5.5 Voltage ratings and taps

5.5.1 General

Standard nominal system voltages and maximum system voltages are included in ANSI C84.1 and listed in **Tables 4 and 5 in this document**.

5.5.2 Voltage ratings

The voltage ratings shall be at no load and shall be based on the turn**s** ratio.

5.5.3 Ratings of transformer taps

Whenever a transformer is provided with taps from a winding for de-energized operation, they shall be full-capacity taps. Transformers with load tap-changing equipment may have reduced capacity taps, unless specified otherwise, for taps below rated winding voltage. When specified, other capacity taps may be provided. In all cases, the capacity shall be stated on the nameplate.

5.6 Connections

Standard connection arrangements are included in the standards for particular types of transformers and in IEEE Std C57.12.70 [B18].

5.7 Polarity, angular displacement, and terminal marking

5.7.1 Polarity of single-phase transformers

Single-phase transformers 200 kVA and below with high-voltage ratings of 8660 V and below (winding voltage) shall have additive polarity. All other single-phase transformers shall have subtractive polarity.

5.7.2 Angular displacement (nominal) between voltages of windings for three-phase transformers

The angular displacement between high-voltage and low-voltage phase voltages of three-phase transformers with Δ- Δ or Y-Y connections shall be zero degrees.

The angular displacement between high-voltage and low-voltage phase voltages of three-phase transformers with Y- Δ or Δ -Y connections shall be 30º, with the low voltage lagging the high voltage as shown in Figure 1. The angular displacement of a polyphase transformer is the time angle expressed in degrees between the line-to-neutral voltage of the reference identified high-voltage terminal H_1 and the line-to-neutral voltage of the corresponding identified low-voltage terminal X_1.

NOTE—Additional phasor diagrams are described in IEEE Std C57.12.70 [B18].

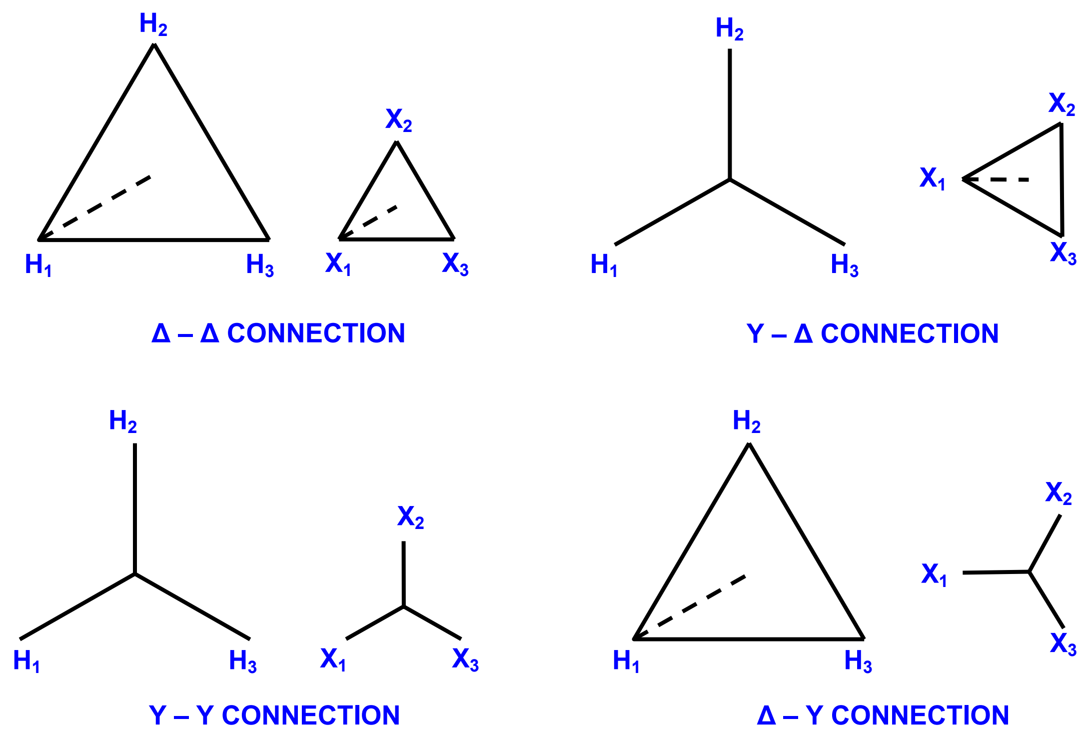


Figure 1—Phase relation of terminal designation for three-phase transformers

5.7.3 Terminal markings

Terminal markings shall be in accordance with IEEE Std C57.12.70 [B18].

5.8 Impedance

The impedance shall be referred to a temperature equal to the sum of the rated average winding temperature rise by resistance, plus 20 ºC. Preferred standard values of impedance are included in the product standards for particular types of transformers.

5.9 Total losses

The total losses of a transformer shall be the sum of the no-load losses and the load losses.

The losses of cooling fans, oil pumps, space heaters, and other ancillary equipment are not included in the total losses. When specified, power loss data on such ancillary equipment shall be furnished.

The standard reference temperature for the load losses of power and distribution transformers shall be 85 ºC. The standard reference temperature for the no-load losses of power and distribution transformers shall be 20 ºC.

For Class II transformers, control/auxiliary (cooling) losses shall be measured and recorded. All stages of cooling, pumps, heaters, and all associated control equipment shall be energized, provided these components are integral parts of the transformer.

5.10 Insulation levels

Transformers shall be designed to provide coordinated low-frequency and impulse insulation levels on line terminals and low-frequency insulation levels on neutral terminals. The primary identity of a set of coordinated levels shall be its **Maximum System Voltage and Basic Lightning Impulse Insulation Level (BIL). BIL will be selected dependent on the degree of exposure of the transformer and characteristics of the over-voltage protection system.**

Power transformers are separated into two different classes as follows:

a) Class I power transformers shall include power transformers with high-voltage windings of 69 kV and below.
b) Class II power transformers shall include power transformers with high-voltage windings from 115 kV through 765 kV.

The following tables on subsequent pages show various system voltages, insulation and test levels for various classes of liquid-immersed power transformers.

- **Table 4 lists Dielectric Insulation Levels for Distribution and Class I Transformers**
- **Table 5 lists Dielectric Insulation Levels for Class II Transformers**
- **Table 6 lists the High Frequency Test Levels.**
-

Table 4: Distribution and Class I Transformers, voltages in kV

Max Sytem Voltage	Nominal System Voltage	Applied Test			Induced Test (phase to ground)	Winding Line-end BIL				Neutral BIL	
		Delta & Fully Insulated	Gr Y	Impedance Gr Y	2 times Nominal Voltage	Min.	Alternates			GrY	Impedance Gr Y
Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8	Col 9	Col 10	Col 11	Col 12
Distribution Transformers											
1.5	1.2	10	-	10	1.4	**30**				30	30
3.5	2.5	15	-	15	2.9	**45**				45	45
6.9	5	19	-	19	5.8	**60**				60	60
11	8.7	26	-	26	10	**75**				75	75
17	15	34	-	34	17	**95**	110			75	75
26	25	50	-	40	29	**125**	**150**			75	95
36	34.5	70	-	50	40	125	**150**	**200**		75	125
48	46	95	-	70	53	200	**250**			95	150
73	69	140	-	95	80	250	**350**			95	200
Class I Power Transformers											
1.5	1.2	10	10	10	1.4	**30**	**45**			30	30
3.5	2.5	15	15	15	2.9	**45**	**60**			45	45
6.9	5	19	19	19	5.8	**60**	**75**			60	60
11	8.7	26	26	26	10	**75**	**95**			75	75
17	15	34	26	34	17	**95**	**110**			75	75
26	25	50	26	40	29	**150**				75	95
36	34.5	70	26	50	40	**200**				75	125
48	46	95	34	70	53	200	**250**			95	150
73	69	140	34	95	80	250	**350**			95	200

Notes:

1 **For Nominal System Voltage greater than Maximum System Voltage use the next higher voltage class for applied test levels.**
Induced tests shall be conducted at 2.0* Nominal voltage.

2 **Bold** typeface BIL's are standard levels.

3 Y-Y connected transformers using a common solidly grounded neutral may use neutral BIL selected in accordance with the low voltage winding rating.

Table 5: **Class II Power Transformers, voltages in kV**

Max System Voltage	Nominal System Voltage	Applied Test			Induced Test (phase to ground)		Winding Line-end BIL				Neutral BIL	
		Delta & Fully Insulated	Gr Y	Impedance Gr Y	Enhanced 7200 cy.	One Hour	Min.	Alternates			Gr Y	Impedance Gr Y
Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8	Col 9	Col 10	Col 11	Col 12	Col 13
Low Voltage Windings (69 kV and lower)												
<=17	<=15	34	26	26	20	15	**110**				110	110
26	25	50	26	34	29	24	**150**				110	110
36	34.5	70	26	50	41	32	**200**				110	125
48	46	95	34	70	55	42	**200**	250			110	150
73	69	140	34	95	81	63	**250**	350			110	200
High Voltage Windings (115 kV and higher)												
121	115	173	34	95	120	105	350	**450**	550		110	250
145	138	207	34	95	145	125	450	**550**	650		110	250
169	161	242	34	140	170	145	550	**650**	750	825	110	350
242	230	345	34	140	240	210	650	**750**	825	900	110	350
362	345	518	34	140	360	315	900	1050	1175		110	350
550	500	N/A	34	140	550	475	1425	1550	1675		110	350
765	735	N/A	34	140	850	750	1950	2050			110	350
800	765	N/A	34	140	885	795	1950	2050			110	350

Notes:

1. **For Nominal System Voltage greater than Maximum System Voltage use the next higher voltage class for applied test levels. Induced tests shall be conducted at 1.58 * Nominal voltage for one hour and 1.80 * Nominal voltage for enhanced 7200 cycle tests.**
2. **Bold** typeface BIL's are standard levels.
3. Y-Y connected transformers using a common solidly grounded neutral may use neutral **BIL selected** in accordance with the low voltage winding rating.
4. For 735kV to 800 kV nominal system voltages, induce test levels do not follow rules in Note 2, and 1950 kV BIL is not a standard IEEE level.

5.10.1 Line terminals

5.10.1.1 Basic lightning impulse insulation level (BIL)

A basic lightning impulse insulation level (BIL) from Table 4 shall be assigned to each line terminal of a winding. The associated insulation levels shall **be provided** regardless of whether tests are or can be performed.

5.10.1.2 Switching impulse insulation level

Windings for system voltages 115 kV and above shall be designed for the switching impulse insulation levels (BSL) associated with the assigned BIL **as shown in Table 6.** In addition, low-voltage windings shall be designed to withstand stresses from switching impulse tests on high-voltage windings regardless of whether or not such tests are specified.

5.10.1.3 Front-of-wave insulation level

Front-of-wave insulation levels and tests shall be specified when desired; otherwise, withstand insulation capability is not required. **See Annex A for table of historical voltage levels and wave shape characteristics.**

5.10.1.4 Wye-winding line terminal

Each wye-winding line terminal shall be specified as suitable or unsuitable for ungrounded neutral operation.

Table 6: High Frequency Test Tables

Lightning Impulse (BIL)	Chopped Wave			Switching Impulse
	kV Crest	Min. Time to Flashover, µs		
kV Crest, 1.2x50 µs	1.1 X BIL	Class I & Dist	Class II	kV Crest, 0.83 X BIL
Col 1	Col 2	Col 3	Col 4	Col 5
30	33	1.0	2.0	See Note
45	50	1.5	2.0	See Note
60	66	1.5	2.0	50
75	83	1.5	2.0	62
95	105	1.8	2.0	79
110	120	2.0	2.0	92
125	138	2.3	2.3	104
150	165	3.0	3.0	125
200	220	3.0	3.0	166
250	275	3.0	3.0	208
350	385	3.0	3.0	291
450	495	N/A	3.0	375
550	605	N/A	3.0	460
650	715	N/A	3.0	540
750	825	N/A	3.0	620
825	900	N/A	3.0	685
900	990	N/A	3.0	745
1050	1155	N/A	3.0	870
1175	1290	N/A	3.0	975
1300	1430	N/A	3.0	1080
1425	1570	N/A	3.0	1180
1550	1705	N/A	3.0	1290
1675	1845	N/A	3.0	1390
1800	1980	N/A	3.0	1500
1950	2145	N/A	3.0	1550
2050	2255	N/A	3.0	1700

Notes: **1.** Switching impulse tests are not always possible for low voltage windings.
2. 1550 kV for the 1950 kV BIL is a special application used by a utility that uses transposition to reduce switching impulse levels. Non-transposed lines should use 1620 kV for 1950 kV BIL.

5.10.1.5 Windings that have no terminals brought out

Windings that have no terminals brought out shall be capable of withstanding voltages resulting from the various tests that may be applied to other terminals corresponding to their respective BIL.

5.10.2 Neutral terminals

5.10.2.1 Wye connection with an accessible neutral external to the tank

A transformer winding designed for wye connection only and with an accessible neutral external to the tank shall be assigned a low-frequency test level for the neutral terminal. This assigned low-frequency test level may be lower than that for line terminals.

5.10.2.2 Neutral terminals that are solidly grounded

The assigned low-frequency test level for neutral terminals that are solidly grounded directly or through a current transformer shall be not less than that specified in **Column 4 of Tables 4 & 5.**

The assigned low-frequency test level for other cases shall be coordinated with voltages that can occur between the neutral and ground during normal operation or during fault conditions, but shall be not less than those specified in **Columns 3, 4, & 5 of Tables 4 & 5.**

It should be noted that IEEE Std 32 [B13] includes additional information on neutral insulation, application, etc.

5.10.2.3 Specific BIL

When specified, neutral terminals shall be designed for a specific BIL instead of a low-frequency test level.

5.10.2.4 Insulation level of the neutral bushing

The insulation level of the neutral end of a winding may differ from the insulation level of the neutral bushing being furnished or of the bushing for which provision for future installation is made. In this case, the dielectric tests on the neutral shall be determined by whichever is lower: the insulation of the neutral end of the winding or the insulation level of the neutral bushing shipped with the transformer.

5.10.2.5 Neutral not brought out of the tank

Insulation levels shall not be assigned where the neutral end of the winding is not brought out of the tank through a bushing. In such cases, the neutral end of the winding shall be directly connected to the tank and the tank solidly grounded, unless specified otherwise.

5.10.3 Coordination of insulation levels

5.10.3.1 BIL levels

The BIL chosen for each line terminal shall be such that the lightning impulse, chopped-wave impulse, and switching impulse insulation levels include a suitable margin in excess of the dielectric stresses to which the terminal will be subjected in actual service. For information on surge arrester characteristics and application, see IEEE Std C62.1 [B44], IEEE Std C62.2 [B45], IEEE Std C62.11 [B46], and IEEE Std C62.22 [B47]. It should be noted that it is recommended that surge-arrester protection be provided for tertiary windings that have terminals brought out.

5.10.3.2 BSL levels

A switching surge impulse occurring at one terminal during test or in actual service will be transferred to other winding terminals with a magnitude approximately proportional to the turns ratio involved. This interaction should be considered when evaluating surge arrester application, evaluating expected magnitude of surges, and establishing coordinated insulation levels.

5.10.3.3 Grounding considerations (TO BE DELETED)

It is necessary to verify the ability of a transformer to withstand temporary overvoltage on unfaulted terminals during single or double line-to-ground faults. In most cases, the low-frequency test is used to provide this verification. The applicable low-frequency test levels are shown in Columns 3, 4, & 5 of Tables 4 & 5. An adequate margin is provided when the low-frequency test coefficient from Table 7 is approximately 1.5 times the coefficient of grounding. The coefficient of grounding is defined in IEEE Std C62.22.3.1.7 [B47], except in this case, a decimal fraction should be used as opposed to a percentage; for example, 0.8 instead of 80%. Caution should be exercised to ensure that the coefficient of grounding has been accurately determined and can be maintained, especially in the case of maximum BIL reductions on delta windings, such as 650 BIL at 230 kV or 350 BIL at 115 kV. Consideration should be given to backfeed in determining if the coefficient of grounding can be maintained. Backfeed would involve energization from the low side of the transformer together with clearing on the high side so that the fault remains on one phase and the system grounding is lost. Under these conditions, a full neutral shift could result on the high-voltage delta winding.

In the case of wye windings for Class II transformers, low-frequency test levels and low-frequency test coefficients in Table 7 are not applicable unless the winding is specified as suitable for application on ungrounded systems. However, when the neutral is solidly grounded to the tank, the neutral end of the winding cannot shift with respect to the tank. Therefore no significant increase in line-terminal-to-ground (tank) voltage during single or double line-to-ground faults should occur provided that proper system grounding practices are employed.

For wye windings where Table 7 does not apply and neutral grounding devices significantly affect the coefficient of grounding of the transformer, alternate tests shall be specified to provide the necessary verification.

Table 7—Low-frequency test coefficients (TO BE DELETED)

Nominal system voltage (kV)	Basic lightning impulse insulation level (BIL) (kV crest)	Low-frequency Applied test level (kV rms)	Low-frequency test coefficient
Column 1	**Column 2**	**Column 3**	**Column 4**
46	**200**	**95**	**1.967**
	250	**95**	**1.967**
69	**250**	**140**	**1.931**
	350	**140**	**1.931**
115	**350**	**173**	1.430
	450	**173**	**1.430**
	550	**173**	**1.430**

138	**450**	**207**	**1.428**
	550	207	**1.428**
	650	**207**	**1.428**
161	**550**	**242**	**1.432**
	650	**242**	**1.432**
	750	**242**	**1.432**
230	**650**	**345**	**1.426**
	750	**345**	**1.426**
	825	**345**	**1.426**
	900	**345**	**1.426**
345	**900**	**518**	**1.431**
	1050	**518**	**1.431**
	1175	518	**1.431**

NOTE 1—The application of this table is covered in Grounding considerations. In particular, the caution regarding application of maximum BIL reductions should be considered.

NOTE 2—The low-frequency test coefficient is the ratio between the low-frequency test level and the maximum line-to-line system voltage.

5.10.4 Low-frequency voltage tests on line terminals for distribution transformers and Class I power transformers

5.10.4.1 General

Low-frequency test requirements for distribution and Class I power transformers shall **be applied-voltage and induced-voltage test levels as specified in Table 4.**

5.10.4.2 Applied-Voltage Requirements

The **applied-voltage** test requirements are as follows:

a) A voltage to ground (not necessarily to neutral) shall be developed at each terminal in accordance with Columns **3, 4 & 5 of Table 4.** For ungraded windings, this voltage shall be maintained throughout the winding.

b) A phase-to-phase voltage shall be developed between line terminals of each three-phase winding in accordance with Column **3 of Table 4.**

c) Two times rated turn-to-turn voltage shall be developed in each winding.

5.10.4.3 Exceptions

Exceptions to the **applied-voltage** test requirements are as follows:

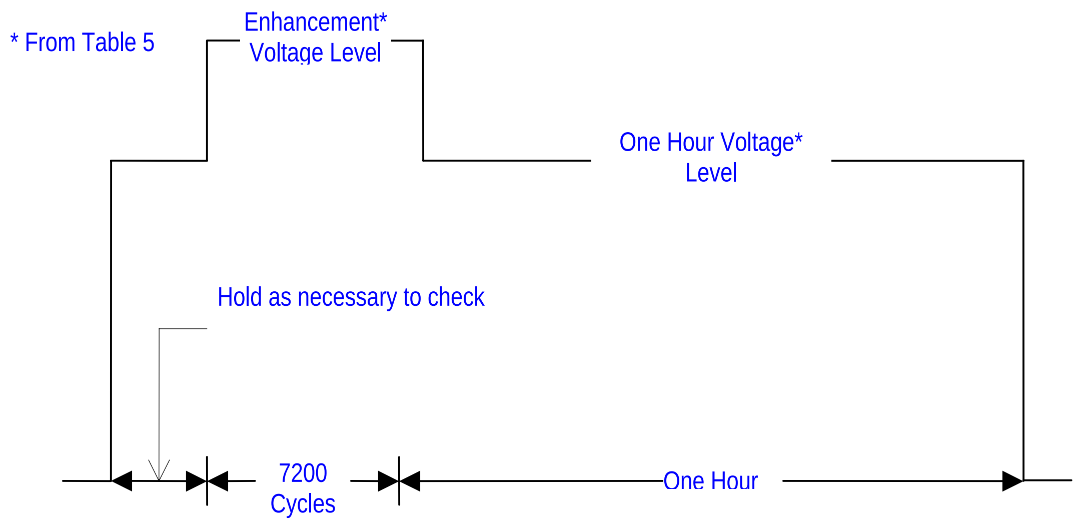
a) Subject to the limitation that the voltage-to-ground test shall be performed as specified in item a) of 5.10.4.2 on the line terminals of the winding with the lowest ratio of test voltage to minimum turns, the test levels may otherwise be reduced so that none of the three test levels required in 5.10.4.2 need be exceeded to meet the requirements of the other two, or so that no winding need be tested above its specified level to meet the test requirements of another winding.

b) For delta windings, the voltage-to-ground developed at each terminal shall be in accordance with **Table 4;** however, voltage within the winding may be reduced to 87% of the voltage developed at the terminals.

5.10.5 Low-frequency voltage tests on line terminals for Class II power transformers

5.10.5.1 Induced-voltage test

With the transformer connected and excited as it will be in service, an induced-voltage test shall be performed as indicated in Figure 2, at voltage levels indicated in **Columns 6 & 7 of Table 5. Minimum line to ground induced test levels for Class II Power**



Transformers shall be a multiple of corresponding line to ground nominal system voltage as follows: 1.58 times for one the hour test and 1.8 times for 7200 cycles for the enhancement level test.

Figure 2—Induced voltage test for Class II transformer

5.10.5.2 Applied-voltage test

Line terminals of delta windings and all terminals of wye windings for application on ungrounded systems shall receive an applied-voltage test at the levels indicated in **Column** 3 of Table 5.

5.10.6 Low-frequency voltage test on neutral terminals for all transformers

Each neutral terminal shall receive an applied-voltage test at its assigned low-frequency insulation level.

5.10.7 Impulse tests

5.10.7.1 Lightning impulse tests

The lightning impulse test shall be performed **at the specified levels per Columns 1 and 2 of Table 6** for Class II power transformers**. When required, lightning impulse tests shall be performed on line and neutral terminals for power transformers.** Lightning impulse tests shall not be made on windings that do not have terminals brought out through the tank or cover. Lightning impulse tests are not required on terminals brought out from buried windings in the following cases:

a) When a single terminal is brought out for the purpose of grounding the buried winding.

b) When two terminals are brought out so that the delta connection may be opened for the purpose of testing the buried winding.

c) When temporary connections to terminals of a buried winding are brought out only for the purpose of factory tests.

5.10.7.2 Switching impulse tests

When required, switching impulse tests shall be performed. Switching impulse tests on the high-voltage line terminals may overtest or undertest other line terminals depending upon the relative BSL levels, the turn**s** ratios between windings, and test connections. Regardless of this fact, tests on the high-voltage terminals shall be controlling, and a switching impulse test at the level specified in **Column 5 of** Table 6 shall be applied to the high-voltage terminals.

The switching surge insulation of other windings shall be able to withstand voltages resulting from the required switching impulse tests to the high-voltage terminals, even though such voltages on the other windings may exceed their designated BSL listed in Table 6, when applicable.

When the application of the switching impulse to the high-voltage terminals result in a voltage on another winding greater than the BSL requirement for that winding in Table 6, no additional test is necessary to demonstrate switching surge insulation withstand capability on that winding.

5.10.7.3 Steep Front Tests

Front-of-wave tests (steep wave tests) are no longer recognized as necessary or standard for Distribution, Class I or Class II transformers and are not included in the 2008 revision of C57.12.00. Gapped Silicon Carbide arresters had switching characteristics that closely mimicked steep front-of- wave shapes. Metal Oxide Varister (MOV) Lightning Arresters have clamping characteristics that more nearly emulate Full Wave and Chopped Wave conditions and have replaced silicon carbide arresters, negating the need for front-of-wave testing. Annex I on page XXX includes the last published (C57.12.00-XXXX) Front-of-wave test levels for historical reference

Annex A (Informative)

The following table of Front-of-Wave insulation and test levels has been included for information and historical benefit. The test levels in this table have come from past issues of C57.12.00, dating back to earlier than 1965 through 1980 issues. Front-of-Wave tests for 30 kV BIL was discontinued prior to the1965 issue. Front-of-Wave tests for 45-75 kV BIL were discontinued by 1980.

The Front Of Wave Test, Voltages in kV : Note that this test is no longer specified but is documented for historical purposes			
Lightning Impulse (BIL) kV Crest, 1.2x50 µs	Front Of Wave		
	kV Crest	Min. Time to Flashover, µs	Min. effective Rate Of Rise, (kV/ µs)
Col 1	Col 2	Col 3	Col 4
30	75	0.5	125
45	75	0.5	125
60	125	0.5	210
75	165	0.5	210
95	165	0.5	275
110	195	0.5	430
125	220	0.5	430
150	260	0.5	430
200	345	0.5	575
250	435	0.5	725
350	580	0.58	850
450	710	0.71	850
550	825	0.825	850
650	960	0.96	850
750	1070	1.07	850
825	1150	1.15	850
900	1240	1.24	850
1050	1400	1.4	850
1175	1530	1.53	850
1300	-	-	-
1550	-	-	-