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Proposed Guide
for
TRANSFORMER IMPULSE TESTS

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FOREWORD

Early in 1955 a Working Group was appointed by the Dielectric Tests Subcommittee of the AIEE Transformers Committee to prepare an Impulse Test Guide for oil-immersed transformers. The first draft of the Guide, prepared by one member of the Group, was not acceptable to the majority of the Working Group members. Another approach to the Guide was begun in April 1958, when members of the Working Group agreed to draft a portion of the Guide in which they had a particular interest. The present content of the Guide is the result of consolidating and editing these writings of the Working Group members.

The Standards of AIEE, NEMA, and ASA plus the purchaser's specifications determine the specific requirements for impulse tests. This Guide will not change the Standards in any way, but adds background information which will aid in the interpretation and application of these Standards. These Standards now provide for some alternate ways of conducting some tests or parts of tests. These alternates have been developed by different testing laboratories with consideration for their individual problems of transformer design, test facilities, etc. It is the object of this Guide to discuss these differences and to show how effective failure detection can be achieved with the testing techniques employed. Although the Guide is written primarily for power transformers, it is applicable generally to distribution and instrument transformers.

The Guide assumes the reader has an educational or practical background equivalent to that of a graduate electrical engineer with some knowledge of transformers.

ACKNOWLEDGMENT

The Institute wishes to acknowledge its indebtedness to those who have so freely given of their time and knowledge and have conducted experimental work on which many of the AIEE publications are based.

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PART I

IMPULSE TESTING TECHNIQUES

GENERAL

1. Insulation is recognized as one of the most important constructional elements of a transformer. Its chief function is to confine the current to useful paths, preventing its flow into harmful channels. Any weakness of insulation may result in failure of the transformer. A measure of the effectiveness with which insulation performs is the dielectric strength. It was once accepted that low-frequency tests alone were adequate to demonstrate the dielectric strength of transformers. As more became known about lightning phenomena, and as impulse testing apparatus was developed, it became apparent that the distribution of impulse voltage stress through the transformer winding may be very different from the low-frequency voltage distribution.

2. Low-frequency voltage distributes itself throughout the winding on a uniform volts-per-turn basis. Impulse voltages are initially distributed on the basis of winding capacitances. If this initial distribution differs from the final low-frequency inductance distribution, the impulse energy will oscillate between these two distributions until the energy is dissipated and the inductance distribution is reached. In severe cases, these internal oscillations can produce voltages to ground that approach twice the applied voltage.

3. As circuit voltages became standardized, impulse levels corresponding to the respective voltage classes were also standardized. Impulse levels, now referred to as Basic Impulse Insulation Levels (BIL), were established in 1937 by an AIEE-NEMA Committee on Insulation Coordination. This committee was formed to consider laboratory technique and data, to determine the insulation levels in common use, to establish the insulation strength of all classes of equipment, and to establish insulation levels for various voltage classifications. Through the use of these BIL's, apparatus can be specified on the basis of demonstrating that the insulation strength of the equipment will be equal to or greater than the selected basic level, and protective equipment can be selected to provide adequate protection. The BIL's and other insulation test voltages are listed in sections of American Standard C57.

IMPULSE WAVE SHAPES

4. Impulse tests are made with wave shapes which simulate those encountered in service. From the data compiled by the AIEE-EEI-NEMA committee about natural lightning, it was concluded that system disturbances from lightning can be represented by three basic wave shapes; full waves, chopped waves, and front-of-waves. In Figure I-1 these three waves are represented in their approximate magnitude and time.

5. It is recognized that lightning disturbances will not always have these basic wave shapes. However, by defining the amplitude and shape of these waves, it is possible to establish a minimum impulse dielectric strength that transformers should meet. A curve can be drawn through

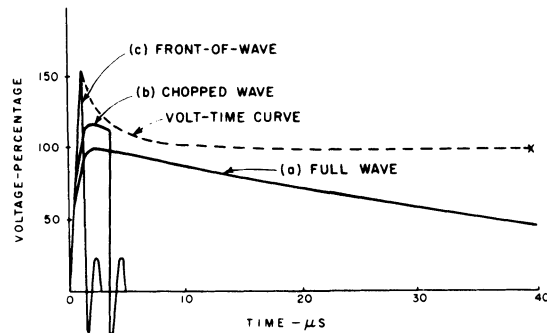


Fig. I-1. Impulse wave shapes

the points established by the amplitude and normal duration of each wave as shown in Figure I-1. For the front-of-wave and chopped wave, the points would be located at the intersection of a vertical line drawn at the time-to-chop and a horizontal line drawn through the crest while for the full wave the vertical line would be located at the time to half value (Reference 8, Sect. 4-2-12). This curve is referred to as the volt-time curve of the composite insulation structure of the transformer. The strength of the insulation to wave shapes other than those defined by Standards can be approximated from the curve.

6. Impulse tests demonstrate that the insulation is equal to or greater than the volt-time curve. Applying protective equipment that has a volt-time curve lower than that of the transformer assures adequate protection of the transformer insulation. If a lightning disturbance travels some distance along the line before it reaches a transformer, its waveshape approaches that of the full wave as shown by curve "a" in Figure I-1. This is a wave that rises from zero to crest value in 1.5 microseconds and then decays to half of crest value at 40 microseconds. It is generally referred to as 1.5×40 wave. The part of the wave between zero and the crest is called the front and the part beyond crest is called the tail.

7. A wave traveling along the line might flash over an insulator after the crest of the wave has been reached. This wave is simulated by the chopped wave which is chosen to be 15 percent greater in magnitude than the full wave. It is shown by curve "b".

8. If a severe lightning stroke hits directly at or very close to a terminal the surge voltage may rise steeply until it is relieved by a flashover, causing a sudden, very steep collapse in voltage. This condition is represented by the front-of-wave curve "c".

9. As can be seen in Figure I-1, these three waves are quite different in duration and in rates of voltage rise and decay and consequently produce different reactions within the transformer winding. The full wave, because of its relatively long duration, causes major oscillations to develop in the winding and consequently stresses not only the turn-to-turn and section-to-section insulation through-

out the winding but also develops relatively high voltages, compared to sixty-cycle stresses, across large portions of the winding and between the winding and ground (core or adjacent windings).

10. The chopped wave, because of its shorter duration, does not allow the major oscillations to develop as fully and generally does not produce as high voltages across large portions of the windings or between the winding and ground. However, because of its greater amplitude it produces higher voltages at the line end of the winding, and because of the rapid change of voltage following flashover of the test gap it produces higher turn-to-turn and section-to-section stresses.

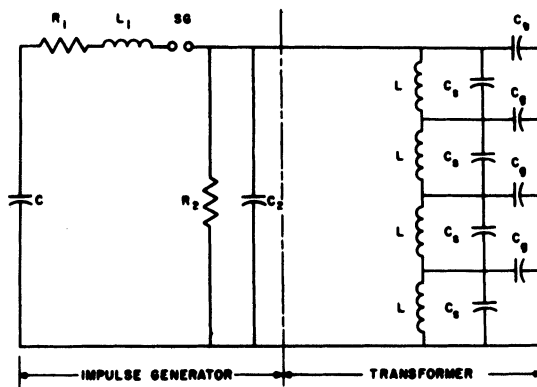
11. The front-of-wave is still shorter in duration and produces still lower winding-to-ground voltages deep within the winding. Near the line end, however, its greater amplitude produces higher voltages from winding to ground and this combined with the rapid change of voltage on the front and following flashover produces a high turn-to-turn and section-to-section voltages near the line end of the winding.

12. The selection of the type and number of test waves is determined by the test specification. These various test specifications may include a number of purchaser specifications in addition to the ones approved by Standards.

IMPULSE TEST CIRCUIT

13. Impulse waves are generated by an arrangement that charges a group of capacitors in parallel and then discharge them in series. (1, 2, 3, 4, 5, 48) The magnitude of the voltage is determined by the initial charging voltage, the number of capacitors in series at discharge, and the regulation of the circuit. The wave shape is determined largely by the constants of the generator and the impedance of the load.

14. Transformer impedance can be represented as a mesh network of inductance and capacitance. Figure I-2 represents a transformer equivalent circuit and also the parameters of a typical impulse generator. The total impedance between the impulsed terminal of the transformer and ground will hereafter be called the effective impedance.



erator capacitance value and C_2 is the load capacitance value. The time to reach crest for both of these traces will be zero since there is no series resistance or inductance to limit the current in charging the load capacitance. Changing the value of the capacitor will only affect the magnitude of the wave and not the time to reach crest magnitude.

17. When a resistor is placed across these terminals as in Figure I-3C a trace similar to "c" will result. Again the crest will be reached instantly but now the tail of the wave will decay exponentially to zero. Decreasing the resistance will cause the tail of the wave to decrease faster as shown in curve "c'". This can be explained by studying the time constant of a resistor and capacitor circuit which is equal to the product RC . Reducing R or C decreases the duration of the wave in direct proportion to the decrease in these parameters.

18. Placing an inductance across the generator capacitor as in Figure I-3D will cause an oscillatory wave similar to "d" to appear. Again the time to crest will be reached instantly but the tail now will oscillate about the zero line rather than reach the zero line exponentially as in the case of the resistor. This is due to the interchange of energy between the electrostatic field of the capacitor and the electromagnetic field of the inductance. Decreasing the inductance or capacitor causes the wave to change from "d" to "d'" which has a shorter period of oscillation. This change in period is proportional to the $\sqrt{LC}$ since the period itself is equal to $2\pi\sqrt{LC}$.

19. Placing a capacitor in parallel with an inductance across the generator capacitor as in Figure I-3E causes an oscillation similar to "e". Here again the wave is oscillating but because of the load capacitor the magnitude is initially less than "d"; the period is increased because the total circuit capacitance is increased.

20. When a circuit consisting of a resistor in series with the capacitor is placed across the generator capacitance as in Figure I-3F a trace similar to "f" will appear on the scope. Now the time to reach crest is affected. Closing the switch causes all the voltage to appear across the resistor initially and also causes a current to flow in the circuit which is limited by the resistor. This current starts to charge the load capacitor which decreases the voltage drop across the resistor. After the capacitor is charged, no further current will flow in the circuit and thus all the voltage will appear across the capacitor.

21. The time required to charge the capacitor is proportional to the time constant R_1C_2 . The capacitor will reach 95 percent voltage in $3R_1C_2$. Increasing the resistance (R_1) will lengthen the front from "f" to "f'". Increasing the capacitor (C_2) will also increase the front and in addition will decrease the magnitude as shown by "f'". If the resistor is initially replaced with an inductance in this example, basically the same result will be obtained except that high-frequency oscillations will be superimposed on the crest. The inductance will initially limit the current available to charge the load capacitor and thus will increase the time to crest.

22. These few examples provide an insight into the

effect of various circuit parameters of a transformer impulse testing circuit upon the generated wave shape. Combining all these parameters results in an equation that is cumbersome and difficult to handle. There have been many technical papers written on the subject of surge generator characteristics for transformer testing.^(3, 4, 5, 48) These examples show that the time to crest of an impulse wave is affected by the series inductance, series resistance and load capacitance. The tail of the wave is controlled by the load resistance, load inductance and also load capacitance. Figure I-3G shows a simplified generator and transformer circuit consisting of the parameters discussed. The wave shape "g" results because the transformer circuit is a complicated network instead of the simplified circuit shown.

23. The extremely large transformers now being built have impedance characteristics that make it difficult to obtain the nominal wave shape specified by Standards. On low-voltage windings it is sometimes impractical to obtain the 40-microsecond tail. From the foregoing material it can be seen that the tail can be increased by increasing the generator capacitance, load resistance or by changing the transformer effective impedance. There is an economical maximum generator capacitance that can be made available for impulse testing and this may not be sufficient to produce a tail of 40 microseconds. This is discussed later in Part I under Impulse Generator Size. Even with infinite load resistance the tail may be too short. The transformer effective impedance can be varied by the manner in which the terminals of windings not being tested are terminated. If they are isolated the maximum effective impedance results. Grounding them through resistance reduces the impedance and grounding them solidly causes further reduction. Later in Part I the advantages and disadvantages of these methods will be discussed under Connection of Non-Impulsed Terminals and Low-Impedance Windings.

24. With large transformers there is also the problem of obtaining the specified front and in the case of front-of-waves, the specified rate of rise. This is due to the large capacitance of the transformer and the inherent self inductance of the generator and of the leads that connect the generator to the transformer.

MEASUREMENT OF IMPULSE VOLTAGES

25. To measure the amplitude and shape of the applied waves which have values ranging from 30 to over 2000 kv for the crest, and 0.2 to 250 microseconds for the duration, special measuring equipment must be used. Oscillographs with high writing speeds and good accuracy, and voltage dividers with response suitable for extremely fast transients are required. A typical impulse testing circuit including the divider and oscillograph is shown in Figure I-4.

26. Because the oscillographs normally used have a voltage rating of a few hundred volts, dividers must be used to reduce the high impulse voltages to a value that can be applied to the oscillograph. The amplitude of the resulting wave should be large enough and the focus of the trace sharp enough so that wave shape deviations of

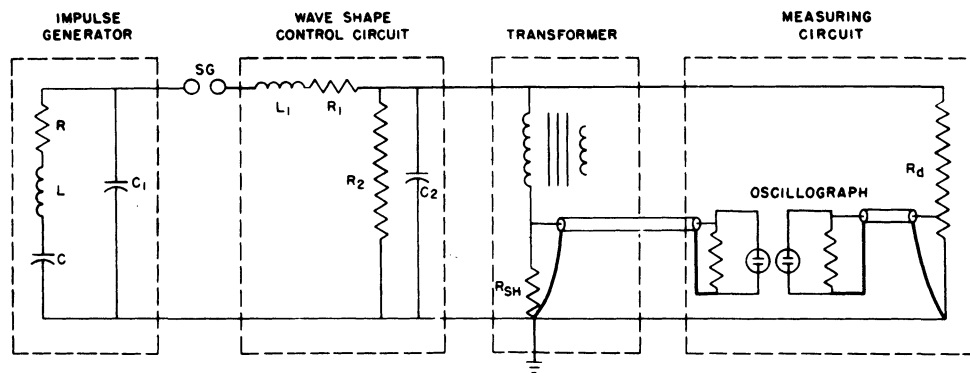


Fig. I-4. Impulse circuit and transformer

two or three percent of the crest value are discernible. Generally there are three basic types of dividers that are suitable for impulse testing. They are resistance, capacitance, and compensated. As the name implies, the resistance divider utilizes the principle that the voltage across a resistor varies directly as the resistance while with the capacitance divider, the voltage varies inversely as the capacitance. Compensated dividers are a combination of resistance, capacitance and sometimes inductance. AIEE Standard No. 4 gives more detail on the various dividers.

27. The divider which must be located close to the device under test is connected by a shielded low-loss cable to the oscilloscope which is located some distance away. When the cable is properly terminated at the oscilloscope, the voltage applied to the cable is accurately reproduced in time and amplitude by the oscilloscope. When long or high-loss cables are used, attenuation occurs.

28. The oscilloscopes utilize an electron beam that is electrostatically deflected in two directions by two pairs of plates. The amount of deflection is proportional to the voltage applied to the plates and the direction of deflection

is controlled by the polarity of the voltage applied. One pair of plates is used to sweep the beam in the X direction which is generally associated with the time of the oscillogram. In Figure I-5 two pairs of deflecting plates are shown. The electron beam which is negative polarity will sweep from position zero to the right when a voltage with polarities indicated is applied to the X plates. With the voltage as indicated applied to the Y plates the beam will move from zero toward the upper plate in the sketch. This pair of plates is usually associated with the voltage to be measured. The rate at which the beam sweeps in the timing direction is a function of the sweep voltage wave shape applied to the X plates. This rate is generally either linear or logarithmic and is dependent on the oscilloscope design. Consistency of the sweep speed is important so that out on the tail of the wave a valid comparison between waves can be made.⁽⁸⁾ In this respect oscilloscopes with linear sweeps are preferred since waves starting at various positions on the oscillograms will all have the same horizontal spread. Because of the various impulse wave shapes that must be recorded, a number of sweep speeds are built into the oscilloscopes.

29. The recommended sweeps for the various wave shapes are:

	<i>Sweep Range</i>	<i>Oscillogram Identification</i>
Front-of-wave voltage	2 to 5 μ s	FOWV
Chopped-wave voltage	5 to 10 μ s	CWV
Reduced full-wave voltage	50 to 70 μ s	RFWV
Full-wave voltage	50 to 70 μ s	FWV
Reduced full-wave current	150 to 300 μ s	RFWC
Full-wave current	150 to 300 μ s	FWC

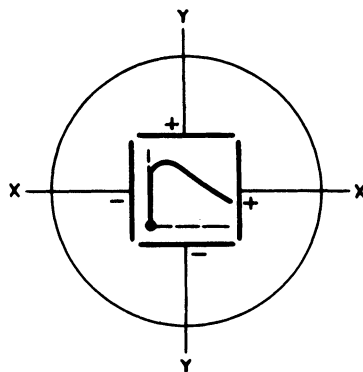


Fig. I-5. Cathode-ray oscilloscope deflection plates

30. In an earlier paragraph it was stated that the full wave stresses the turn-to-turn and coil-to-coil insulation throughout the winding. The stresses are affected by the slope of the wave front and not necessarily by the actual time-to-crest. In Figure I-6 a full wave is sketched. The time, $t_2 - t_0$, is the time to actual crest but the rate-of-rise of the wave that causes the stresses is $E/(t_1 - t_0)$.

31. The same reasoning applies to scaling the front of front-of-wave tests. The front is derived from the slope of the wave. In Figure I-7 the rate-of-rise is $E/(t_1 - t_0)$ and not $E/(t_2 - t_0)$. The time-to-chop (or time-to-flash-

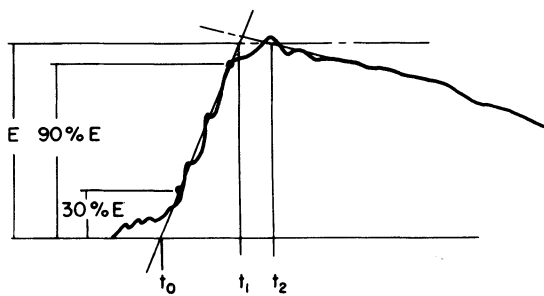


Fig. I-6. Measurement of front of full wave

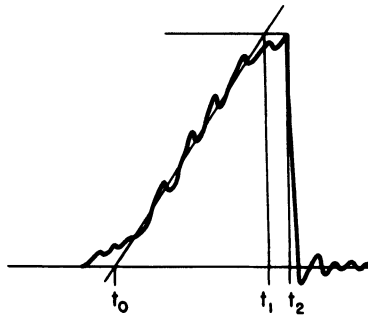


Fig. I-7. Measurement of front-of-wave

over) is $t_2 - t_0$. In cases where the transformer capacitance is large the wave rounds off near the crest and there this distinction between the wave front and the time-to-chop must be made.

32. Whenever questions arise in scaling or interpreting film, the intent of and purpose of the particular wave application should determine the method employed. In a later section the pros and cons of short tail full wave versus long tail waves obtained by changing the circuit effective impedance and other impulse testing differences will be discussed. Here again the purpose and the ultimate desired stresses in the winding should determine the course to follow.

GROUNDING PRACTICES

33. The currents flowing in the impulse circuit generally are fairly large and have high rates of change (di/dt). Consequently a voltage drop exists between points connected by a conductor through which an impulse current flows. Because of this it is difficult to hold two different points at the same potential or, stated another way, to have two different points at ground potential.

34. The difference in potential between two points will depend upon the length of the interconnecting lead, and the rate of change of the current flowing in the lead. The potential difference can be substantial. For example, if a current changing at a rate of 1000 amperes per micro-

second flows through a wire 10 feet long, the two ends of the wire will differ in potential by 3000 to 4000 volts. This is not at all unusual for the ordinary impulse circuit. Because of this, impulse circuits must be carefully arranged. This is particularly true of the circuits used for front-of-wave testing.

35. There are two prime considerations when grounding practices are established: a) safety to personnel and, b) accuracy of measurements. For safe operation all the devices in the vicinity of the operator should be at the same potential. If the devices have unlike potentials there is the danger of the operator coming in contact with two pieces of equipment at different potentials. For accurate measurement, the measuring system should be connected directly across the two points to be measured like the leads of a voltmeter. In some cases this would electrically elevate the chassis of the oscillograph with respect to other apparatus in the vicinity since the transformer under test might be located some distance from the oscillograph. Fulfilling these two considerations is sometimes difficult and some compromises must be made. This is illustrated by considering several circuits.

36. In Figure I-8 the voltage measured by the divider is between points A and B. The main current paths are indicated by the heavy lines. On the fronts of full and chopped waves, the voltage drop between B and C is usually negligible and the capacitive current to the control room shield is also small. On the fronts of front-of-waves, the drop across BC is dependent on the capacitive currents that flow through the transformer and the inductance of the lead BC. The capacitive current for large-kva, low-voltage windings may produce a voltage drop across the lead inductance that will be almost 25 percent of the total voltage measured by the voltage divider. To eliminate the voltage drop BC the divider should be connected to point C as shown in Figure I-9 and the return lead from the transformer should be run directly to the bottom end of the impulse generator. With this arrangement the divider is connected to read the voltage AC. However, the stray capacitive currents flowing from the generator, the high-voltage leads to the control room and building ground and from transformer tank to ground will flow back to the generator through the lead BC and the building floor. The potential difference between the control room and oscillograph will depend upon the magnitude and rate-of-change of the currents. However, it is common practice to ground the oscillographs to the control room for personnel safety. This forces current to flow from C through the sheath of the measuring cables to the control room ground and back to B and causes disturbances on the oscillograms of both the voltage and current. To minimize this effect lead BC should be as short as possible. In severe cases a multiplicity of leads or wide foil may be run from B to C. In special cases a doubly shielded control room may be used.⁽⁶⁾

37. The method of Figure I-9 is especially useful when the generator is some distance from the transformer providing the bottom end of the generator has sufficient insulation to the ground plane and the voltage drop between point C and the oscillographs can be kept small.

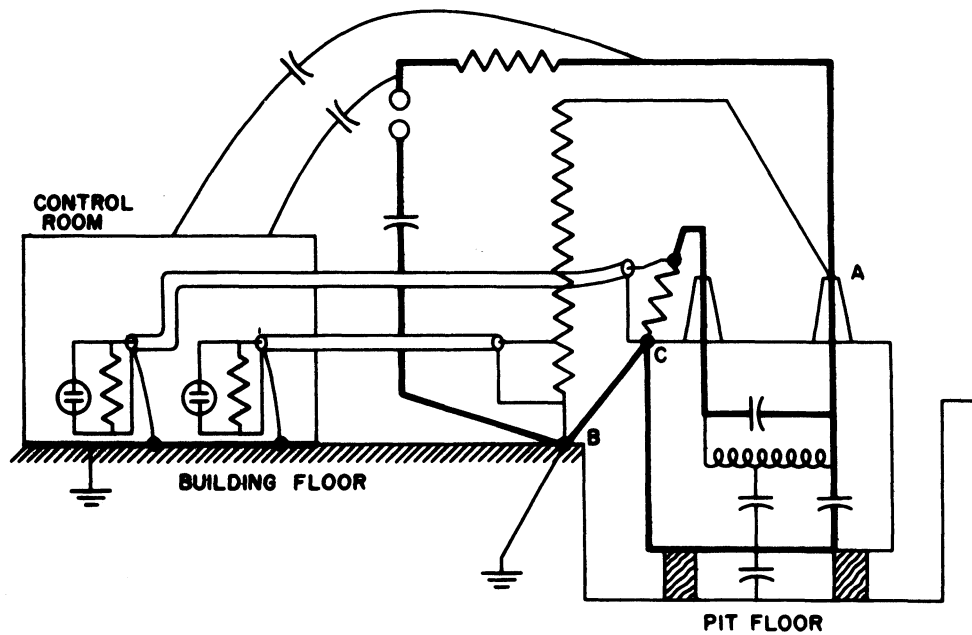


Fig. I-8. A grounding method

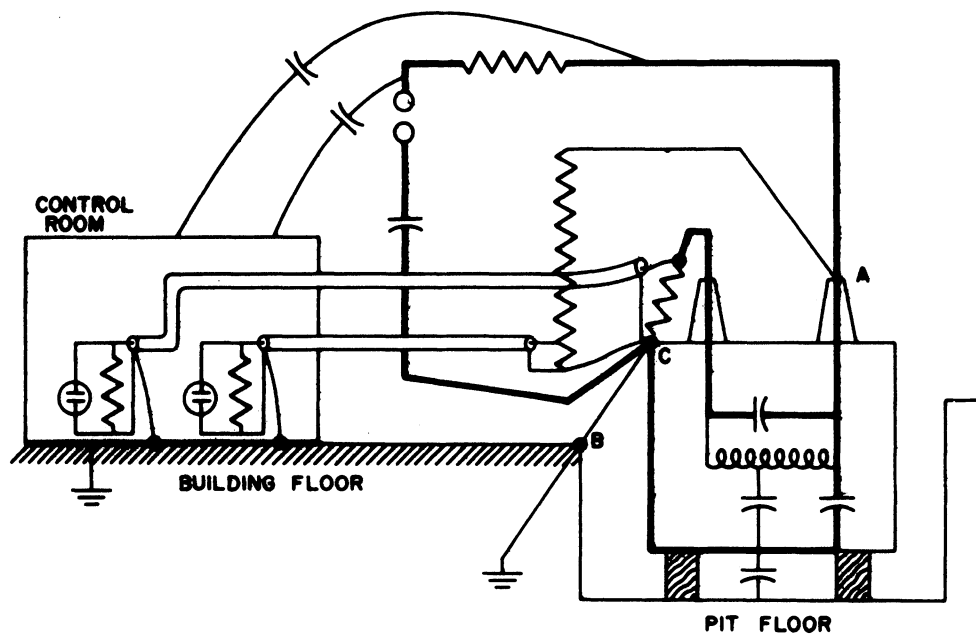


Fig. I-9. Preferred grounding method

38. For generators that are not insulated sufficiently at the bottom end and therefore must be grounded to the building at their bases, the method in Figure I-10 is used. In this method it is particularly helpful to run several connections from B to the tank (as indicated by BC and BD) and to have many leads or a wide foil from B back

to the bottom end of the generator to reduce the voltage drops between these points. However, the measured voltage will be in error by the magnitude of the voltage drop between the tank and point B. As in Figure I-9, the bottom end of the divider may be connected to point D to eliminate the voltage drop in lead BD.

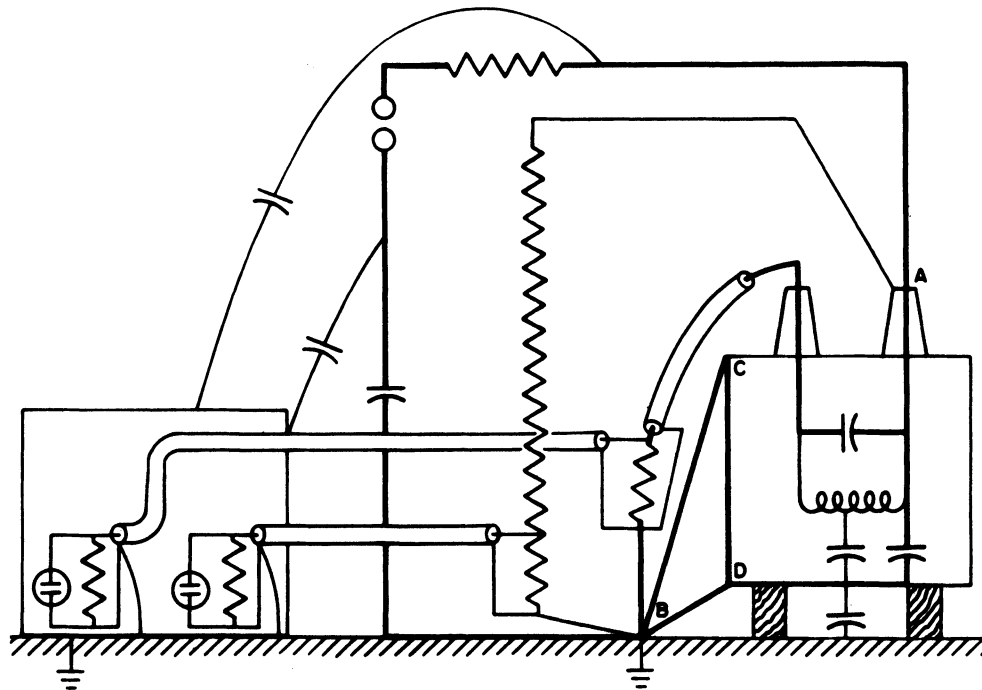


Fig. I-10. Grounding with grounded generator

39. The location of the resistance shunt for current measurement must also be selected with consideration of the ground problem. In Figure I-8 with the resistance shunt located at the transformer tank, the cable sheath is raised above ground by the potential drop in lead BC. Current will flow from C through the cable sheath and back to B causing disturbance on the current wave. If the shield is allowed to float at point C, sufficient clearance from shield to inner conductor must be provided.

40. Small disturbances may appear on current oscillograms which are due to the voltage drops in the ground leads "spitting" to non-connected metal. For instance, if a piece of metal was floating electrically near the ground lead it would be possible for the lead to flash to the metal. The disturbance indicated on the scope would be a function of the capacitance-to-ground of the metal. A large capacitance would cause a greater disturbance since more energy would be required to charge up the capacitance. If the floating metal was located near the measuring cables the disturbance on the oscillogram would be even greater.

41. When front-of-waves are applied, the best procedure is to locate the chopping gap directly on the bushing of the transformer under test because of the voltage drops that develop when the capacitive current is flowing. For the low-voltage large capacitance windings, the voltage deter-

mined by the gap spacing can be more accurate than the oscillographic record when it is not possible to obtain a well-grounded circuit. As pointed out in the discussion above, the voltage drop across lead BC in Figure I-8 might be 25 percent of the total voltage measured. If the gap were connected between A and B, full front-of-wave voltage would not be applied to the transformer.

42. Another method employed is shown in Figure I-11. This is sometimes called the "line current method" as discussed in Part II, paragraph 26. In this method the shunt can be located close to the ground mat or floor of the test area and the exposed lead from the transformer to the shunt can be kept short thus minimizing electrostatic pickup. On the other hand this method collects all the current flowing out of the transformer and generally will result in a higher initial inrush current than the previously described methods. Methods of dealing with high initial currents are presented in Part II.

43. It is the intent of this Section to give a little insight into the conditions that affect the measurement of impulse waves. A complete analysis of all ground conditions cannot be given because each test set-up is different. Once the philosophy of grounding is understood, compromises can be made to assure the most accurate and safest measurement.

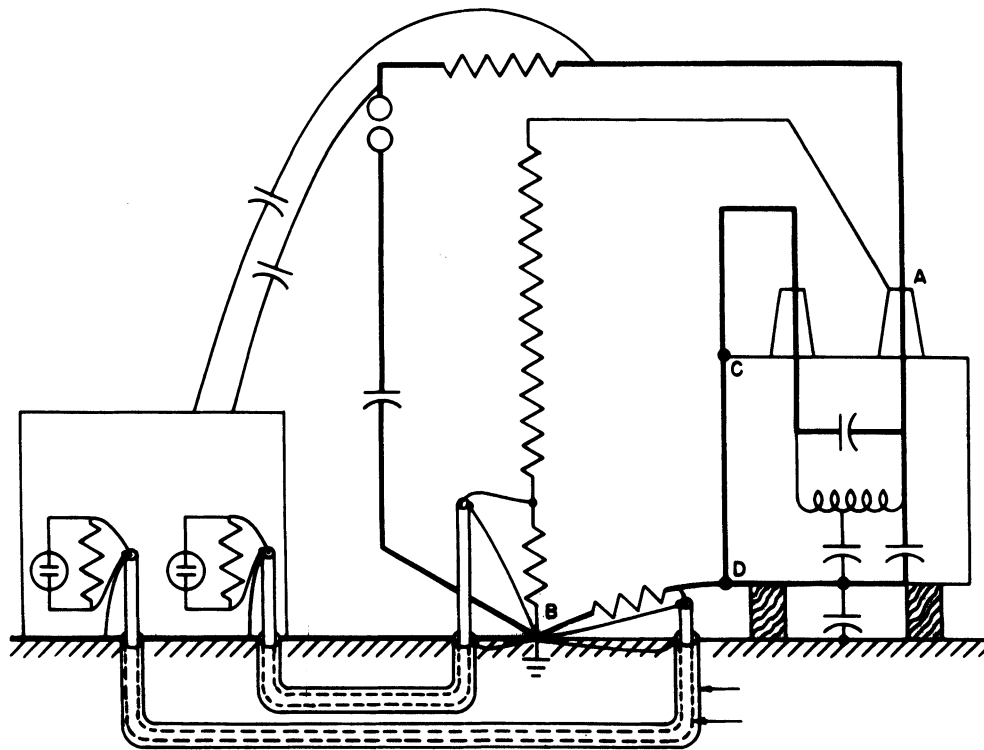


Fig. I-11. Grounding with "Line Current" method

FAILURE DETECTION

44. One of the most important phases of impulse testing is the detection of failure. There is no one definite and positive method available, but operating experience on units that have been impulse tested demonstrate that by utilizing a combination of all the methods, failure detection is assured. Of these methods, the cathode-ray oscillogram is most effective.

45. Detection by cathode-ray oscillograms is based on the premise that an insulation failure will change the impedance of the transformer to impulse voltages. This change will cause variations in the impulse current flowing through the winding and in the voltage measured across the winding. The interpretation of such variations is discussed in detail in Part II of the Guide. The voltage oscillograms which are taken to measure the applied voltage magnitude and wave shape are used to detect such wave shape variations. To detect variations in the current it is necessary to have current oscillograms. These are obtained by measuring the voltage drop across a suitable shunt which is connected between the grounded end of the impulsed winding and ground. When possible, simultaneous oscillograms of the voltage and current should be taken. If only one oscillograph is available, then the recommended procedure is to have the voltage oscillogram precede the current oscillogram.

46. Because of the complicated nature of impulse testing and the different forms of transformer construction, the various transformer manufacturers have developed

throughout the years, impulse testing techniques suitable for their use. As the American Standard was revised throughout the years, it was modified to cover the different techniques in use. As a result, there are several alternate approaches to some of the problems.

47. There are three principal testing techniques in which there is a divergence of practice. These are:

1. Connection of non-impulsed terminals.
2. Low-impedance windings.
3. Use of capacitors across current shunts.

48. Each of the three techniques is treated in detail in Sections of this Guide. The first two will be found in this part of the Guide following this Section. The use of capacitors across current shunts is covered in Part II.

CONNECTION OF NON-IMPULSED TERMINALS

49. In the American Standard C57 under paragraph 12-92.410 it states: "Terminals Not Being Tested. One terminal of the winding under test shall be grounded directly or through a low resistance if current measurements are to be made (For exceptions see 12-92.411). The terminals of the winding that are not being tested may be grounded directly or through a resistor in order to limit the voltage induced in these windings. It is desirable that the voltages on terminals that are not being tested should not exceed 80 percent of the full-wave voltage for their voltage class." Three different alternative practices are used to comply with this paragraph.

Alternate 1—All winding terminals except the terminals being tested are grounded.

Alternate 2—One terminal of each winding not being tested is grounded through a resistance. The other terminals are either grounded directly or through resistances or isolated.

Alternate 3—All winding terminals except the terminals being tested are grounded unless the obtainable wave tail is less than 40 microseconds. In this case, series resistances are inserted in some or all of the leads of the windings not being tested.

50. Alternate 1 is the simplest and reduces the time and labor required for impulse testing and eliminates questions of resistance values to be used. Alternate 2 provides maximum length of wave tail because of the effect of the short-circuited winding in reducing the effective impedance of the transformer when Alternate 1 is used. However, for transformers with low impedance the difference in wave tail is only a few microseconds.

51. Experience has shown that sensitive failure detection is obtainable with any one of the three alternatives. (12, 19, 21).

LOW-IMPEDANCE WINDINGS

52. In American Standard C57, there are three permissible methods for testing windings of a very low impedance. These methods are:

1. Connect together all terminals of the same BIL in the winding.
2. Insert a resistor of not more than 500 ohms in the grounded end.
3. Accept the short length of wave tail.

Method 1

53. Connecting the terminals together produces a high stress on the winding-to-ground insulation and a rather low sustained stress to the turn-to-turn, coil-to-coil and across-the-coil insulation. This is because the turn-to-turn and coil-to-coil stress is primarily a function of the capacitance from one end of the winding to the other and the capacitance-to-ground. These statements can be visualized a little better through the use of a simple example.

54. Let the transformer constants be represented with an equivalent circuit as shown in Figure I-12a. The through capacitance (capacitances from one end of the winding to the other end) of the transformer are represented by C_1 and C_2 and the ground capacitance by C_3 . L_1 and L_2 are the transformer inductance. If the through capacitances, C_1 and C_2 , are large with respect to the ground capacitance an initial distribution similar to Curve X in Figure I-12b will result. Since the final distribution is line Y the envelope of the winding oscillation will be between curves X and X'. This example demonstrates a low turn-to-turn and coil-to-coil stress but a high stress to ground throughout the winding. If the through capacitances are small compared to the ground capacitance an initial distribution similar to curve Z in Figure I-12b will result. The same final distribution line Y will occur and

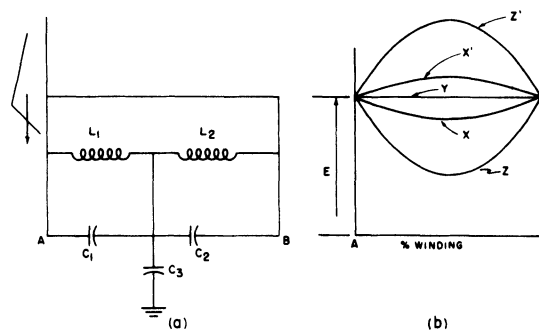


Fig. I-12. Low impedance windings—connecting terminals together

thus the envelope of oscillation will be between curves Z and Z'. This produces a high turn-to-turn, coil-to-coil and insulation-to-ground stress. The objections to using this method of test for transformers having the parameter relationships assumed is that parts of the winding may oscillate to 200 percent of the applied voltage. Testing in this manner for these particular capacitance relationships is not justified since in service a surge is rarely applied to both terminals simultaneously.

55. This method of testing does not lend itself to ground-current measurements since only the capacitance current of the winding under test to the tank and other windings can be measured.

Method 2

56. Inserting a resistance in the grounded end of the winding will produce different turn-to-turn and coil-to-coil stresses than Method 1. The change in stress is a function of the winding constants. In Figure I-13a, the typical equivalent network of the transformer with one end of the winding grounded through a resistor is shown. If the through capacitances are extremely large compared to the ground capacitance a distribution similar to curve P in Figure I-13b will result. The final distribution would be something similar to line Q where all or almost all the voltage is across the resistor. The envelope of oscillation

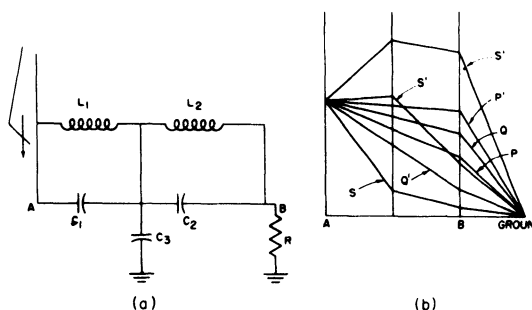


Fig. I-13. Low impedance windings—winding grounded through a resistor

will then be between curve P and P'. In this case the turn-to-turn and coil-to-coil stress is increased over the example that has the same capacitance relationship in