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Telcordia GR-1089-CORE Issue 4 Topics
Primary Protection

Bourns engages in standards development and produces components that will help customers' products comply with published standard requirements. For these reasons, Bourns took part in Issue 3 and Issue 4 revisions of GR-1089-CORE. Bourns has created the Telcordia GR-1089-CORE Issue 4 Topics series to help customers understand the changes in section 4 from Issue 3 to Issue 4. The series author, Mick Maytum, is Bourns standards representative on the IEC, ITU-T, IEEE, ATIS, JEDEC and TIA surge protection committees.

Telcordia GR-1089-CORE Issue 4 Topics —
Primary Protector and EUT Electronics Protection Coordination – Part 1

Section 1: Introduction

GR-1089-CORE Issue 3 had the protection coordination test of clause 4.6.7.1, becoming an objective on 1 January 2005 and a requirement on 1 January 2006. At the last minute Telcordia extended the requirement date to the publication date of the new Issue 4 (July 2006), Figure 1.

Figure 1. Telcordia announcement of coordination test delay until Issue 4

Notices to the Industry	**January 2006**
Proposed *New* Change for GR-1089	Telcordia would like to notify the industry that the Telcordia Technical Forum (TTF) that is currently revising Issue 3 of GR-1089 has decided the following: The effective date on which objective O4-5 (133) in Section 4.6.7.1, *Protection Coordination*, becomes a requirement is extended until the publication of the new issue of GR-1089.

In some ways, this was good, as many customers did not understand the coordination test procedure from the way it was written. Another problem was that test criteria C (the specified voltage or the specified current are not reached) broke the laws of physics — something even Telcordia cannot do.

Issue 4 has a clearer explanation of protection coordination and applies protection coordination for two conditions, clause 4.6.7 First-Level Lightning Protection Tests [PDF file page 124] and clause 4.7 Lightning Protection Tests for Equipment to Be Located in High-Exposure Customer Premises and OSP Facilities [PDF file page 156]. Note that the helpful title words "Protection Coordination" are now missing!

GR-1089-CORE, Issue 4 covers another type of coordination — Fusing coordination (not a strictly correct title, as non-fusing resettable current limiters are comprehended). Possible confusion may arise as clause 4.9.3.1 is out of step and is titled Overcurrent Protection Coordination Test for Protected Circuits. In this document, the term protection coordination means Primary Protector and EUT Electronics Coordination.

Telcordia specifies surge impulse waveshapes as maximum rise and minimum decay times. In this document these requirements are implicit, e.g. a 10/1000 waveshape means a <10/>1000 waveshape.

> *Author's Comments*
> *The suggestions and opinions expressed herein do not necessarily state or reflect those of Bourns or Telcordia, and shall not be used for claiming product compliance.*

This Part 1 document discusses the clause 6.7 10/1000 and the clause 4.7 10/250 protection coordination tests. The Part 2 document gives the rational for the coordination generator and a protection coordination example. The Author's GR-1089-CORE, Issue 4, PDF file Document Properties box lists the creation date as 13/07/2006. To assist in locating the 13/07/2006 Issue 4 clauses referenced here, the document PDF file page numbers are shown in square brackets.

Section 2: Purpose of protection coordination testing
Coordination is a first level test and the EUT must withstand the stress levels. The test is intended to verify that the combination of primary protection and the EUT electronics survives (withstands) a specified impulse level. In the case of integrated and embedded primary protection, the primary protection is part of the EUT.

Section 3: Sequence of protection coordination testing
Bourns found that a large number of designers were confused on the meaning and implementation of the GR-1089-CORE, Issue 3 10/1000 impulse coordination test, particularly those that understood the ITU-T coordination test. For an explanation of the ITU-T coordination, circuit conditions see *The New ITU-T Telecommunication Equipment Resistibility Recommendations* at http://www.ce-mag.com/archive/02/01/Maytum.html.

The following sub-clauses cover these steps in protection coordination verification:

- Determination of the primary protector maximum limiting voltage, V_L
- Verification of the EUT first-level 10/1000 surge performance
- Verification of the 10/1000 protection coordination performance
- Verification of the 10/250 protection coordination performance

Section 3.1: 3.1 Determination of the primary protector maximum limiting voltage, V_L
If protection coordination testing is done without the primary protector in place, then the primary protector maximum limiting voltage let-through to the EUT electronics needs to be known. The letter symbol for this voltage value is V_L. There are a number of terms used for this symbol:

- Maximum voltage-limiting value is used in
  - 4.6.7 First-Level Lightning Protection Tests (Telecommunications Type 1, 3, and 5 Ports)[PDF file page 124]
  - 4.7 Lightning Protection Tests for Equipment To Be Located in High-Exposure Customer Premises and OSP Facilities (Type 3 and 5 Telecommunications Ports) [PDF file page 156]
- Minimum open-circuit voltage is used in
  - 4.6.7 First-Level Lightning Protection Tests (Telecommunications Type 1, 3, and 5 Ports)[PDF file page 124]
  - 4.7 Lightning Protection Tests for Equipment To Be Located in High-Exposure Customer Premises and OSP Facilities (Type 3 and 5 Telecommunications Ports) [PDF file page 156]
  - Table 4-13 Parameter Values Used for Equipment Intended for Agreed Primary Protection [PDF file page 160]
  - Table 4-15 Parameter Values Used for Equipment With Integrated Primary Protection [PDF file page 167]
- Voltage Limiting Maximum is used in
  - GR-974-CORE, Issue 3, Generic Requirements for Telecommunications Line Protector Units (TLPUs), 4.11 Voltage Limiting

"Minimum open-circuit voltage" is a strange term to use but it applies to the equipment electronics rather than the primary protector. High-impedance equipment must have a minimum voltage withstand of V_L, but in primary protector terms, it is the maximum voltage-limiting value at the open-circuit output terminals of the protector.

The value of V_L for protection coordination is determined using the GR-974-CORE 1000 V/µs test method.

GR-974-CORE standardizes on linear voltage ramps of 0.1 V/µs, 2 V/µs, 100 V/µs and 1000 V/µs. The two slowest ramps have short circuit currents of 10 A peak and rates of rise in the 0.1 A/µs to 2 A/µs range. The two fastest ramps have short circuit currents of 100 A peak and rates of rise in the 8 A/µs to 10 A/µs range.

There are four V_L values in data row 1 of Tables 4-13 [PDF file page 160] and 4-15 [PDF file page 167]. Three are 1000 V/µs Voltage Limiting Maximum values from GR-974-CORE (400 V, 600 V and 1000 V) together with one agreed value, Table 1. Unless otherwise specified, protection coordination testing uses a default carbon block 3-sigma V_L of 1000 V.

Table 1. V_L values from Table 4-13 and Table 4-15

Test #	V_L Value V			
	Low-Voltage Limiting Category	Medium-Voltage Limiting Category	High-Voltage Limiting Category	Special-Voltage Limiting Category
1	400	600	1000	Maximum voltage limiting value at 1 kV/µs

A point to remember is that protection coordination testing uses a double-exponential impulse whose rate of rise varies with time. For example, the 1000 V, 10/1000 surge waveform of test 3, Table 4-2 [PDF file page 123] has an initial rate of voltage rise of 270 V/µs that slows to 20 V/µs at 10 µs (Figure 3, *Lightning surge voltage limiting and survival properties of telecommunication thyristor-based protectors*, M. J. Maytum et al, 16th Annual Electrical Overstress/Electrostatic Discharge Symposium, September 26-29 1994).

Protection coordination testing with a GDT-based primary protector in place will lead to lower EUT electronics stress. For example the Bourns® 2420 Series 5-Pin GDT Protector has V_L values of 625 V at 100 V/µs and 875 V at 1000 V/µs. Applying a 1000 V, 10/1000 surge waveform is likely to result in a maximum limiting voltage of something more like 700 V.

> *Author's comment*
> *The 10/1000 is a slow "energy" impulse; had the faster rising 1.2/50 "insulation" test impulse been used, the limiting voltage and the EUT electronics stress would have been much higher. For this reason, the ITU-T is considering a supplementary fast rise coordination test.*

Section 3.2: Verification of the EUT first-level 10/1000 surge performance
4.6.6 First-Level Lightning Surge Tests (Telecommunications Type 1, 3, and 5 Ports) [PDF file page 120]

The 10/1000 first-level impulse tests of Table 4-2 First-Level Lightning Surge (Telecommunications Port) [PDF file page 123] are shown in Table 2.

Equipment that has a low-impedance during a surge might use a secondary protection circuit of a series fuse current limiter and shunt thyristor voltage limiter. Typical components used are the Bourns® B1250T Telefuse™ telecom fuse and the TISP4C290H3BJ thyristor. Both these components are designed to withstand a current of 100 A, 10/1000. Being low-impedance, the equipment conducts nearly the full 100 A, 10/1000 of short-circuit generator current of tests 1 or 3.

High-impedance equipment will develop voltages approaching or exceeding the specified V_L value in tests 2 or 3.

Table 2. First-level surge tests using 10/1000 from Table 4-2

Test #	Generator			Repetitions each polarity
	Minimum open-circuit voltage at each output V	Minimum short-circuit current at each output A	Waveshape open-circuit voltage and short-circuit current	
1	600	100	10/1000	25
2	1000	100	10/360	25
3	1000	100	10/1000	25
Testing options are either test 3 or tests 1 and 2 Primary protection is removed Tests done in both metallic and longitudinal modes				

These two special cases, where either the generator short-circuit current or a voltage near or exceeding V_L results, gives an indication of 10/1000 coordination test performance. In issue 4, the 10/1000 coordination test is a requirement and the generator used can deliver up to 100 A into all values of V_L up to 1000 V. These two limit coordination conditions, 100 A and V_L, are close to the two special case conditions of Table 4-2 testing. These special case equipments are considered as passing 10/1000 protection-coordination testing if the Table 4-2 test results are:

1) equipment terminal current exceeding 95 A, 10/1000
Or
2) equipment terminal voltage exceeding 95 % of V_L (950 V for the default V_L value)

The criteria of >95 A is quite generous as the Telcordia test 3 10/1000 amplitude ranges are 1000 V to 1150 V and 100 A to 115 A. If the 10/1000 generator had been set had been set to 1050 V and 105 A to comprehend measurement inaccuracy, the EUT could develop 200 V and still have a 95 A measured current. Setting the test amplitudes higher, increases the chances of not having to perform the 10/1000 coordination test.

Author's comment
Had the requirement been expressed as exceeding 95 % of the generator measured short-circuit current, 99.8 A in this example, the equipment could only develop 53 V. Rather than the published absolute >95 A value, perhaps a relative current value, like the voltage value, might have been a better criterion.

In many respects, tests 1 and 2 of Table 4-2 are redundant and only test 3 is needed. Equipment, other than the two special case types, will need to be coordination tested to the 1000 V or 100 A, 10/1000 level anyway.

Section 3.3: Verification of the 10/1000 protection coordination performance
Clause 4.6.7 First-Level Lightning Protection Tests (Telecommunications Type 1, 3, and 5 Ports) [PDF file page 124]

Section 3.3.1: Overview
Test setup, using defined impulse conditions, can be done with or without a connected primary protector. It is important to realize that these two configurations can give different stress conditions on the EUT electronics. The procedure for both configurations is in two stages, set-up and repetitious test. Issue 4 merges the two configuration procedures, to aid understanding, this document deals with the procedure for each configuration separately.

Without a connected primary protector, the generator voltage should be adjusted to cause either of these two EUT conditions:

- conduct a current of 95 A
- develop a voltage of 95 % of V_L

It is possible for both of these conditions to occur simultaneously.

With a connected primary protector, the generator voltage should be adjusted to cause either of the these two primary protector input terminal conditions:

- conduct a current of 95 A
- just operate the connected primary protector

Author's comment
The connected primary protector case should really be set-up and tested differently than those given in Issue 4 (13/07/2006) for reasons given later.

The EUT must not fail during either of the setup procedures.

The EUT must then withstand 10 repetitions in each polarity under Table 3 conditions. After testing, the EUT must meet the first-level criteria of clause 4.6.1 [PDF file page 107]

Table 3. Protection Coordination Lightning Test

Surge	Generator Charging Voltage (Volts)	Maximum Rise/ Minimum Decay time for Voltage and Current[2] (µs)	Repetitions Each Polarity[4]	Test Connections
1	V_0[1]	10/1000	10	A (longitudinal and metallic)

Notes:
1. If the input impedance of the EUT is asymmetrical, giving polarity dependent end point values of V_g, V_p and I_p, then the value of V_o is determined for each polarity.
2. Double-exponential waveshape as defined in Issue 4, Appendix A [PDF file page 281]. Maximum rise and minimum decay times apply to the voltage waveshape measured into an open circuit and to the current waveshape measured into a short circuit.

Section 3.3.2: Test configuration
The impulse generator used must have a charging voltage, V_g, with a range of at least 400 V to 2000 V and be capable of delivering a 100 A, 10/1000 impulse to each output terminal with a load voltage of 1000 V.

Section 3.3.2.1: Without connected primary protector configuration
If the specified primary protector has a series element, the lowest impedance value, R_c, of that series element should be series connected to the EUT port terminal. The measured EUT terminal voltage, V_p, must include the series element voltage drop caused by terminal current I_p, Figure 2.

Section 3.3.2.2: Fitted primary protector configuration
Clause 4.6.7 states that the fitted primary protector must have a 1000 V/µs limiting voltage of V_L ±5 %. The measurement of voltage (V_p) and current (I_p) is done at the primary protector input terminals Figure 3.

> *Author's comment*
> *The fitted primary protector should really have a 1000 V/µs limiting voltage of V_L +10 % to –0 %. This would then be inline with the tradition GR-1089-CORE test philosophy of minimum stress values such as the >1000 V, >100 A, <10/>1000 impulse generator.*

Figure 2. Test Circuit without connected primary protector configuration

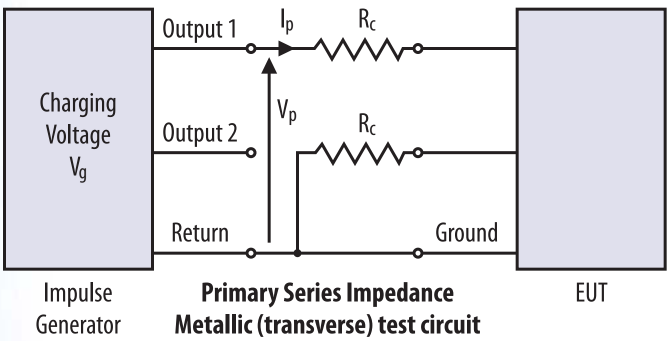
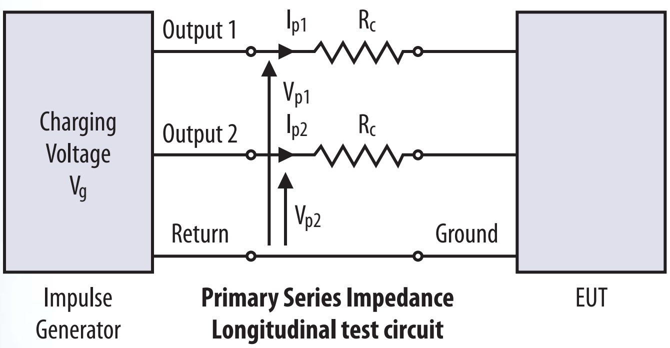


Figure 3. Test Circuit for fitted primary protector configuration



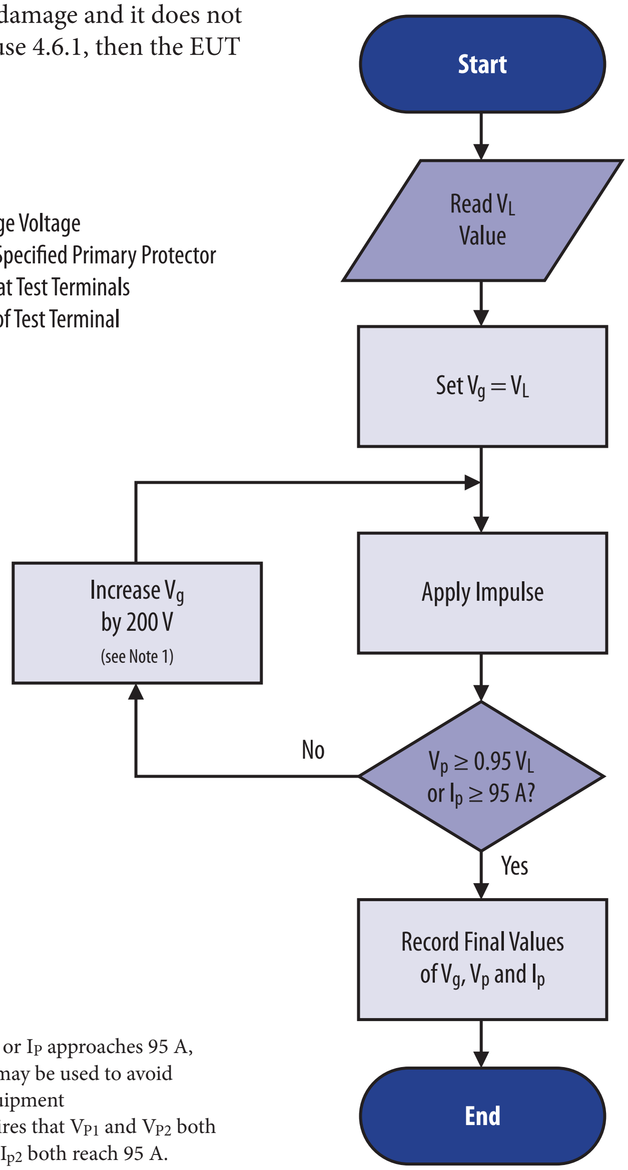
Section 3.3.3: Set-up procedure
Set-up determines the generator voltage, V_o, for the repetitive impulse tests of Table 3.

Section 3.3.3.1: Without connected primary protector configuration
The charging voltage of the generator, V_g, is increased in 200 V steps from the specified voltage-limiting value, V_L, of the primary protector (400 V, 600 V, 1000 V or an agreed value) until all the measured EUT terminals develop a voltage, V_p, of at least 95 % V_L or conducts a current, I_p, of at least 95 A (95 % of 100 A). As the measured V_p value approaches 0.95 V_L or the measured I_p value approaches 95 A, the nominal 200 V step size can be reduced to avoid excessive stress on the EUT electronics. Figure 4 shows the flow chart version for determining the end point values of V_g, V_p and I_p. If the input impedance of the EUT is asymmetrical, the end point values of V_g, V_p and I_p must be determined in both impulse polarities. Longitudinal testing requires that V_{p1} and V_{p2} both reach ≥0.95 V_L or I_{p1} and I_{p2} both reach ≥95 A.

The final V_g value is the V_o value used for Table 3 tests.

Figure 4. Procedure to determine the end point values of V_g, V_p and I_p
If this set-up procedure causes EUT damage and it does not operate properly as described in Clause 4.6.1, then the EUT has failed Protection Coordination.

V_g = Impulse Generator Charge Voltage
V_L = Limiting Voltage of the Specified Primary Protector
V_p = Peak Measured Voltage at Test Terminals
I_p = Peak Measured Current of Test Terminal



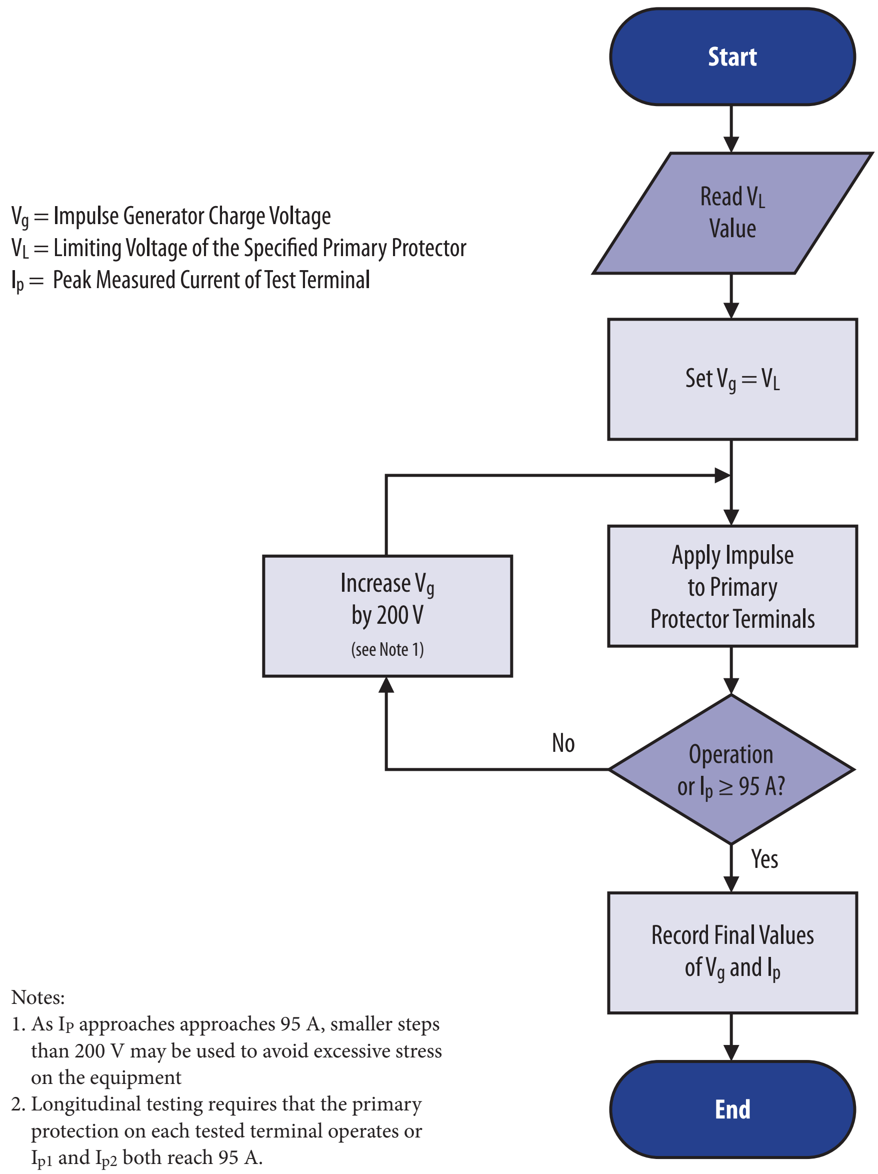
Notes:
1. As V_P approaches 0.95 V_L or I_P approaches 95 A, smaller steps than 200 V may be used to avoid excessive stress on the equipment
2. Longitudinal testing requires that V_{P1} and V_{P2} both reach 0.95 V_L and I_{p1} and I_{p2} both reach 95 A.

Section 3.3.3.2: Fitted primary protector configuration

The charging voltage of the generator, V_g, is increased in 200 V steps from the specified voltage-limiting value, V_L, of the primary protector (400 V, 600 V, 1000 V or an agreed value) until the fitted protector operates or the measured terminal current, I_p, at least 95 A (95 % of 100 A). As the measured I_p value approaches 95 A, the nominal 200 V step size can be reduced to avoid excessive stress on the EUT electronics. Figure 5 shows the flow chart version for determining the end point values of V_g, V_p and I_p. If the input impedance of the EUT is asymmetrical, the end point values of V_g, V_p and I_p must be determined in both impulse polarities. Longitudinal testing requires that the primary protection on each tested terminal operates or I_{p1} and I_{p2} both reach ≥95 A.

The final V_g value is the V_o value used for Table 3 tests.

Figure 5. Procedure to determine the end point values of V_g and I_p



Author's comment
Had the fitted primary protector voltage been V_L +10 % to –0 %, and then the end points of testing could have been:
- *conduct a current of 100 A*
- *connected primary protector operates*

The V_o value used for Table 3 tests would then be 95 % of the final V_g value. This level will not operate the primary protector and the maximum current level is 95 A. With this approach, the primary protector does not have to be removed for the repetitive testing of Table 3.

Section 3.3.4: Coordination verification test
Per Table 3, the test configuration must withstand 10 repetitions in each polarity with the generator set to V_o. Both metallic and longitudinal configurations are tested. The fitted primary protector configuration has the protector removed before applying Table 3 tests. After testing, the EUT must meet the first-level criteria of clause 4.6.1 [PDF file page 107]

Author's comment
As noted in the previous clause, protector removal in the fitted primary protector configuration would not be necessary had the primary protector voltage been selected as V_L +10 % to –0 % and the V_o value used been 95 % of the final V_g value.

Section 3.3.5: Coordination testing considerations

Section 3.3.5.1: Fitted protector: GDT based protector V_L
Clause 3.1 showed that GDT based protectors can have a much lower limiting voltage than V_L under double-exponential impulse conditions. The use of an auxiliary short-term voltage clamp can reduce this variation. For example, the Bourns® 2410 Series 5-pin MSP® multi-stage protector, which uses an MOV clamp, has V_L values of 600 V at 100 V/µs and 650 V at 1000 V/µs, c.f. the previous clause 3.1 values of 625 V and 875 V.

The potential problem here is that starting with a generator voltage setting of V_L, may cause a fitted GDT based primary protector to operate. In this case, the generator voltage must be reduced in voltage steps, not increased in steps, to determine when the primary protector just operates and hence the V_o value.

Section 3.3.5.2: Without fitted protector: EUT impedance stability
In some cases, the impedance of the EUT may change because of the generator setting or repetitive surging.

Ceramic PTC (Positive Temperature Coefficient) Thermistors have a voltage-dependent resistance. The resistance substantially decreases with increasing voltage. There can be a three to one reduction in resistance from dc to maximum rated impulse level. Designers need to comprehend this increased current into the following circuitry. In determining V_o, equal steps of V_g will not result in equal current increases of I_p. Ideally, the voltage step size should be progressively reduced for EUTs using ceramic PTC thermistors and without a connected primary protector.

The application of 10 impulses of opposite polarities at a generator setting of V_o, assumes the EUT impedance does not change and hence the related V_L value is always the same. EUT impedance increase will result in a higher EUT voltage stress, possibly causing a failure of an otherwise compliant EUT that would not happen if the primary protector were connected.

Author's comment
Polymer PTC thermistor current limiters used in EUTs and primary protectors can show an impedance change as a result of impulse testing and be vulnerable to overvoltage failure with the primary protector voltage limiting function is not present for Table 4-3 testing.

Section 3.3.5.3: Connected or unconnected primary protector?
Unless the EUT can conduct the full coordination current, without the need of a primary protector, the ITU-T always has the (special) primary protector connected for testing coordination. The preceding clauses give some reasons why.

Author's comment
Issue 4, in clause 4.6.7 [PDF page 124] states "If a primary protection is used for determining V_o, it should be removed during the tests specified in Table 4-12." The test table in clause 4.6.7 is Table 4-3. The corresponding 10/250 protection coordination clause (4.7 [PDF file page 157]) has the same text referencing Table 4-12. Thus, the 4.6.7 Table 4-12 looks wrong; the reference should be Table 4-3.

A Telcordia response to an author's inquiry stated that the referenced Table 4-12 looks wrong. This is symptomatic of the rushed closure of the Issue 4 development.

Testing with the primary protector fitted is real life and captures supplementary nuances such as a secondary dv/dt function. Table 4-3 testing with the primary protector then removed loses this extra function. The text states that the primary protector should be removed for Table tests. Sensibly, one would restore continuity by using shorting links. To make testers aware of simple removal consequences, a better statement would be that its equivalent series impedance replaces the primary protector.

When the final V_g value is determined with a connected primary protector of V_L +10 % to –0 %, the sensible thing to do would be to leave the protector in place and test at a generator setting of $V_o = 0.95\ V_g$.

Section 3.4: 10/250 impulse protection coordination testing
Clause 4.7 Lightning Protection Tests for Equipment To Be Located in High-Exposure Customer Premises and OSP Facilities (Type 3 and 5 Telecommunications Ports) [PDF file page 156]

The 10/250-impulse protection coordination test is intended for customer premise and outside plant locations suffering severe lightning conditions. In ITU-T parlance, the 10/250 is an enhanced level test and the 10/1000 is a basic level test. The 10/250 set-up and verification procedure is similar to the 10/1000 one.

Generator and configuration differences from the 10/1000 coordination test are

1) A 10/250, 2x500 A @ 1 kV, 4 kV charging maximum generator replaces the 10/1000, 2x100 A @ 1 kV, 2 kV charging maximum generator.
   (A 10/250, 2x500 A @ 1 kV, 4 kV charging maximum generator can be made from the standard 4 kV, 2 kA, 10/250 generator by adding two 2 W (maximum) external current sharing resistors from the single output.)
2) The test is done in the longitudinal mode only.

End point differences from the 10/1000 coordination test without a primary protector

1) develop a voltage of 100 % of V_L, rather than 95 % V_L
2) generator setting reaches 4 kV, rather than 95 % of 500 A

After set-up, the EUT must then withstand 10 repetitions in each polarity under Table 4 conditions. After testing, the EUT must meet the first-level criteria of clause 4.6.1 [PDF file page 107]

Table 4. Protection Coordination Lightning Test

Surge	Generator Charging Voltage (Volts)	Maximum Rise/ Minimum Decay time for Voltage and Current[2] (µs)	Repetitions Each Polarity[4]	Test Connections
1	V_0[1]	10/250	10	B (longitudinal)

Notes:
3. If the input impedance of the EUT is asymmetrical, giving polarity dependent end point values of V_g and V, then the value of V_o is determined for each polarity.
4. Double-exponential waveshape as defined in Issue 4, Appendix A [PDF file page 281]. Maximum rise and minimum decay times apply to the voltage waveshape measured into an open circuit and to the current waveshape measured into a short circuit.

Author's comment
The clause 4.6.7 and 4.7 coordination tests ought to correlate between themselves.

Why is 10/1000 done to a 95 % V_L level and 10/250 done to a 100 % V_L level for the without protector case? Rationally, the end points should be the same, preferably 95 % V_L.

On 10/250, why monitor generator voltage rather than delivered current? Depending on the load voltage (possible 0 to 1000 V range), the 4 kV generator setting delivers 2x670 A to 2x500 A. Rationally the current should be monitored and the generator voltage is what it is.

Using the 10/1000 formulations, the 10/250 V_o generator condition should be:
1) develop a terminal voltage of 95 % of V_L
2) conduct a terminal current 95 % of 500 A.

Section 4: Summary
Before surge testing the EUT, the primary protector V_L value needs to be determined.

Next perform the First-Level Lightning Surge Tests (Table 4-2), measuring the EUT terminal voltage and current for the tests involving 1000 V and 100 A (10/1000). If the EUT conducts a current exceeding 95 A or develops a voltage exceeding 95 % of V_L then that EUT is exempted from 10/1000 protection coordination testing.

The 10/1000 and 10/250 set up procedures establish the generator voltage setting, V_o, for repetitive testing. Although set up can be done with a real life limit primary protector fitted, for repetitive testing, Issue 4 requires that the protector be removed. Protector removal creates potential problems for certain types of EUT and some of the authors suggestions seek to remove these vulnerabilities and give test consistency.

Section 5: Disclaimer

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