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UL 489C

OUTLINE OF INVESTIGATION
FOR
MOLDED-CASE CIRCUIT BREAKERS AND MOLDED-CASE SWITCHES FOR
USE WITH WIND TURBINES

Issue No. 1

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Summary of Topics

This is the first issue of the Outline of Investigation for Molded-Case Circuit Breakers and Molded-Case Switches for Use with Wind Turbines.

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CONTENTS

INTRODUCTION

1 Scope	5
2 Components	5
3 Units of Measurement	6
4 Undated References	6
5 Glossary	6

CONSTRUCTION

6 General	6
7 Spacings	6
8 Wire Terminals	7

PERFORMANCE

9 General	8
10 Calibration	8
11 Overload Test	9
12 Endurance Test	9
13 Dielectric Voltage-Withstand Test	10
14 Extreme Ambient Cycling	10
15 Temperature Test	10
16 Electromagnetic Compatibility Test	10

RATINGS

17 General	10
------------------	----

MARKINGS

18 General	11
------------------	----

SUPPLEMENT SA - ADDITIONAL TESTS FOR CIRCUIT-BREAKERS WITH ELECTRONIC OVERCURRENT PROTECTION

SA1 Scope	SA1
SA2 Tests	SA1
SA2.1 Electromagnetic compatibility (EMC) tests	SA1
SA2.2 Suitability for multiple frequencies	SA2
SA2.3 Dry heat test	SA2
SA2.4 Damp heat test	SA2
SA2.5 Temperature variation cycles at a specified rate of change	SA2
SA3 General Test Conditions	SA3
SA4 Immunity Tests	SA3
SA4.1 Harmonic currents	SA3
SA4.2 Electrostatic discharges	SA5
SA4.3 Radiated radio-frequency electromagnetic fields	SA6

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SA4.4	Electrical fast transient/burst (EFT/B)	SA6
SA4.5	Surges	SA6
SA4.6	Conducted disturbances induced by radio-frequency fields (common mode)	SA7
SA4.7	Current dips	SA7
SA5	Emission tests	SA8
SA5.1	Harmonics	SA8
SA5.2	Voltage fluctuations	SA8
SA5.3	Conducted RF disturbances (150 kHz – 30 MHz)	SA8
SA5.4	Radiated RF disturbances (30 MHz – 1 GHz)	SA8
SA6	Suitability for multiple frequencies	SA9
SA6.1	General	SA9
SA6.2	Test conditions	SA9
SA6.3	Test procedure	SA9
SA6.4	Test results	SA10
SA7	Dry Heat Test	SA10
SA7.1	Test procedure	SA10
SA7.2	Test results	SA11
SA7.3	Verification of overload releases	SA11
SA8	Damp Heat Test	SA11
SA8.1	Test procedure	SA11
SA8.2	Verification of overload releases	SA11
SA9	Temperature variation cycles at a specified rate of change	SA11
SA9.1	Test conditions	SA11
SA9.2	Test procedure	SA12
SA9.3	Test results	SA12
SA9.4	Verification of overload releases	SA12

SUPPLEMENT SB - ELECTROMAGNETIC COMPATIBILITY (EMC) – REQUIREMENTS AND TEST METHODS FOR CIRCUIT BREAKERS

SB1	General	SB1
SB2	Immunity	SB2
SB2.1	General	SB2
SB2.2	Electrostatic discharges	SB4
SB2.3	Radiated radio-frequency electromagnetic fields	SB5
SB2.4	Electrical fast transients/bursts (EFT/B)	SB5
SB2.5	Surges	SB6
SB2.6	Conducted disturbances induced by radio-frequency fields (common mode)	SB6
SB3	Emission	SB7
SB3.1	General	SB7
SB3.2	Conducted RF disturbances (150 kHz – 30 MHz)	SB8
SB3.3	Radiated RF disturbances (30 MHz – 1000 MHz)	SB8

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INTRODUCTION

1 Scope

1.1 These requirements cover molded-case circuit breakers and molded-case switches rated up to 690 V ac intended for use in wind turbine applications in nacelle, hub, tower, and ground installations.

1.2 A circuit breaker or switch intended for use in wind turbine applications shall comply with the applicable requirements of UL 489, except as modified or supplemented by the following requirements.

1.3 These circuit breakers and switches shall have the same construction and comply with the requirements for 600 V ac rated circuit breakers and switches.

1.4 This Outline contains the following Supplements:

- a) Supplement SA – Additional tests for circuit breakers with electronic overcurrent protection; and
- b) Supplement SB – Electromagnetic compatibility (EMC) - Requirements and test methods for circuit breakers.

2 Components

2.1 Except as indicated in 2.2, a component of a product covered by this Outline shall comply with the requirements for that component.

2.2 A component is not required to comply with a specific requirement that:

- a) Involves a feature or characteristic not required in the application of the component in the product covered by this Outline; or
- b) Is superseded by a requirement in this Outline.

2.3 A component shall be used in accordance with its rating established for the intended conditions of use.

2.4 Specific components are incomplete in construction features or restricted in performance capabilities. Such components are intended for use only under limited conditions, such as certain temperatures not exceeding specified limits, and shall be used only under those specific conditions.

3 Units of Measurement

3.1 Values stated without parentheses are the requirement. Values in parentheses are explanatory or approximate information.

4 Undated References

4.1 Any undated reference to a code or standard appearing in the requirements of this outline shall be interpreted as referring to the latest edition of that code or standard.

5 Glossary

5.1 For the purpose of this Outline, the following definitions apply.

5.2 WIND TURBINE (WT) MOLDED-CASE CIRCUIT BREAKER – A molded-case circuit breaker intended to operate in a wind turbine application to provide overcurrent protection.

5.3 WIND TURBINE (WT) MOLDED-CASE SWITCH – A molded-case switch intended to operate in a wind turbine application to provide a disconnecting means.

CONSTRUCTION

6 General

6.1 The construction of a WT circuit breaker shall comply with Section 6 of UL 489 except as noted in Sections 7 and 8 of this Outline as applicable.

6.2 The construction of a WT switch shall comply with Section 10 of UL 489 except as noted in Sections 7 and 8 of this Outline as applicable.

7 Spacings

7.1 The electrical spacings for WT circuit breakers and switches rated 601 – 690 V shall meet the requirements for 600 V.

8 Wire Terminals

8.1 The field wiring terminal(s) of a WT circuit breaker or switch shall have a capacity acceptable for the number, wire size, and type of stranding associated with the circuit breaker and in addition shall be acceptable for at least the size indicated in Table 8.1.

Table 8.1
50°C ambient corrected conductor size

Terminal current ^a , A	Copper conductors ^{b,c}		Aluminum conductors ^{b,c}	
	Number of conductors	AWG or kcmil	Number of conductors	AWG or kcmil
15 or less	1	14	1	12
20	1	10	1	10
25	1	10	1	8
30	1	8	1	8
40	1	6	1	4
50	1	4	1	3
60	1	4	1	2
70	1	3	1	1
80	1	2	1	1/0
90	1	1	1	1/0
100	1	1/0	1	2/0
110	1	1/0	1	3/0
125	1	2/0	1	4/0
150	1	3/0	1	250
175	1	250	1	350
200	1	300	1	400
200	2	1/0	2	2/0
225	1	350	1	500
225	2	1/0	2	3/0
250	1	400	1	600
250	2	2/0	2	4/0
275	1	500	1	700
300	2	3/0	2	250
325	2	4/0	2	300
350	2	250	2	350
350	3	2/0		
400	2	300	2	400
450	2	350	2	500
450	3	3/0	3	250
500	2	400	2	600
500	3	250	3	300
550	2	500	3	350
600	3	300	3	400
700	3	400	3	500
800	3	500	4	400
800	4	300	5	300
1000	4	400	4	600
1200	5	400	6	400
1200	6	300	8	250
1400	5	500	6	500
1400	6	400	9	250

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Table 8.1 Continued on Next Page



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Table 8.1 Continued

Terminal current ^a , A	Copper conductors ^{b,c}		Aluminum conductors ^{b,c}	
	Number of conductors	AWG or kcmil	Number of conductors	AWG or kcmil
1600	6	500	6	700
1600	7	400	8	400
2000	6	500	10	400
2000	8	400	8	600
2500	9	500	10	600

^a For terminal current other than indicated, the next higher rating is to be used – for example, if rated 35 A, enter at 40 A.
^b Table is based on 75°C wire ampacities.
^c Based on 50°C correction factor of Table 310.15(2)(a) of the National Electrical Code, ANSI/NFPA-70.

8.2 A WT circuit breaker or switch may also be evaluated for use with metric wire sizes, and/or other class and strand configurations as indicated by its marking in accordance with Annex B, Reference No. 6 of UL 489.

PERFORMANCE

9 General

9.1 The representative device selection and performance test sequences of a WT circuit breaker shall be conducted as specified in Tables 7.1.1.1 and 7.1.1.2 respectively of UL 489 except as modified by this Outline.

9.2 WT switches shall be tested in accordance with Section 11 of UL 489 except as modified by this Outline.

9.3 For a field-wired WT switch or circuit breaker, unless otherwise specified, the wire is to be sized in accordance with UL 489.

10 Calibration

10.1 In addition to the Calibration Test specified in Section 7.1.2 of UL 489, a WT circuit breaker shall be subjected to the Calibration Test specified in Section 7.1.2.4 of UL 489 at 50°C (122° F). A calibration test at 40°C (104°F) is not required.

10.2 A WT circuit breaker shall be wired with a conductor sized in accordance with Table 8.1 or bus bars in accordance with 7.1.4 of UL 489, and subjected to a temperature of 50°C (122°F) for a period of 3 hours or until temperatures stabilize. While at 50°C (122°F), the circuit breaker shall be subjected to the Calibration Test at 100 percent of rated current as described in 7.1.2.4 of UL 489, until temperatures stabilize. The WT circuit breaker shall not trip.

10.3 In addition to the 200 Percent Calibration Test in Section 7.1.2.2 of UL 489, a WT circuit breaker shall be tested at the extremes of its temperature ratings, except that the tripping times may be adjusted based on the temperature rerating (adjustment) factors published by the manufacturer, in accordance with 10.4.

10.4 A WT circuit breaker shall be wired with a conductor sized in accordance with Table 8.1 or bus bars in accordance with 7.1.4 of UL 489, and subjected to both extremes of the temperature range stated in 17.3. The circuit breaker with leads attached shall be terminated in its intended manner and shall be mounted throughout the tests on a vertical surface in an oven, freezer, compartment, or room. The ambient temperature shall be measured as indicated in 7.1.4.1.7 of UL 489. The 200-Percent Calibration Test shall be made when the temperature at the points shown in Figures 7.1.4.1.1 – 7.1.4.1.4 of UL 489 becomes constant. While at each end of the temperature range, the circuit breaker shall be subjected to the Calibration Test at 200 percent of rated current. The WT circuit breaker shall trip within the allowable time.

11 Overload Test

11.1 A WT circuit breaker shall be subjected to the Overload Test specified in 7.1.3 of UL 489 at the maximum rated voltage specified by the manufacturer. The WT circuit breaker shall be wired with a conductor sized in accordance with Table 8.1. The number of operations and test current shall be in accordance with Table 11.1.

Table 11.1
Overload test

Circuit breaker rating	Test current	No. of operations
249 A and less	600%	50
250 A and greater	135%	25

12 Endurance Test

12.1 WT circuit breakers and switches shall be capable of performing successfully when subjected to the Endurance Test specified in 7.1.5 of UL 489 at the maximum rated voltage specified by the manufacturer. The number of operations of the Endurance Test shall be in accordance with Table 12.1.

Table 12.1
Endurance test

Circuit breaker rating	No. of operations	
	With load	Without load
249 A and less	1000	4000
250 A and greater	400	2000

13 Dielectric Voltage-Withstand Test

13.1 WT circuit breakers and switches shall be subjected to the Dielectric Voltage-Withstand Test specified in 7.1.9 of UL 489. The test voltage for a circuit breaker or switch rated 690Y/400 shall be based on 690 V.

14 Extreme Ambient Cycling

14.1 A WT circuit breaker shall perform successfully when operated under conditions indicated in 14.2 and 14.3.

14.2 Three WT circuit breakers are each to be subjected to temperature cycling without load consisting of 50 cycles of heating and cooling; each cycle consisting of 15 minutes at minus 30°C (minus 22°F), or at minus 40°C (minus 40°F) at the manufacturer's option, followed by 15 minutes at 65°C (149°F) (any convenient ramp rate). At the conclusion of the 50 cycles, the representative devices shall be returned to room temperature $23 \pm 3^\circ\text{C}$ ($73.4 \pm 5.4^\circ\text{F}$) for a minimum of 3 hours.

14.3 With the WT circuit breaker at $23 \pm 3^\circ\text{C}$ ($73.4 \pm 5.4^\circ\text{F}$), the circuit breaker shall be subjected to the 200 Percent Calibration Test in Section 7.1.2.2 of UL 489. The trip times shall not exceed the allowed limits as required in Table 7.1.2.2.1 of UL 489.

15 Temperature Test

15.1 A WT circuit breaker or switch shall be subjected to the Temperature Test as specified in Section 7.1.4 of UL 489 except as noted in 15.2.

15.2 Parts of a WT circuit breaker or switch shall not exceed the values in Section 7.1.4 and 7.6.5 of UL 489 except the temperature rise limits shall be adjusted by subtracting 10°C from the allowable rise.

16 Electromagnetic Compatibility Test

16.1 A solid-state trip WT circuit breaker or switch shall be subjected to the EMC tests as specified in Supplements SA and SB of this Outline.

RATINGS

17 General

17.1 In addition to the rating requirements of Section 8 of UL 489, a WT circuit breaker or switch shall comply with 17.2 and 17.3.

17.2 A WT circuit breaker or switch shall be rated for one or more voltages, 690 V maximum.

17.3 The rated ambient temperature range for a WT circuit breaker shall be minus 30 to +50°C (minus 22°F to +122°F), or at minus 40°C (minus 40°F) at the manufacturer's option.

MARKINGS

18 General

18.1 A WT circuit breaker shall be provided with the applicable required markings specified in Section 9 of UL 489.

18.2 A WT switch shall be provided with the required markings as specified in Section 13 of UL 489.

18.3 A WT circuit breaker or switch shall be marked "Wind Turbine" or "WT." Location Category B.

18.4 A WT circuit breaker or switch may also be marked with metric wire sizes, and/or other class and strand configurations in accordance with 8.2. The marking shall include wire size or wire range, the type and/or class of wire and the stranding if different from Class B concentric and compressed, or Class C concentric. Location Category B.

18.5 If a WT circuit breaker or switch has ratings for other applications, the markings shall be clearly separate from the WT ratings.

18.6 A WT circuit breaker or switch shall be marked with both extremes of the temperature range stated by the manufacturer, in accordance with 17.3. Location Category C.

18.7 A WT circuit breaker or switch shall be marked as being suitable for 75°C (167°F) wire. Devices intended only for bus bar connections shall be marked in accordance with 18.8. Location Category B.

18.8 When a WT circuit breaker or switch has been tested using bus bars larger or smaller than those specified in Table 7.1.4.1.3 of UL 489, it shall be marked to show the minimum size bus bar with which it can be used. Location Category B.

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SUPPLEMENT SA - ADDITIONAL TESTS FOR CIRCUIT-BREAKERS WITH ELECTRONIC OVERCURRENT PROTECTION

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SA1 Scope

These requirements apply to circuit-breakers intended to be installed on a.c. circuits and providing overcurrent protection by electronic means, incorporated in the circuit-breaker and independent of the line voltage or any auxiliary supply.

The tests verify the performance of the circuit-breaker under the environmental conditions stated in this Supplement.

Specific tests for electronic means intended for functions other than overcurrent protection are not covered by this Supplement. However, the tests of this Supplement shall be performed to ensure that these electronic means do not impair the performance of the overcurrent protective functions.

For the purposes of this Supplement, the term "EUT" is defined as "equipment under test".

For the purposes of this Supplement, "power terminal(s)" covers the main circuit, auxiliary power supply terminals(s) and any auxiliary connected to the main circuit.

SA2 Tests

Tests specified in this Supplement are in addition to the tests of Section 7 of UL 489.

NOTE: Where a standard for specific environmental conditions exists, reference is systematically made to this standard, if relevant.

SA2.1 Electromagnetic compatibility (EMC) tests

SA2.1.1 General

Circuit-breakers with electronic overcurrent protection shall be tested according to Tables SB1 and SB3.

SA2.1.2 Performance criteria

The results of immunity tests shall be evaluated on the basis of the performance criteria given in SB2.1 with the following specifications:

Performance criterion A:

For step 1, the circuit-breaker when loaded at 0.9 times the current setting shall not trip and the monitoring functions, if any, shall correctly indicate the status of the circuit-breaker. For step 2, when loaded at 2.0 times the current setting, the circuit-breaker shall trip within 0.9 times the minimum value and 1.1 times the maximum value of the manufacturer's time current characteristic, and the monitoring functions, if any, shall correctly indicate the status of the circuit-breaker.

Performance criterion B:

During the test, the circuit-breaker when loaded at 0.9 times the current setting shall not trip. After the test, the circuit-breaker shall comply with the manufacturer's time current characteristic when loaded at 2.0 times the current setting and the monitoring functions, if any, shall correctly indicate the status of the circuit-breaker.

SA2.2 Suitability for multiple frequencies

The test shall be performed in accordance with Section SA6.

SA2.3 Dry heat test

The test shall be performed in accordance with Section SA7.

SA2.4 Damp heat test

The test shall be performed in accordance with Section SA8.

SA2.5 Temperature variation cycles at a specified rate of change

The test shall be performed in accordance with Section SA9.

SA3 General Test Conditions

SA3.1 General

Tests according to this Supplement may be performed separately from the tests of Section 7 of UL 489. In the case of the EMC tests, Supplement SB applies with the additional requirements specified in SA4 and SA5.

SA3.2 Electromagnetic compatibility tests

For immunity tests of SA4, one circuit-breaker per frame size and per type of current sensor design shall be tested; a change of winding turns is not considered as a different design in this context.

The current setting shall be adjusted to the minimum value.

Short-time and instantaneous release settings shall each, if applicable, be adjusted to the minimum value but to not less than 2.5 times the current setting.

The tests shall be performed with the appropriate test circuit, as specified in the following subclauses, taking into account any phase-loss sensitive features.

For circuit-breakers having electronic overcurrent protection, it may be assumed that the tripping characteristics are the same, whether tests are performed:

- a) On individual poles of multipole circuit-breakers;
- b) On two or three phase poles in series; or
- c) By three-phase connection.

SA4 Immunity Tests

SA4.1 Harmonic currents

SA4.1.1 General

These tests apply to circuit-breakers with electronic trip units where current sensing means are stated by the manufacturer to be r.m.s. responsive.

This shall be indicated either by marking "r.m.s." on the circuit-breaker or given in the manufacturer's literature, or both.

The EUT shall be tested in free air unless it is intended to be used only in a specified individual enclosure, in which case it shall be tested in such an enclosure. Details including the dimensions of the enclosure shall be stated in the test report.

Where applicable, the tests shall be performed at the rated frequency.

NOTE: The test currents may be generated by a source of power based on the use of thyristors (see Figure SA1), saturated cores, programmable power supplies, or other appropriate sources.

SA4.1.2 Test currents

The test current waveform shall consist of one of the following two options:

Option a): Two waveforms applied successively:

- i) a waveform consisting of a fundamental and a third harmonic component;
- ii) a waveform consisting of a fundamental and a fifth harmonic component.

Option b): A waveform consisting of a fundamental and a third, fifth and seventh harmonic component.

Test currents shall be:

For option a): test of the third harmonic and peak factor

- i) 72 percent of fundamental component $\leq$ third harmonic $\leq$ 88 percent of fundamental component;
- ii) peak factor: 2.0 ± 0.2 ;

test of the fifth harmonic and peak factor

- i) 45 percent of fundamental component $\leq$ fifth harmonic $\leq$ 55 percent of fundamental component;
- ii) peak factor: 1.9 ± 0.2 ;

For option b): the test current, for each period, consists of two equal opposite half-waves defined as follows:

- i) current conduction time, for each half-wave is $\leq$ 21 percent of the period;
- ii) peak factor: ≥ 2.1 .

NOTE 1: The peak factor is the peak value of the current divided by the r.m.s. value of the current wave. For the relevant formula, see Figure SA1.

NOTE 2: This test current for option b) has at least the following harmonic content of the fundamental component:

- i) – third harmonic > 60 percent;
- ii) – fifth harmonic > 14 percent;
- iii) – seventh harmonic > 7 percent.

Higher harmonics may also be present.

NOTE 3: The test current waveform for option b) may be produced by, for example, two back-to-back thyristors (see Figure SA1).

NOTE 4: The test currents 0.9 current setting and 2.0 current setting (see performance criterion A) are the r.m.s. values of the composite waveforms.

SA4.1.3 Test procedure

The tests shall be performed on two-phase poles, chosen at random in accordance with Sections 7.2 and 7.7.3 of UL 489 as applicable, carrying the test current at any convenient voltage, connections being in accordance with Figure SA2. For releases with a phase loss sensitive feature, connections shall be made in accordance with Figures SA3 or SA4, as applicable.

Undervoltage releases, if any, shall either be energized or disabled. All other auxiliaries shall be disconnected during the test.

The duration of the test to verify the immunity to unwanted tripping (at 0.9 times the current setting) shall be 10 times the tripping time, which corresponds to twice the current setting.

SA4.1.4 Test results

Performance criterion A of SA2.1.2 shall apply.

SA4.2 Electrostatic discharges

Supplement SB, in particular SB2.2, applies with the following additions.

The test set-up shall be in accordance with Figures SA16 and SB3.

The test circuit shall be in accordance with Figure SA2. For releases with a phase-loss sensitive feature, the test circuit shall be in accordance with Figure SA3 or Figure SA4, as applicable.

The bus bar routing shown in Figures SA2, SA3 and SA4 may be varied providing the 0,1 m distances, with a tolerance of minus 0, +10 percent, to the enclosure are maintained. The actual configuration used shall be shown in the test report.

Performance criterion B of SA2.1.2 applies.

SA4.3 Radiated radio-frequency electromagnetic fields

Supplement SB, in particular SB2.3, applies with the following additions.

The test set-up shall be in accordance with Figures SA16 and SA17.

The test circuit shall be in accordance with Figure SA2. For releases with a phase-loss sensitive feature, the test circuit shall be in accordance with Figure SA3 and SA4, as applicable.

Performance criterion A of SA2.1.2 applies.

SA4.4 Electrical fast transient/burst (EFT/B)

Supplement SB, in particular SB2.4, applies with the following additions.

The test set-up shall be in accordance with Figures SA16 and SA18 for testing power lines and with Figures SA16 and SA19 for testing signal lines. The circuit-breaker being supplied from the other phase poles, in accordance with Figure SA6.

For releases which have a phase-loss sensitive feature, the test shall be performed as shown in Figure SA7 for the three phase poles in series connection or as shown in Figure SA8 on a phase pole chosen at random for the three-phase connection.

Performance criterion A of SA2.1.2 applies. However, temporary changes to the monitoring functions (e.g. unwanted LED illumination) during the tests are acceptable, in which case the correct functioning of the monitoring shall be verified after the tests. For step 2, the disturbance shall be applied until the circuit-breaker trips.

SA4.5 Surges

Supplement SB, in particular SB2.5, applies with the following additions.

On main terminals, the disturbance shall be applied on one phase pole chosen at random, the EUT being supplied from the other two phase poles, in accordance with Figure SA9 (line-to ground) and Figure SA12 (line-to-line).

For releases which have a phase-loss sensitive feature, the test shall be performed as shown in Figure SA10 (line-to-ground) and Figure SA13 (line-to-line) for the three phase poles in series connection or as shown in Figure SA11 (line-to-ground) and Figure SA14 (line-to-line) on a phase pole chosen at random for the three-phase connection.

Performance criterion B of SA2.1.2 applies.

SA4.6 Conducted disturbances induced by radio-frequency fields (common mode)

Supplement SB, in particular SB2.6, applies with the following additions.

The test set-up shall be in accordance with Figures SA16, SA20 and SA21, SA22 or SA23 for testing power lines and with Figure SA16 for testing signal lines.

On the main terminals, the disturbance shall be applied on one phase pole chosen at random, the circuit-breaker being supplied from the other phase poles, in accordance with Figure SA2.

For releases which have a phase-loss sensitive feature the test circuit shall be in accordance with Figure SA3 or Figure SA4 as applicable.

Performance criterion A of SA2.1.2 applies.

SA4.7 Current dips**SA4.7.1 Test procedure**

The EUT shall be tested in free air unless it is intended to be used only in a specified individual enclosure, in which case it shall be tested in such an enclosure. Details including the dimensions of the enclosure shall be stated in the test report.

The test circuit shall be in accordance with Figure SA2 on two-phase poles chosen at random.

For releases with a phase loss sensitive feature, the test circuit shall be in accordance with Figures SA3 or SA4, as applicable.

The tests shall be performed with a sinusoidal current at any convenient voltage. The current applied shall be according to Figure SA5 and to Table SA1.

The duration of each test shall be between three and four times the maximum tripping time corresponding to twice the current setting or 10 min, whichever is the lower.

Table SA1
Test parameters for current dips and interruptions

Test no.	Test current	Δt , cycles
1	0	0.5
2		1
3		5
4		25
5		50
6	0.4 current setting	10
7		25
8		50
9	0.7 current setting	10
10		25
11		50