

C57.13.5™

IEEE Standard of Performance and Test Requirements for Instrument Transformers of a Nominal System Voltage of 115 kV and Above

IEEE Power Engineering Society

Sponsored by the
Transformer Committee



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Transformer Committee
of the
IEEE Power Engineering Society

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IEEE-SA Standards Board

Abstract: This standard covers the test requirements, including test sequences, criteria, methods, and documentation for instrument transformers of 115 kV nominal system and above. It is to be used a supplement to IEEE Std C57.13™-1993. Besides the provision of up-to-date test requirements, the standard also provides test procedures that were not adequately covered in the previous standard.

Keywords: design tests, high voltage, instrument transformers, routine tests, special tests, test criteria, test method, test requirements, test sequence

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Introduction

(This introduction is not part of IEEE Std C57.13.5-2003, IEEE Standard of Performance and Test Requirements for Instrument Transformers of a Nominal System Voltage of 115 kV and Above.)

The mission of Working Group PC57.13.5 is to develop a comprehensive set of performance and test requirements for instrument transformers of a nominal system voltage of 115 kV and above. The objective is to improve the performance and safety of the instrument transformers in response to the concern indicated in the publication EPRI Workshop on Failed High Voltage Instrument Transformers, held in September 1990.

This standard is also intended to introduce

- a) New tests to reflect our present understanding of fast high-voltage transient induced on instrument transformers under the operation of system disconnect conditions.
- b) New tests to verify the protection against internal arc, which has gradually been adopted by some utilities.

Suggestions for improvement gained in the use of this standard will be welcome. They should be sent to the IEEE Standards Department.

Participants

This standard was produced by the IEEE Working Group PC57.13.5 on the Test Requirements for Instrument Transformers of a Nominal System Voltage of 115 kV and Above, which had the following membership:

Joseph K. Ma, Co-Chair

Pierre Riffon, Co-Chair

Wayne Hansen
Anthony Jonnatti
Vladimir M. Khalin

Paul Millward
Ross McTaggart

James E. Smith
Alejandro Villasenor
Loren B. Wagenaar

The following members of the balloting committee voted on this standard. Balloters may have voted for approval, disapproval, or abstention.

Samuel Aguirre
Stan J. Arnot
W. J. (Bill) Bergman
Thomas Blackburn
Alain Bolliger
Jeffrey Britton
Steven Brown
Stephen Conrad
Tommy Cooper
James Cross
John Crouse
Guru Dutt Dhingra
Paul Drum
Fred Elliott
Gary Engmann
Jorge Fernandez-Daher
Marcel Fortin
Harry Gianakouros
Randall Groves
Bal Gupta

Agit Gwal
Wayne Hansen
Robert Hartgrove
Edward Horgan, Jr.
James D. Huddleston, III
Gael Kennedy
Vladimir M. Khalin
Stephen R. Lambert
Boyd Leuenberger
Maurice Linker
Thomas Lundquist
Gregory Luri
Joseph K. Ma
Al Maguire
John Matthews
Thomas McCaffrey
Nigel McQuin
Ross McTaggart
Joseph Melanson

Gary Michel
Krstje Najdenkoski
Bipin Patel
Dhiru Patel
Wesley Patterson
Paulette Payne
Carlos Peixoto
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Thomas Prevost
R. Rebbapragada
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Pierre Riffon
James Ruggieri
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H. Jin Sim
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Alan Cookson, *NIST Representative*
Satish K. Aggarwal, *NRC Representative*

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IEEE Standard of Performance and Test Requirements for Instrument Transformers of a Nominal System Voltage of 115 kV and Above

1. Overview

1.1 Scope

This standard applies to new single-phase instrument transformers of a nominal system voltage of 115 kV and above with capacitive insulation system for line-to-ground connection and for both indoor and outdoor application.

This standard is intended for use as a supplement to IEEE Std C57.13TM-1993 and as a basis for performance and safety of equipment. It also describes test sequences, criteria, methods, and documentation for the test.

1.2 Purpose

The intended purpose of the standard is to supplement IEEE Std C57.13-1993 on the following:

- a) Up-to-date requirements of performance characteristics and test for instrument transformers of a nominal system voltage of 115 kV and above,
- b) Information related to test procedures, which have not been adequately covered in the present standard, and
- c) Information related to the new test items.

2. References

This standard shall be used in conjunction with the following publications. When the following standards are superseded by an approved revision, the revision shall apply.

CAN/CSA-C50052-99, Cast Aluminum Alloy Enclosures for Gas-Filled High-Voltage Switchgear and Controlgear.¹

¹CSA publications are available from the Canadian Standards Association (Standards Sales), 178 Rexdale Blvd., Etobicoke, Ontario, Canada M9W 1R3 (<http://www.csa.ca/>).

CAN/CSA-C50068-99, Wrought Steel Enclosures for Gas-Filled High-Voltage Switchgear and Controlgear.

CAN/CSA-C50064-99, Wrought Aluminum and Aluminum Alloy Enclosures for Gas-Filled High-Voltage Switchgear and Controlgear.

CAN/CSA-C50069-99, Welded Composite Enclosures of Cast and Wrought Aluminum Alloys for Gas-Filled High-Voltage Switchgear and Controlgear.

CAN/CSA-C1264-99, Ceramic Pressurized Hollow Insulators for High-Voltage Switchgear and Controlgear.

IEC 60270 (2000-12), High-Voltage Test Techniques—Partial Discharge Measurements.²

IEC 61181 (1993-06), Impregnated Insulation Materials—Application of Dissolved Gas Analysis (DGA) to Factory Tests on Electrical Equipment.

IEEE Std 4TM-2001, IEEE Standard Techniques for High Voltage Testing.^{3,4}

IEEE Std C57.12.90TM-1999, Standard Test Code for Liquid-Immersed Distribution, Power and Regulating Transformers.

IEEE Std C57.13-1993, IEEE Standard Requirements for Instrument Transformers.

IEEE Std C57.19.01TM-2000, IEEE Standard Performance Characteristics and Dimensions for Outdoor Apparatus Bushings.

IEEE C57.19.100TM-1995 (Reaff 1997), IEEE Guide for Application of Power Apparatus Bushings.

IEEE Std C57.98TM-1994, IEEE Guide for Transformer Impulse Tests.

IEEE Std C57.106TM-2002, IEEE Guide for Acceptance and Maintenance of Insulating Oil in Equipment.

IEEE Std 693TM-1997, IEEE Recommended Practices for Seismic Design of Substations.

NEMA Standards Publication No. 107-1987 (R 1993), Methods of Measurement of Radio Influence Voltage (RIV) of High Voltage Apparatus.⁵

1997 Uniform Building Code (Version 1.3).⁶

²IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3, rue de Varembe, CH-1211, Genève 20, Switzerland/Suisse (<http://www.iec.ch/>). IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

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⁴IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (<http://standards.ieee.org/>).

⁵NEMA publications are available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (<http://global.ihs.com/>).

⁶ICBO publications are available from the International Conference Board of Officials, 5360 Workman Mills Road, Whittier, CA 90601-2298, USA (<http://www.icbo.org/>).

3. Definitions

For the purposes of this standard, the following terms and definitions apply. IEEE 100, *The Authoritative Dictionary of IEEE Standards Terms*, Seventh Edition [B4],⁷ should be referenced for terms not defined in this clause.

3.1 capacitive insulation system: An arrangement of internal insulation and electrodes to distribute both the alternating and impulse voltages along the bushing of the instrument transformer with capacitive dielectric layers and/or electrode(s) to achieve an improved coordination between the internal and external insulation for the purpose of increasing the overvoltage withstand capability.

3.2 internal arc protection class I: A special transformer design with a feature that, during an internal line-to-ground arc test with the arc taking place at a location, which is technically the most probable, the debris of the transformer will be confined to a circle, centered at the transformer. The diameter of this circle is equal to the sum of twice the length of the transformer and the diameter of the transformer.

3.3 internal arc protection class II: A special transformer design with a feature that, during an internal line-to-ground arc test with the arc taking place at a location, which is technically the most probable, will not fracture the insulator or housing of the transformer.

NOTE—The above definitions (3.2 and 3.3) regarding the classification of internal arc protection apply only to the test conditions specified in the standard. The instrument transformers may have different performance during an in-service internal arc fault. Refer to Annex D for more information regarding the interpretation of internal arc protection. The performance does not apply to any internal pressure relief device (e.g., rupture disc) provided with the transformer.

3.4 prescribed extinction voltage: The lowest required line-to-ground voltage for the transformer at which the partial discharge is determined if the reference intensity is met when the voltage applied to the transformer is gradually decreased without interruption from the power frequency withstand voltage or pre-stress voltage value during the partial discharge test.

NOTE—The reference partial discharge intensity for the transformers covered in this standard is 10 pC.

3.5 rated voltage factor: A multiplier applied to the rated (primary) voltage to derive the maximum voltage at which a transformer must comply with the relevant thermal requirements for a specified time and with the relevant accuracy requirements.

NOTE—Refer to Annex F for additional information.

4. General

For performance and safety, the instrument transformers shall comply with IEEE Std C57.13-1993, supplemented with the requirements provided in this clause. If any conflicts or inconsistencies exist between IEEE Std C57.13-1993 and this standard, the clauses in this standard shall take precedence.

4.1 Insulation requirements

4.1.1 Voltage ratings, dielectric test levels, and prescribed extinction voltages

The voltage ratings, dielectric test levels, and prescribed extinction voltages for instrument transformers are given in Table 1.

⁷The numbers in brackets correspond to those in the bibliography in Annex G.

NOTES

1—For nominal system voltages 230, 345, and 500 kV, good service experiences with instrument transformers of reduced insulation levels have been reported. The users should review their own records and decide accordingly. This standard recommends the use of the standard insulation voltage levels, which are of higher values for each system voltage.

2—The dielectric test levels and prescribed extinction voltages are applicable to instrument transformers used in grounded or effectively grounded neutral systems.

Table 1—Voltage ratings, dielectric test levels, and prescribed extinction voltages

Nominal system voltage (r.m.s.) (kV)	Maximum system voltage (r.m.s.) (kV)	Lightning impulse voltage (peak)		Switching impulse voltage (peak) (kV)	Power frequency withstand voltage ^a (r.m.s.)		Prescribed extinction voltage ^b (r.m.s.) (kV)
		Full wave (kV)	Chopped wave ^c (kV)		Dry (kV)	Wet (kV)	
115	123	550	630	—	230	230	123
138	145	650	750	—	275	275	145
161	170	750	860	—	325	325	170
230	245	950	1090	—	395	395	245
		1050	1210	—	460	460	
345	362	1175	1350	950	510	—	362
		1300	1500	975	575	—	
500	550	1550	1785	1175	680	—	550
		1800	2070	1300	830	—	
765	800	2100	2420	1550	975	—	800

^a The duration for the power frequency voltage withstand test shall be in accordance with 4.1.8 for both dry and wet test conditions.

^b The definition is provided in 3.3. The reference partial discharge intensity for the instrument transformers is 10 pC and shall be measured in accordance with IEC 60270 (2000-12).

^c The minimum time to chopping shall be 3 μ s.

4.1.2 Capacitance and dissipation factor requirements

The capacitance and dissipation factor of the transformer shall be measured at power frequency and at maximum rated voltage.

The test shall be performed before and after the dielectric tests.

The increase of capacitance measured after compared with that measured before the dielectric tests shall be less than the value produced by the breakdown of one capacitive element.

The dissipation factor shall be in accordance with the following requirements:

- a) For oil-immersed transformers:
 - 1) The dissipation factor shall be 0.5% maximum, and

- 2) The absolute increase of the dissipation factor value measured after compared with the value measured before the dielectric tests shall be less than 0.1%.
- b) For gas-filled transformers:⁸
 - 1) The dissipation factor shall be 0.15% maximum, and
 - 2) The absolute increase of the dissipation factor value measured after compared with the value measured before the dielectric tests, shall be less than 0.03%.

4.1.3 Creepage distance requirements

The ratio of minimum creepage distance on the external surface of the porcelain insulator to the nominal line-to-ground voltage shall be in accordance with IEEE Std C57.19.01-2000. The ratios for light and heavy pollution levels shall be 28 mm/kV and 44 mm/kV respectively. Table 2 provides minimum creepage distances as a function of nominal system voltage and level of pollution.

Table 2—Creepage distance

Nominal system voltage (r.m.s.) (kV)	Maximum system voltage (r.m.s.) (kV)	Minimum creepage distance (mm)	
		Light pollution	Heavy pollution
115	123	1 860	2 920
138	145	2 230	3 510
161	170	2 600	4 090
230	245	3 720	5 850
345	362	5 580	8 770
500	550	8 080	12 700
765	800	12 400	19 400
NOTES 1—The definitions of light and heavy pollution levels are given in IEEE Std C57.19.100-1995. 2—The creepage distance for composite insulator with silicone rubber sheds has not been established. This standard recommends the use of the same creepage distance as that for the porcelain insulator.			

4.1.4 External radio influence voltage (RIV) requirements

The maximum external RIV of the instrument transformer shall be in accordance with Table 3 when the test voltage is applied to the primary terminal. The transformer shall be assembled as in service for the test. Any external electrodes, if not parts of the transformer, shall not be used for the test.

4.1.5 Routine partial discharge test

The partial discharge intensity measured at the voltage corresponding to the prescribed extinction voltage level as provided in Table 4 shall be less than or equal to the reference intensity of 10 pC. The measuring method shall be in accordance with IEC 60270 (2000-12).

⁸As the inherent capacitance of gas-filled instrument transformers is very low (in the range of 100–300 pF), the laboratory should take the necessary precautions to reduce the stray effects of the neighboring equipment on the capacitance measurement, and also the effects of the leakage current over the insulator surface on the dissipation factor measurement.

Table 3—RIV

Nominal system voltage (r.m.s.) (kV)	Maximum system voltage (r.m.s.) (kV)	Radio influence test voltage (r.m.s.) (kV)	Maximum radio influence voltage ^a (μV)
115	123	71	200
138	145	84	200
161	170	98	200
230	245	142	250
345	362	209	250
500	550	303	350
765	800	462	500

^aThe background noise level shall not be higher than half the maximum RIV.

The partial discharge test shall be carried out subsequent to the power frequency voltage withstand test as described in 7.7.⁹

Table 4—Routine partial discharge test voltage

Nominal system voltage (r.m.s.) (kV)	Maximum system voltage (r.m.s.) (kV)	Pre-stress voltage (r.m.s.) (kV)	Prescribed extinction voltage (r.m.s.) (kV)
115	123	185	123
138	145	220	145
161	170	260	170
230	245	315 ^a	245
		370	
345	362	410 ^a	300 ^b
		460	
500	550	545 ^a	435 ^b
		665	
765	800	780	665 ^b

^aThe values shown are for the reduced insulation levels in reference to Table 1.

^bThe standard recognizes the difficulties of partial discharge measurement at these voltage levels under the industrial environments with high noise level. The problem is aggravated if the test laboratories are undersized and world-class extra-high-voltage laboratories are required. Therefore, for the transformers of these voltage ratings, the prescribed extinction voltages are reduced to 1.5 times the rated voltages, which are considered still acceptable since the ground fault factor for a grounded or effectively grounded system does not exceed 1.4.

⁹An exception case is when the partial discharge test is repeated after the sealing test on transformers with air in contact with the oil during the sealing test.

The transformer shall withstand, for an appropriate duration in accordance with 4.1.8, the pre-stress voltage provided in Table 4 before the partial discharge is measured. Insulation resistance requirements

4.1.6 Insulation resistance requirements

The insulation resistances between individual winding and ground and between windings shall be measured at 1.0 kV (dc) or higher voltage. The values shall not be less than 200 MΩ.

4.1.7 Power frequency voltage withstand test

The power frequency withstand voltage shall be in accordance with the value provided in Table 1.

For current transformers, the voltage shall be applied to the primary winding.

For voltage transformers, the test voltage shall be either impressed between the primary and neutral terminals or induced from the secondary winding with the primary winding open-circuit. The neutral terminal shall be grounded during the test.

The voltage shall be maintained for 60 s. The time may be reduced in accordance with 4.1.8 if the frequency is higher than 120 Hz.

NOTE—This test can also be called induced voltage withstand test for voltage transformers.

4.1.8 Duration of power frequency voltage withstand test for test frequency higher than 120 Hz

If a test frequency of higher than 120 Hz is used for the power frequency voltage withstand test or for the pre-stress voltage for partial discharge measurement, the duration of the test may be reduced as given in the following expression:

$$Time(s) = \frac{7200}{Test\ Frequency(Hz)}$$

The duration shall not be less than 18 s and the test frequency shall not be greater than 400 Hz.

4.2 Mineral oil requirements

The mineral oil used for oil-immersed instrument transformers shall be processed from the naphthenic base crude oil or its equivalent.¹⁰ It shall be in accordance with 2.1 of IEEE Std C57.106-2002. The characteristics of the new processed oil shall be in accordance with 2.2 and 2.3 of that standard.

For the extreme cold climate, the manufacturers and users have to agree on the mineral oil specification.

4.3 Requirements for accuracy and accuracy calibration systems

The accuracy performance shall be in accordance with the requirements of IEEE Std C57.13-1993.

All transformers with accuracy ratings of 0.3 or 0.6 shall be determined using calibration techniques and methods that shall give adequate results within 0.1% of the ratio and 3 minutes of phase angle. All

¹⁰A new insulating oil processed with the latest technology may be commercially available from the refinery. The user should check with the manufacturer for more information.

transformers with accuracy ratings of 1.2 shall be determined using calibration techniques and methods that shall give adequate results within 0.3% of the ratio and 6 minutes of phase angle.

The test burdens shall be in accordance with Tables 9 and 15 of IEEE Std C57.13-1993 for current transformers and voltage transformers respectively.

The equipment used for accuracy tests shall be traceable to the national standards. Records of accuracy verification for the calibration systems by an independent laboratory shall be regularly maintained.

NOTE—The maximum interval shall be five years for non-electronic equipment and two years for electronic devices, unless specified otherwise by the measuring equipment manufacturer.

4.4 Mechanical performance requirements

All instrument transformers shall comply with the mechanical performance requirements described in 4.4.1 and 4.4.2.

4.4.1 Sealing tests

All instrument transformers shall be sealed against leakage of insulating fluid for the normal service conditions stated in the IEEE Std C57.13-1993.

For oil-immersed transformers, the manufacturers shall review the sealing tests outlined in Table 5 and adopt the one most suitable for their transformers.

Table 5—Sealing test for oil-immersed instrument transformers

Test	Average oil temperature (°C)	Internal pressure (kPa)	Time (h)
(I)	50	35	24
(II)	50	103	12
(III) ^a	85	0	12
(IV)	25	35	60
(V)	25	103	24

^aThe standard recommends this procedure for transformers with oil expansion diaphragms or bellows. Other procedure as shown in the table, with application of pressure, e.g., by clamping the oil expansion diaphragms or bellows, instead of raising the average oil temperature of the transformer to 85 °C shall also be considered acceptable.

For gas-filled transformers, the construction of the tank shall be in accordance with the national standards on enclosures for gas-filled electrical equipment.¹¹ The manufacturer shall submit the certificate of the tank to the user for approval before the routine tests.

The maximum leakage-rates of the transformers designed for various ranges of ambient temperature shall be as follows:

¹¹The Canadian standards are listed in Clause 2.

- a) Average ambient temperature (20 °C): 0.5% / year
- b) Low ambient temperature ($T_L = -5, 10, -15, \text{ or } -25$ °C) 1.5% / year
- c) Extra-low ambient temperature ($T_L = -40$ °C) 3.0% / year
- d) Ultra-low ambient temperature ($T_L = -50$ °C) 6.0% / year

Where T_L is the lower limit of the ambient temperature range.

The manufacturer shall submit the routine sealing test procedure and acceptance criteria to the user for approval.

4.4.2 Mechanical strength of the transformer

All instrument transformers intended for pedestal mounting shall be capable of withstanding the non-simultaneous cantilever forces equivalent to those produced by winds of 160 km/h and the horizontal seismic force resulting from a zero-period acceleration¹² of 0.2 m/s².

All instrument transformers intended for suspension mounting shall be capable of withstanding a tension equal to 13 kN in addition to its own weight.

4.5 Thermal performance requirements

All instrument transformers shall not exceed the temperature rise limits given in Table 4 of IEEE Std C57.13-1993 when tested in accordance with 10.8 of this standard.

4.6 Ground shield requirements

All instrument transformers shall be provided with a ground shield between the primary winding and the secondary windings.

NOTE—The ground shield provides some degree of protection in the secondary circuit against an insulation failure between the primary and secondary windings.

4.7 Dissolved gas and water content requirements for new oil-immersed transformers

For new oil-immersed transformers, the maximum concentration of the dissolved gas and water content in the oil, after the test program, shall be in accordance with the values in Table 6.

The minimum sensitivity of a gas spectrum analyzer shall be in accordance with the last column of the table.

4.8 Endurance capability for fast high-voltage transient

All instrument transformers of a nominal system voltage of 345 kV and above shall be suitably designed to endure the fast high-voltage transient stress induced during the operation of the line disconnect switch located in its vicinity.

NOTE—To verify if the transformer design will comply with the requirement, the user should specify the endurance chopped-wave test (12.1).

¹²The acceleration value corresponds to the conventional 0.2g in seismic terminology.