

IEEE Guide for the Parameter Measurement of AC Transmission Lines

IEEE Power and Energy Society

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IEEE Guide for the Parameter Measurement of AC Transmission Lines

Developed by the

**Transmission and Distribution Committee
of the
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Abstract: In this guide, the field testing methodology and techniques are presented for measuring electrical parameters of ac transmission lines. The topics discussed are safety precautions; requirements for measuring instruments; measurement of induced voltage and current; phase verification and insulation resistance measurement; dc resistance measurement; off-line parameter measurement of symmetrical transmission line; off-line parameter measurement of asymmetrical transmission lines; eliminating power frequency interference during off-line measurement; zero-sequence parameter measurement with adjacent lines in operation; and online parameter measurement of transmission lines.

Keywords: admittance measurement, asymmetrical lines, distributed parameter, electrical parameter, IEEE 1870™, impedance measurement, off-line measurement, on-line measurement, open-circuit impedance, short-circuit impedance, transmission line

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Introduction

This introduction is not part of IEEE Std 1870-2019, IEEE Guide for the Parameter Measurement of AC Transmission Lines.

The purpose of electrical parameter measurement of ac transmission lines is to provide true parameters for power flow calculation, short-circuit current computation, power system stability analysis, protective relay setting, line fault location, and so on compared to solely calculated parameters. Therefore, a working group was formed to develop a guide that would provide guidance for parameter measurement of ac transmission lines.

This guide was prepared by working group P1870 of the IEEE-SA Board of Governors/Corporate Advisory Group (BOG/CAG).

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IEEE Guide for the Parameter Measurement of AC Transmission Lines

1. Overview

1.1 Scope

This guide will provide testing methods for impedance measurement of ac transmission lines and calculating methods for the resistance, inductance, and capacitance (RLC) distribution parameters of the tested line. It will also provide testing and calculating methods to obtain mutual inductance and coupling capacitance between double circuit lines on the same tower. This guide will outline the measuring instruments and the safety of the measurement. In addition, it will include test procedures to obtain the open-circuit and short-circuit impedances of the tested line as well as the formulas to get the distributed parameters from impedance measurements.

1.2 Purpose

The accurate parameter of the power transmission line is the basis of precise power flow calculations, stability analysis, protective settings, and line fault location. Therefore, it is necessary to develop a uniform guide to provide technical guidance for the accurate parameter measurement of ac transmission lines.

1.3 Background

To understand the importance of measuring electrical parameters, in particular, the short-circuit, positive-sequence impedance Z_1 and zero-sequence impedance Z_0 , the following case study compares measured and calculated values for the positive-sequence impedance Z_1 and zero-sequence impedance Z_0 of 40 power lines with different configurations (power cables, overhead lines and mixed lines consisting of both, power cables, and overhead lines).

In [Figure 1](#), the deviation between calculated and measured values for R and especially X of Z_1 are small relative to the ones of Z_0 . This is because Z_1 can be accurately calculated by means of the geometry and the material of the conductors. However, for the calculation of Z_0 , the properties of the soil return path shall be known, such as soil resistivity in different soil layers and other parallel buried conductors such as pipes and other grounded elements in residential or industrial areas. All of these properties are unknown and therefore make the calculation inaccurate in contrast to the measurement, which reflects all present properties of the soil return path and therefore provides true values for Z_0 .

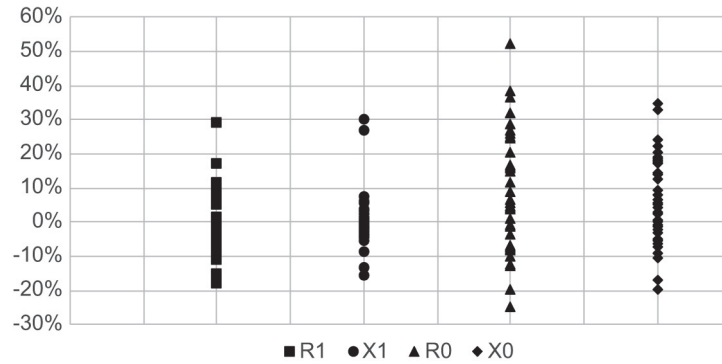


Figure 1—Deviation between measured and calculated values

Inaccurate zero-sequence impedance strongly affects zone reaches and accuracy of impedance-based fault location of distance protection relays in the event of a single line to ground fault. The example described here is taken from a measurement on an overhead distribution line with a length of 7 km. Table 1 compares the measured and the calculated values for Z_1 and Z_0 .

Table 1—Error calculation between measured and calculated values

Error calculation				
	Z_1		Z_0	
	R in Ω	X in Ω	R in Ω	X in Ω
Measured value	0.722	1.938	1.095	5.067
Calculated value	0.740	1.940	1.450	8.500
Error (ref. to measured value) in %	2.54	0.09	32.42	67.75

The values for Z_1 only deviate negligibly from each other, whereas the deviation for Z_0 is significantly high. With respect to this example, the actual zone reach for all phase-to-phase and all phase-to-ground faults is determined and shown in the chart of Figure 2 (grading factor is 90%, which means the zone of zone 1 is supposed to be 90% of the line length).

As expected, the actual zone reach for phase-to-phase faults is close to 90%. This example also considers the measurement of the line's asymmetrical parameters and, therefore, reflects the small deviations in the reaches among the three different phase-to-phase faults.

For phase-to-ground faults, however, the reaches are beyond 120%, which might make the relay overreaching and not operating selectively. Using the actual values for Z_1 and Z_0 , which are derived from the measurement, would correct the actual reach to 90% and avoid unselective performance of the relay.

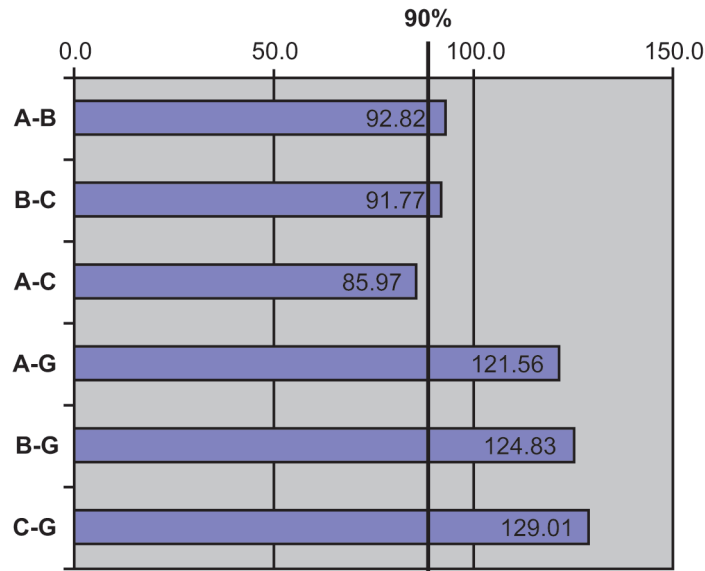


Figure 2—Zone reach in percentage of line length

In regard to the accuracy of the impedance-based fault locator, the displayed fault location for a fault at 7 km is determined accurately for phase-to-phase faults. Phase-to-ground faults are displayed much closer to the relay as they actually are, as shown in the chart of Figure 3. Using the actual values for Z_1 and Z_0 would locate faults much more accurately.

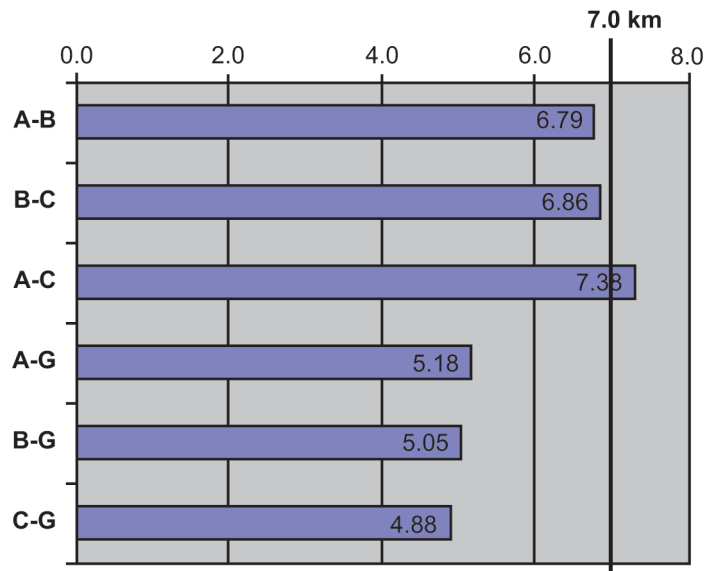


Figure 3—Fault location in kilometers

1.4 Application of distributed parameter measurement of ac lines

Normally in power system calculation, the equivalent Π representation is used rather than the distributed parameters of the lines. Actually, some measurement results described in this guidance are shown as distributed parameters. In [Annex E](#), the equivalent Π representation and lumped parameter calculation from distributed parameters are indexed and introduced.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

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3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.³

capacitance per unit length: Capacitance of a transmission line, in unit length.

conductance per unit length: ac conductance of a transmission line, in unit length.

conductor: Phase of a transmission line consisting of a bundle of wires.

coupling capacitance: Capacitance between two phase conductors from the same or different circuits of transmission lines, or capacitance between two transmission lines.

double-circuit transmission lines: Two single-circuit transmission lines built in parallel along the same corridor or arranged on the same tower.

down-lead: Wires between the terminals of transmission lines and the measuring instruments, grounding grid, and so on.

electrical parameters per unit length (distributed parameters): Resistance, inductance, and capacitance uniformly distributed along a transmission line; for convenience, they are expressed in unit length (normally in 1 km).

equivalent circuit of a transmission line: Π or T representations for the equivalent circuit of a transmission line.

ground wire: Conductors built above the overhead transmission lines to prevent lightning strikes.

grounding: System, circuit, or apparatus provided with a ground(s) for the purpose of establishing a ground return circuit and maintaining its potential at approximately the potential of Earth.

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³*IEEE Standards Dictionary Online* is available at: <http://dictionary.ieee.org/>.

grounding wire: Lead or wire connected to the substation grounding grid for maintaining the neutral point of equipment, protective grounding point, or short-circuit grounding point at approximately the potential of Earth.

induced current: Current resulting from the flow of charge due to an induced voltage.

induced voltage: Voltage caused by electromagnetic or electrostatic effect of adjacent energized lines or equipment.

inductance per unit length: Inductance of a transmission line, in unit length.

long-distance transmission line: Overhead lines with a length greater than 100 km or cables with a length greater than 30 km.

lumped equivalent parameter: Parameters in the equivalent circuit of a transmission line.

multicircuit transmission lines along the same corridor: Two or more circuits of transmission lines densely arranged along the same corridor.

multicircuit transmission lines on the same tower: Two or more circuits of transmission lines on the same tower with the same or different voltage levels.

mutual inductance: Inductance between two phase conductors from the same or different circuits of transmission lines, or inductance between two transmission lines.

off-frequency method: Method that can precisely measure the parameters of transmission lines by applying a power source with a frequency different from but close to the power frequency.

off-line measurement: Measurements performed when the transmission lines to be measured are not in service.

online measurement: Measurements performed when all the lines are in service.

open-circuit impedance: Input impedance of a transmission line at the sending terminal when the receiving terminal is open-circuited.

positive-sequence, open-circuit impedance: Input impedance of a transmission line at the sending terminal with a positive-sequence power source applied when the receiving terminal is in open-circuit.

positive-sequence, short-circuit impedance: Input impedance of a transmission line at the sending terminal with a positive-sequence power source applied when the receiving terminal is short-circuited.

power frequency: Values of frequency used in normal operation of the power system.

receiving terminal: Terminal opposite to the sending terminal of a transmission line.

resistance per unit length: ac resistance of a transmission line, in unit length.

sending terminal: Terminal of a transmission line, at which a power source is applied for the parameter measurement of the transmission line.

short-circuit impedance: Input impedance of a transmission line at the sending terminal when the receiving terminal is short-circuited.

short-distance transmission line: Overhead lines with a length less than 100 km or underground cables with a length less than 30 km.

single-circuit transmission line: Transmission line consisting of three phases of conductors.

single-phase conductor: Conductor in one phase of three-phase transmission lines.

symmetrical three-phase system: Three-phase system having equal impedance and admittance for each phase, in which the three-phase voltages and currents are of the same amplitude and have a 120° difference in phase angle.

synchronous measurement: Measurement mode that can synchronously sample voltages and currents.

transposition: Method by which the three-phase conductors change their positions in turn to achieve symmetrical impedance and admittance among three phases.

zero-sequence, short-circuit impedance: Input zero-sequence impedance of a transmission line at the sending terminal with a single-phase power source applied when the receiving terminal is shorted to the ground.

zero-sequence, open-circuit impedance: Input impedance of a transmission line at the sending terminal with a single-phase power source applied when the receiving terminal is in open-circuit.

3.2 Acronyms and abbreviations

c_1	positive-sequence capacitance of a single-phase conductor, F/km
c_g	capacitance between the single-phase conductor and the ground, F/km
c_p	coupling capacitance between two phase conductors in a single-circuit line, F/km
c_L	coupling capacitance between a conductor from circuit I and another conductor from circuit II in double-circuit lines, F/km
$c_{I-II,0}$	zero-sequence coupling capacitance between circuit I and circuit II in double-circuit lines, F/km
$c_{I,g}, c_{II,g}$	ground capacitance of circuit I or circuit II in double-circuit lines, F/km
C_1	positive-sequence capacitance of a short-distance transmission line, F
$C_{i-i,0}$	zero-sequence capacitance related to circuit i , F
$C_{i-k,0}$	zero-sequence coupling capacitance between circuit i and circuit k , F
D	length of a transmission line, km
f	frequency of a test power source, Hz
f_s	power frequency or system frequency, Hz
g	conductance between the single-phase conductor and the ground, S/km
l	self-inductance of the single-phase conductor of a transmission line, H/km
l_1	positive-sequence inductance in a single-phase conductor, H/km
$l_{I,0}, l_{II,0}$	zero-sequence self-inductance of circuit I or circuit II in double-circuit lines, H/km
L_1	positive inductance of a single-phase conductor in a short-distance line, H

m_p	mutual inductance between two conductors in a single-circuit line, H/km
m_L	mutual inductance between a conductor from circuit I and another conductor from circuit II in double-circuit lines, H/km
$m_{I-II,0}$	zero-sequence mutual inductance between circuit I and circuit II in double-circuit lines, H/km
R_a	dc resistance of conductor a , Ω
R_{ab}	dc resistance when conductor a and conductor b are connected in series, Ω
r	ac resistance of a single-phase conductor, Ω/km
r_1	positive-sequence resistance in a single-phase conductor, Ω/km
$r_{I,0}$, $r_{II,0}$	zero-sequence resistance of circuit I or circuit II in double-circuit lines, Ω/km
r_g	Earth resistance, Ω/km
R_1	positive-sequence resistance of a single-phase conductor in a short-distance line, Ω
U_s	test power source
y_0	zero-sequence admittance of a single-phase conductor, S/km
y_1	positive-sequence admittance of a single-phase conductor, S/km
$y_{I,I-II}$	two-phase positive-sequence admittance of double-circuit lines, S/km
y_{a-a} , y_{b-b} , y_{c-c}	self-admittance of conductors a , or b , or c of an asymmetrical single-circuit line, S
y_{a-b} , y_{b-c} , y_{c-b}	coupling admittance between conductors a and b , or b and c , or c and a , of an asymmetrical single-circuit line, S
y_{i-i}	self-admittance of conductor i of asymmetrical multicircuit lines, S
y_{i-k} , y_{k-i}	coupling admittance between conductors i and k of asymmetrical multicircuit lines, S
Y_1	parallel admittance of the Π representation, S
$\mathbf{Y}_{\text{asy}}$	admittance matrix of asymmetrical multicircuit lines, S
$Y_{i-i,0}$	zero-sequence self-admittance of circuit i , S
$Y_{i-k,0}$	zero-sequence coupling admittance between circuit i and circuit k , S
z_0	zero-sequence impedance of a single-phase conductor, Ω/km
z_1	positive-sequence impedance of a single-phase conductor, Ω/km
$z_{I,I-II}$	two-phase positive-sequence impedance of double-circuit lines, Ω/km
z_{a-a} , z_{b-b} , z_{c-c}	self-impedance of conductors a , or b , or c of an asymmetrical single-circuit line, Ω
z_{a-b} , z_{b-c} , z_{c-b}	mutual impedance between conductors a and b , or b and c , or c and a , of an asymmetrical single-circuit line, Ω
z_{i-i}	self-impedance of conductor i of asymmetrical multicircuit lines, Ω
z_{i-k} , z_{k-i}	mutual impedance between conductors i and k of asymmetrical multicircuit lines, Ω
$z_{c,0}$	zero-sequence characteristic impedance of a single-phase conductor, Ω
$z_{c,1}$	positive-sequence characteristic impedance of a single-phase conductor, Ω
$z_{c1,I-II}$	two-phase positive-sequence characteristic impedance of double-circuit lines, Ω
$z_{c,I}$	characteristic impedance of circuit I in double-circuit lines, Ω

$z_{c,II}$	characteristic impedance of circuit II in double-circuit lines, Ω
$Z_{0,OC}$	zero-sequence, open-circuit impedance of a transmission line, Ω
$Z_{0,SC}$	zero-sequence, short-circuit impedance of a transmission line, Ω
$Z_{0,I-II,OC}$	zero-sequence, open-circuit impedance of double-circuit transmission lines, Ω
$Z_{0,I-II,SC}$	zero-sequence, short-circuit impedance of double-circuit transmission lines, Ω
Z_1	positive-sequence series impedance of the Π representation, Ω
$Z_{1,OC}$	positive-sequence, open-circuit impedance of a transmission line, Ω
$Z_{1,SC}$	positive-sequence, short-circuit impedance of a transmission line, Ω
$Z_{1,I-II,OC}$	positive-sequence, open-circuit impedance of double-circuit transmission lines, Ω
$Z_{1,I-II,SC}$	positive-sequence, short-circuit impedance of double-circuit transmission lines, Ω
$\mathbf{Z}_{asy}$	impedance matrix of asymmetrical multicircuit lines, Ω
$Z_{i-i,0}$	zero-sequence self-impedance of circuit i , Ω
$Z_{i-k,0}$	zero-sequence mutual impedance between circuit i and circuit k , Ω
$Z_{I,0}$	zero-sequence, short-circuit impedance of circuit I of double-circuit lines with one terminal of circuit II grounded
$Z_{I-II,0}$	zero-sequence mutual impedance between circuit I and circuit II of double-circuit lines
$Z_{II,0}$	zero-sequence, short-circuit impedance of circuit II of double-circuit lines with one terminal of circuit I grounded
$Z_{pg,0}$	zero-sequence, short-circuit impedance of circuit I of double-circuit lines with both terminals of circuit II grounded
Z_s	system impedance to be measured, Ω
γ_0	zero-sequence propagation coefficient of a transmission line, 1/km
γ_1	positive-sequence propagation coefficient of a transmission line, 1/km
$\gamma_{1,I-II}$	two-phase, positive-sequence propagation coefficient of double-circuit lines, 1/km
γ_I	propagation coefficient of circuit I in double-circuit lines
γ_{II}	propagation coefficient of circuit II in double-circuit lines
$\omega = 2\pi f$	angular frequency
Δf	frequency deviation from power frequency in an off-frequency measuring method
GPS	global positioning system
PMU	phasor measurement unit
SNR	signal-to-noise ratio

4. Safety precautions

In the parameter measurement of a transmission line, measures shall be taken to prevent from operator injuries and instrument damages caused by the induced voltage and current on the line under measurement. Sometimes the induced voltage may be greater than tens of kilovolts and the induced current hundreds of amperes or higher. The induced voltage is extremely high when both terminals in open circuit.

The following safety precautions shall be taken for the tests described in this guide:

- a) Measures shall be taken to minimize induced voltage and current when there are dangers for operators and instruments; otherwise, the measurement shall be stopped.
- b) To help ensure safety while performing measurements, operators shall wear personal protective equipment, such as insulation shoes, gloves, mats, safety belts, and so on.
- c) Transmission lines shall be solidly grounded when the measuring mode is changed so as to help ensure the safety of instruments and personnel.
- d) The down-lead or grounding wire shall be solidly connected. Any wire used in the measurement shall be insulated and able to withstand testing voltage and induced voltage.
- e) It is necessary to install a protective gap between the grounding wire and the down-lead to protect operators and measuring equipment from lightning strikes.

In addition, personnel who participated in the measurement shall follow the national and regional safety codes of electric utilities and take adequate protective measures. In North America, for example, the test personnel should be familiar with relative parts of the National Electric Safety Code® (NESC®) (Accredited Standards Committee C2).⁴

5. Requirements for measuring instruments

The measuring equipment should have suitable ranges and capacity, and it can withstand induced voltage and current, as estimated according to [Annex A](#).

5.1 Current transformer

The current transformer (CT) should have a class of accuracy of 0.5 or higher.

5.2 Potential transformer

The potential transformer (PT) should have a class of accuracy of 0.5 or higher.

5.3 Special instruments for parameter measurement of transmission lines

A special instrument can be developed for parameter measurement of transmission lines, and its algorithm to obtain the parameters of transmission lines should adhere to the following requirements.

- a) The instruments should be capable of synchronously sampling and analyzing single-phase or three-phase voltage and current signals.
- b) The class of accuracy of the voltage should be within 0.5.
- c) The class of accuracy of the current should be within 0.5.

During digital signal processing of the instrument, the frequency resolution should be within 2.5 Hz; the accuracy of signal amplitude and phase shift should be within 0.1% and 0.05°, respectively. Moreover, the signal analysis system should have the ability to eliminate signal aliasing and leakage.

⁴Information on references can be found in [Clause 2](#).

5.4 Off-frequency power source

The off-frequency power source in off-line measurements should be capable of outputting sinusoidal signals at a single frequency that can be adjustable. Normally the power source should generate a sinusoidal signal at $f_s - \Delta f$ or $f_s + \Delta f$, where Δf can be 2.5 Hz, 5 Hz, 7.5 Hz, 10 Hz, or other applicable frequencies.

The total harmonic distortion for the voltage output of the power source should be within 3%.

5.5 Instruments for dc resistance measurement

The instrument to obtain the dc resistance of a transmission line can be a special instrument or the combination of a dc power source, a dc voltmeter, and a dc ammeter.

The dc resistance tester can be used, and its class of accuracy should be within 0.5. Alternatively, for the combined measuring instrument for dc resistance, the power source can be several batteries connected in series, and the class of accuracy of the dc voltmeter and ammeter should be within 0.5.

6. General considerations during measurement

The following items should be considered before conducting off-line measurements:

- a) Make sure that all the temporary grounding wires along the line are dismantled and nobody is working on the transmission line.
- b) Pay close attention to the weather condition along the lines during the measurement. The measurement shall be stopped if the weather is not suitable for measurement, for example, when there is thunderstorm, rain, or snow along the transmission line.
- c) The leads of shunt reactors, capacitors, and capacitive voltage transformers (CVTs) should be disconnected from the transmission line in the off-line measurement. The transmission line shall be disconnected from bus-bars.
- d) Any series compensation device used in the transmission line shall be bypassed during the measurement.
- e) If the transmission line under measurement is composed of cables and overhead lines, it is recommended to measure the parameters of the overhead lines and cables, respectively.
- f) The substation grounding grid should serve as protective grounding, neutral point grounding, and short-circuit grounding. The grounding point of a tower is prohibited to be the grounding point of the measurement.

7. Measurement of induced voltage and current

7.1 General

If there is any energized ac transmission line close to the transmission line to be measured, the mutual inductance and coupling capacitance may lead to a high induced ac voltage on the line to be measured. When both terminals are grounded, a large induced ac current may emerge on the line to be measured. If there is any dc transmission line nearby, a high induced dc voltage may appear as well.

Before the measurement, the induced voltage and current should be estimated according to [Annex A](#), and then the voltage dividers, voltmeters, and ammeters with suitable ranges are selected.

By measuring the induced voltage and current, their amplitudes can be evaluated so as to take precautions to prevent operator injuries and instrument damage.

It is recommended to measure the induced current first and then estimate the amplitude of the induced voltage. If the induced voltage is safe for operators and instruments, then the induced voltage can be measured directly. Otherwise, a device to suppress the induced voltage should be installed in parallel.

7.2 Induced current measurement

As shown in Figure 4, make the sending and receiving terminals of the single-circuit line be shorted to the ground, respectively, and measure the ac/dc induced current of each phase.

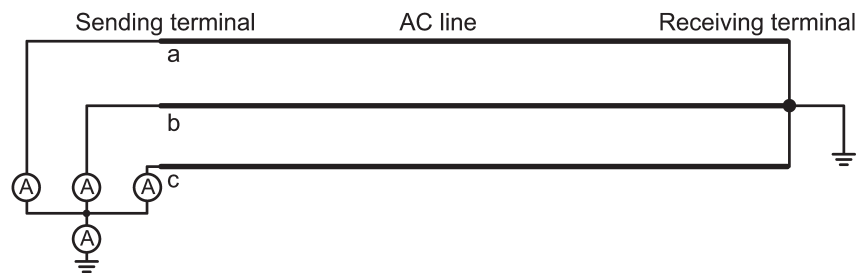


Figure 4—Induced current measurement

7.3 Induced voltage measurement

The procedures for conducting the induced voltage measurement are as follows:

a) **Induced voltage measurement with receiving terminals shorted to the ground:**

The induced voltage can be evaluated by means of induced current measurement and the estimated impedance. If it is safe for operators and instruments, the induced voltage can be measured directly. Otherwise, a device to suppress the induced voltage should be installed in parallel.

As shown in Figure 5, make the three-phase receiving terminals shorted to the ground, connect a resistive-capacitive divider between the sending terminal of phase *c* and the ground, and measure the ac/dc induced voltages, respectively.

Refer to the same procedures when measuring the other two phases.

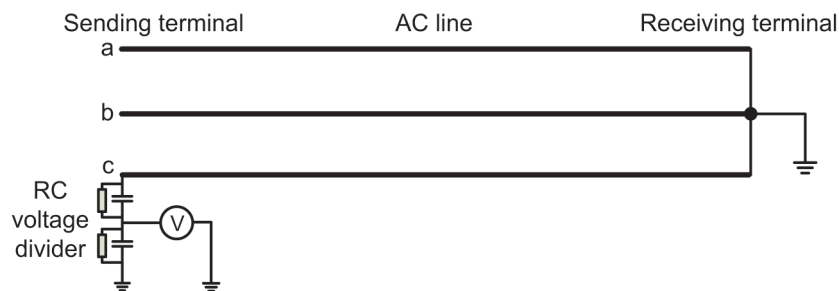


Figure 5—Induced voltage measurement with receiving terminals shorted to ground

b) **Induced voltage measurement with receiving terminals open:**

With both terminals open, the induced voltage may be extremely high, for example, greater than 10 kV, which is high enough to cause personnel injuries. Hence, operators shall be careful during the measurement and had better evaluate the induced voltage before the measurement ([Annex A](#)).

As shown in [Figure 6](#), keep the receiving and sending terminals open-circuit, measure the induced voltage of phase *c* at the sending terminal by a resistive-capacitive divider, and measure the ac/dc induced voltages, respectively.

Refer to the same procedures when measuring the other two phases.

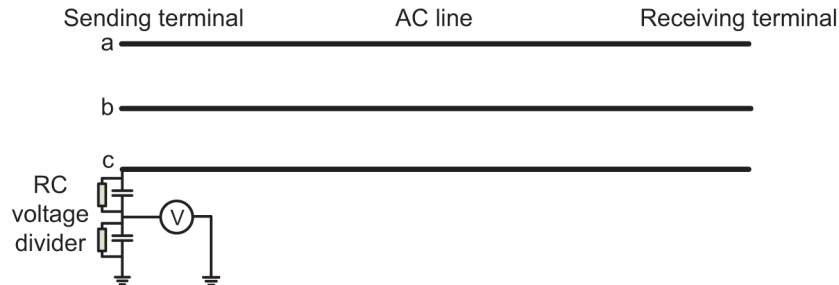


Figure 6—Induced voltage measurement with receiving terminals open

8. Phase verification and insulation resistance measurement

8.1 General

Phase verification and insulation resistance measurement are performed when all the conductors are not in service.

Phase verification is adopted to check the consistency of phase labels at both terminals, so as to prevent the power system from serious impacts when the transmission line is switched into service, especially for newly built or reconfigured lines.

The insulation resistance measurement is adopted to check whether any protective grounding wire has been dismantled along the newly built or reconfigured lines.

8.2 Phase verification using dc (or ac) power sources

DC power sources are recommended to be used for phase verification if the induced voltage of the measured line is about several hundred volts. Take the phase verification of phase *c* as an example. The procedures are as follows.

As shown in [Figure 7](#), let the sending terminals and receiving terminals of phases *a* and *b* be shorted to ground, and make the receiving terminal labeled *c'* be grounded through an ammeter. Connect a power source between the ground and the sending terminal labeled *c*. The power source can be a dc voltage source or an ac current source at off-frequency:

- a) When a dc voltage source is applied, check the dc current into the ground at both terminals. If the dc currents at both terminals are equal, the phase labels (*c* and *c'*) at the terminals are matched, and there is no grounding point along the conductor of phase *c*. Otherwise, a short-circuit point exists. If

the dc current at the receiving terminal labeled c' equals zero, there may be breaking points along the conductor of phase c , or terminal c does not match terminal c' .

- b) When an ac current source at off-frequency is applied, a mobile fast Fourier transform (FFT) device connected to a Rogowski coil should be configured at the receiving terminal to measure the current. Check the ac current into the ground at both terminals. If the ac currents at both terminals are almost equal, the phase labels (c and c') at both terminals are consistent and there is no grounding point along the conductor of phase c . Otherwise, a short-circuit point exists. If the ac current at the receiving terminal labeled c' differs greatly from that at the sending terminal labeled c , there may be breaking points along the conductor of phase c , or terminal c does not match terminal c' .

Refer to the same procedures for phase verification of the other two phases.

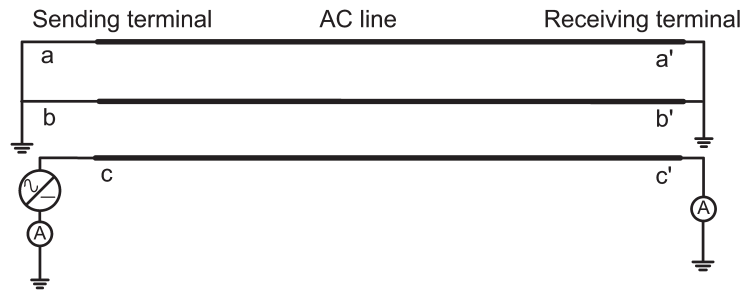


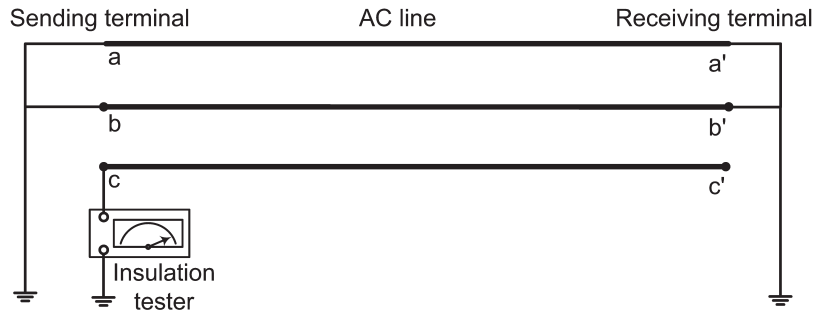
Figure 7—Phase verification using a power source

8.3 Phase verification using insulation testers

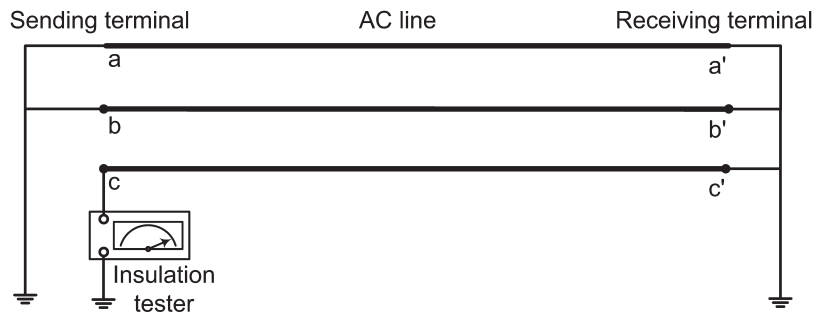
Insulation testers are recommended to be used to measure insulation resistance and verify phases if the induced voltage of the measured line is less than 500 V. Take phase verification of phase c as an example. The procedures are as follows:

- a) As shown in Figure 8(a), make the terminals of phase c in open-circuit, and make the sending and receiving terminals of the other two phases shorted to the ground; use an insulation tester to measure the insulation resistance of phase c . If the insulation resistance does not equal zero, the phase labels (c and c') at both terminals may be consistent. Otherwise, the sending terminals labeled as c are not consistent with the receiving terminal labeled as c' , or there may be grounding points along the conductor of phase c .
- b) As shown in Figure 8(b), make the receiving terminal labeled as c' grounded, and make the sending and receiving terminals of the other two phases shorted to the ground; use an insulation tester to measure the insulation resistance of phase c . If the insulation resistance equals zero, the phase labels (c and c') at both terminals are matched. Otherwise, there may be breaking points along the conductor of phase c .

Refer to the same procedures for phase verification and insulation resistance measurement of the other two phases.



(a) Receiving terminal of phase **c** in open circuit



(b) Receiving terminal of phase **c** grounded

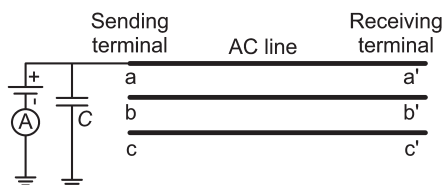
Figure 8—Phase verification and insulation resistance measurement of phase **c**

8.4 Considerations

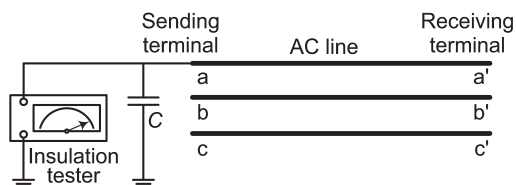
If an electromagnetic PT is equipped at any terminal of the line to be measured, it is difficult to obtain the correct result by the method described in item a) of 8.2 and in 8.3. If an insulation tester or dc power source is used, the electromagnetic PT shall be disconnected.

If the induced voltage on the line to be measured is too high to exceed the rated input voltage of the instrument, a large capacitor can be connected in parallel with the sending terminal of the line to release the charge. Take care that the capacitor shall withstand the current passing through and the induced voltage. The diagram of charge release through a capacitor is shown in Figure 9.

In addition, there is an alternative method to suppress the induced voltage (see Annex C).



(a) Capacitor in parallel with a dc power source



(b) Capacitor in parallel with an insulation tester

Figure 9—Charge released through a capacitor

9. DC resistance measurement

9.1 DC resistance measurement of three-phase transmission lines

A dc resistance measurement is not mandatory, and this procedure may not be carried out. However, dc resistance may be taken as a reference to verify the ac parameter measurement. As known, the ac resistance at power frequency in per unit length should be slightly higher than the dc resistance. If the ac resistance differs greatly from the dc resistance, there may be mistakes during the ac parameter measurement.

The dc resistance of transmission lines should be measured when the lines are not in service. One method is to use the combination of a battery, a dc voltmeter, and a dc ammeter, and the alternative method is to use a dc resistance tester. The procedures are described as follows.

As shown in Figure 10, short-circuit the receiving terminals of the three conductors and apply a dc power source between phases *a* and *b* at the sending terminals; record the dc voltage U_{ab} and the dc current I_{ab} , the series resistance R_{ab} of conductors *a* and *b* can be calculated by Equation (1).

$$R_{ab} = U_{ab} / I_{ab} \quad (1)$$

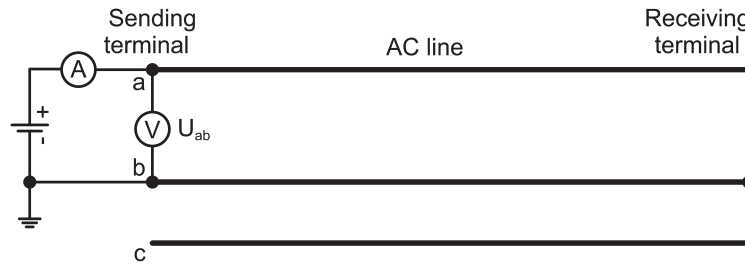


Figure 10—Measurement of the dc resistance R_{ab}

Refer to the same procedures for the dc resistance R_{bc} of conductors *b* and *c* as well as the dc resistance R_{ac} of conductors *c* and *a*. The dc resistance of each phase conductor can be given by Equation (2).

$$\begin{aligned} R_a &= (R_{ab} + R_{ca} - R_{bc}) / 2 \\ R_b &= (R_{ab} + R_{bc} - R_{ca}) / 2 \\ R_c &= (R_{ca} + R_{bc} - R_{ab}) / 2 \end{aligned} \quad (2)$$

where

R_a is the dc resistance of conductor *a*, Ω
 R_b is the dc resistance of conductor *b*, Ω
 R_c is the dc resistance of conductor *c*, Ω

The dc resistance of the down-lead should be subtracted from the measuring result when the length of the measured line is too short.

If the ac induced voltage of the measured line is larger than the withstand voltage of the instrument, a single grounding point at the sending or the receiving terminal may be selected to reduce the induced voltage.

9.2 DC resistance calculation

Record the environmental temperature of both terminals while measuring the dc resistance; then convert the measured dc resistance R_a of conductor a into the resistance $R_{a,20\text{ }^{\circ}\text{C}}$ at 20 °C by Equation (3).

$$R_{a,20\text{ }^{\circ}\text{C}} = \frac{R_a}{1 + (t - 20)\beta} \quad (3)$$

where

- t is the average temperature of both terminals, °C
- β is the temperature coefficient of the resistance of the conductor, 1/°C

For instance, for aluminum, $\beta = 0.00403(1/^{\circ}\text{C})$; for copper core cable, $\beta = 0.00393(1/^{\circ}\text{C})$.

Refer to the same procedures for the dc resistance $R_{b,20\text{ }^{\circ}\text{C}}$ and $R_{c,20\text{ }^{\circ}\text{C}}$ of conductors b and c at 20 °C.

10. Index for parameter measurement of ac transmission lines

The following methods in 10.1 to 10.3 concerning the parameter measurement of ac transmission lines are recommended in this guide.

10.1 Off-line measurement

Off-line measurement refers to the measurement when lines to be measured are not in service and can be classified into six categories, as follows:

- a) Measurement and calculation of the electrical parameters of a single-circuit transmission line (11.1)
- b) Measurement and calculation of the electrical parameters of double-circuit lines on the same tower (11.2)
- c) Measurement of the coupling parameters of short-distance double-circuit lines (11.3)
- d) Off-line parameter measurement of asymmetrical transmission lines (Clause 12)
- e) Eliminating power frequency interference during the off-line measurement (Clause 13)
- f) Measurement and calculation of the electrical parameters of four-circuit lines on the same tower (Annex D)

An open-circuit impedance measurement is a necessary procedure for the parameter measurement. But the induced voltage should be assessed before the open-circuit impedance measurement. If potential dangers exist for operators and instruments, installing a device to suppress the induced voltage is recommended (Annex C). Otherwise the open-circuit impedance measurement shall not be carried out.

10.2 Zero-sequence parameter measurement with adjacent lines in operation

For a zero-sequence parameter measurement with adjacent lines in operation, see Clause 14.

10.3 On-line measurement

For an online parameter measurement of transmission lines, see Clause 15.