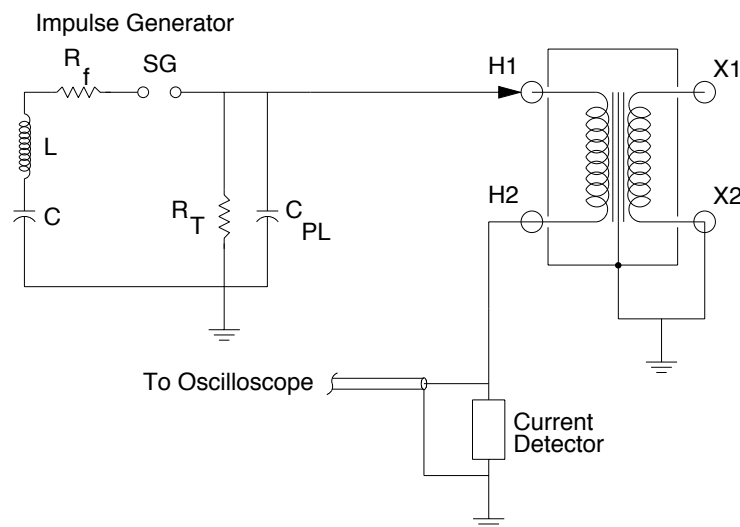


Figure 7—Connections for two large voltage terminals

5.2.2.4 Single low-voltage terminals

Units with only a single low-voltage terminal usually have only one high-voltage terminal.

Figure 8 shows the connection for such a unit.

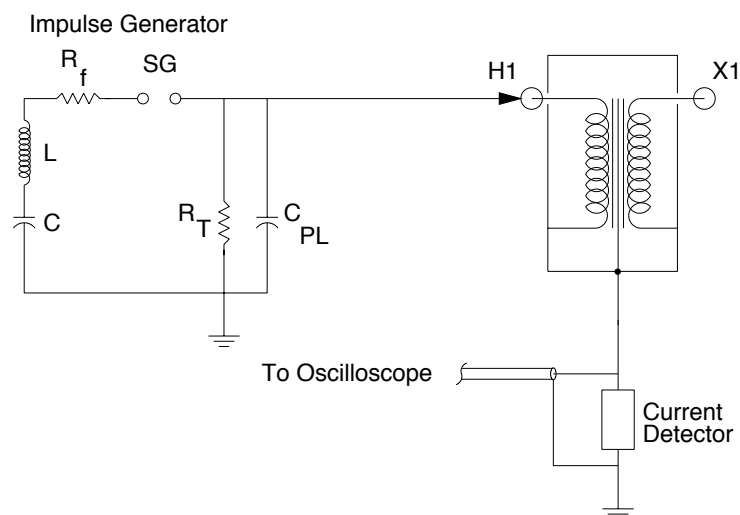


Figure 8—Single HV and single LV bushing connections

5.2.3 Three-phase transformer connections

The most common three-phase connections are described in the following clauses. Transformers with ungrounded wye connected windings that have no accessible neutral point may be tested using the connections for transformers with delta connected windings. Tee-tee connected transformers may be tested using the test connections for wye or delta connected windings that the tee-tee connections simulate.

5.2.3.1 Wye-wye connections

Connections that might be used in three-phase wye-wye distribution transformers are shown in Figures 9, 10, and 11. When possible the connection shown in Figure 9 should be used because it provides the greatest detector sensitivity. On wye-wye units the detector and ground connections are the same for impulses on all three phases. Only one connection is required per phase for routine impulse testing of wye-wye distribution transformers.

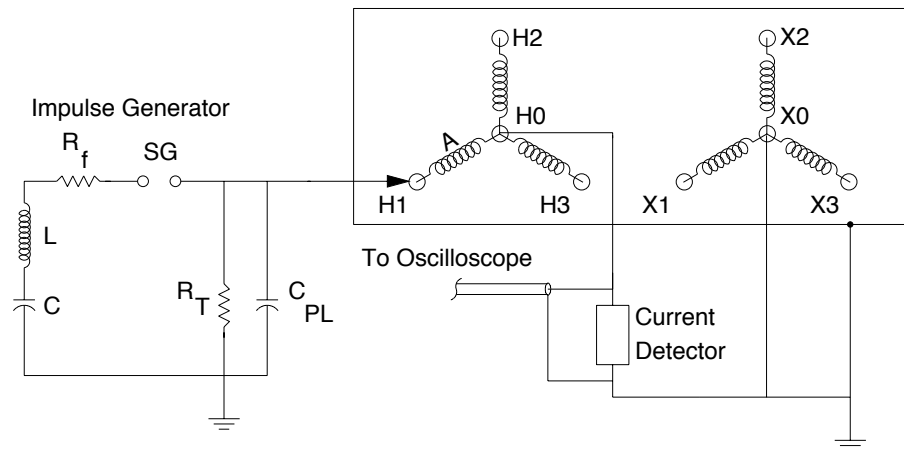


Figure 9—Standard connection for three-phase WYE-WYE transformer

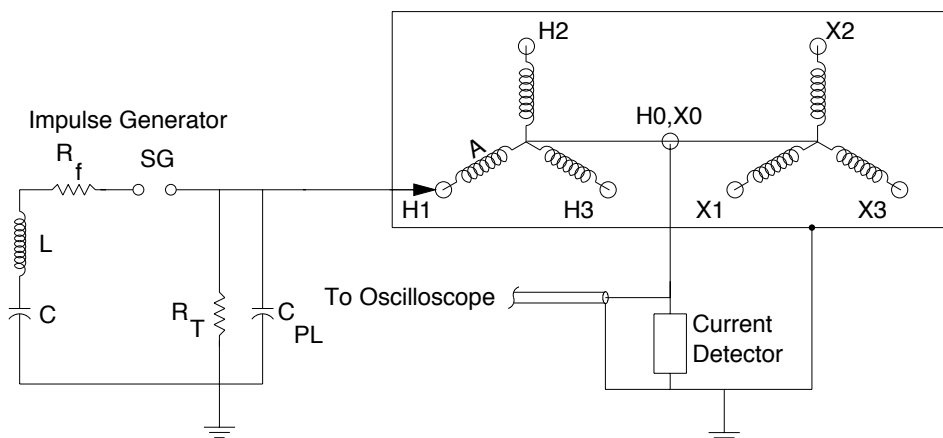


Figure 10—Connections for WYE-WYE transformer with internal HO-XO link

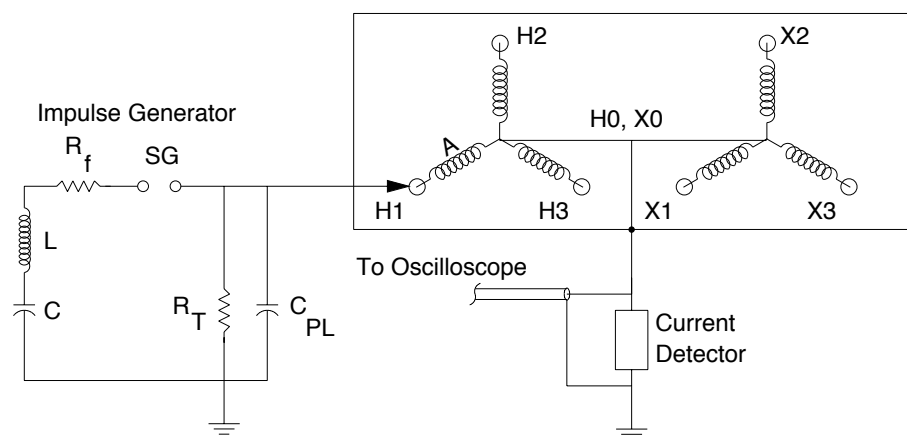


Figure 11—Connection for WYE-WYE transformer with internal grounds

5.2.3.2 Wye-delta connections

Connections for routine impulse testing of phase A on a wye-delta connected three-phase distribution transformer are shown in Figures 12 and 13. Figure 12 is the preferred connection when possible. As other phases are tested the secondary ground connection should be rotated around to other terminals such that one end of the secondary winding of the coil being tested is connected directly to ground. For example when $H2$ is tested, either $X2$ or $X3$ should be grounded, but not both. Only one connection is required per phase for routine impulse testing of wye-delta distribution transformers.

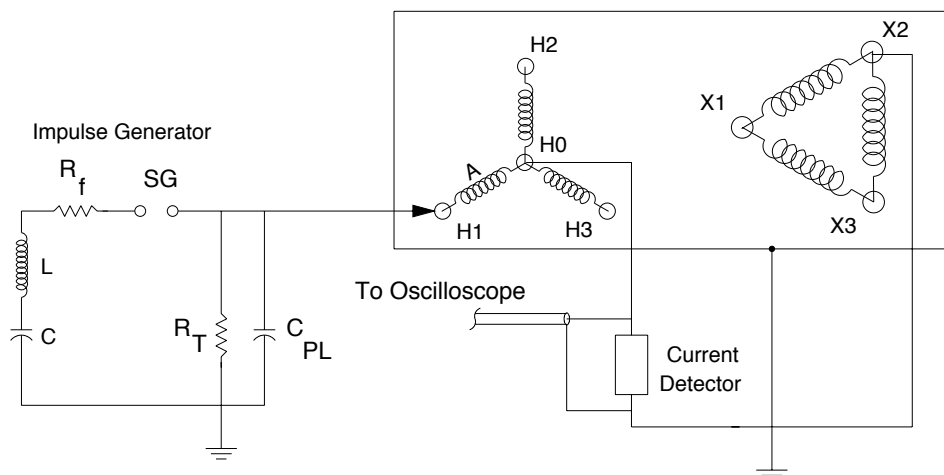


Figure 12—Standard connection for WYE-Delta transformer

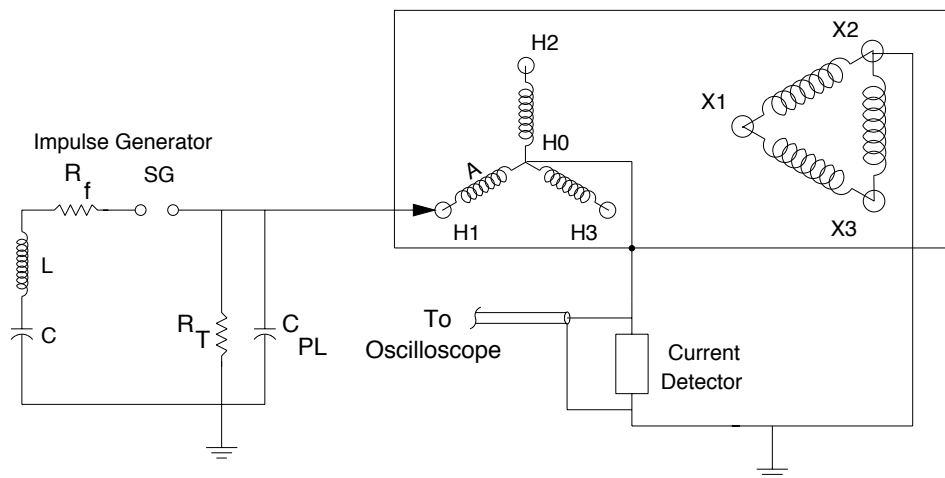


Figure 13—Connection for WYE-Delta transformer with internal HO ground

5.2.3.3 Delta-delta connections

An accepted connection for routine impulse testing of the phase A winding of a delta-delta connected three-phase distribution transformer is shown in Figure 14. Another method of testing the same winding is to connect it as shown in Figure 15. Some manufacturers actually use both connections, performing two impulse tests on each phase of a delta connected primary winding. Using this method provides for each phase winding to receive an impulse from either end. This two-test method requires that a total of six impulse tests be run for each three-phase delta primary transformer.

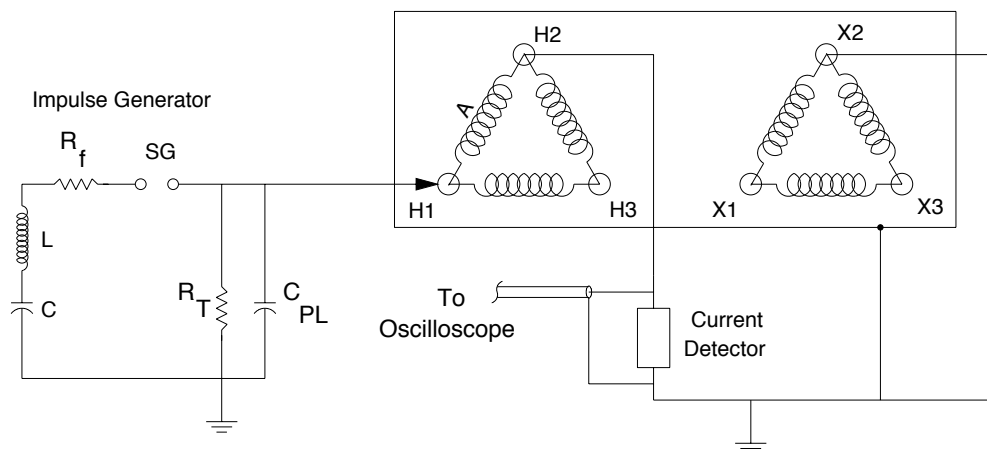


Figure 14—Delta-Delta connections