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Indian Standard

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IEC 60353 :1989

प्रत्यावर्ती धारा (ए.सी) पावर सिस्टम्स के लिए लाइन ट्रैप

(दूसरा पुनरीक्षण)

Line Traps for A.C. Power Systems

(Second Revision)

ICS 33.200

भारतीय मानक ब्यूरो
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Power System Control and Associated Communication Sectional Committee, LITD 10

NATIONAL FOREWORD

This Indian Standard (Second Revision) which is Identical to IEC 60353 : 1989 'Line traps for a.c. power systems' issued by the International Electrotechnical Commission (IEC) was adopted by the Bureau of Indian Standards on the recommendations of the Power system control and associated communication sectional committee and approval of the Electronics and Information Technology Division Council.

This Indian Standard was originally published in 1978 and was largely based on IEC 60353 : 1971. The first revision of this standard was published in 1995 and was largely aligned with IEC Publication 353-1989 (Second Edition) Line Traps for a.c. Power Systems. The second revision of this standard aligns this Indian Standard with IEC 60353 :1989 along with amendment 1 Published in 2002.

Amendment 1 : 2002 is attached at the end of this document.

The text of IEC Standard has been approved as suitable for publication as an Indian Standard without deviations. Certain conventions are however not identical to those used in Indian Standards. Attention is particularly drawn to the following:

a) Wherever the words 'International Standard' appears referring to this standard, they should be read as 'Indian Standard'; and

b) Comma (,) has been used as a decimal marker while in Indian Standards, the current practice is to use a point (.) as the decimal marker.

In this adopted standard, reference appears to certain International Standards for which Indian Standards also exist. The corresponding Indian Standards, which are to be substituted in their places, are listed below along with their degree of equivalence for editions indicated. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies:

International Standards	*Corresponding Indian Standards*	*Degree of Equivalence*
IEC 60071-1 : 1976 Insulation co-ordination — Part 1: Terms, definitions, principles and rules	IS/IEC 60071-1 : 2019 Insulation Co-ordination: Part 1 Definition, principles and rules (*first revision*)	Identical
IEC 60076-2 : 1976 Power transformers — Part 2: Temperature rise	IS 2026 (Part 2) : 2010 Power transformers: Part 2 Temperature - rise (*first revision*)	Technically Equivalent
IEC 60085 : 1957 Thermal evaluation and classification of electrical insulation	IS 1271 : 2012/IEC 60085 : 2007 Electrical insulation — Thermal evaluation and designation (*second revision*)	Identical
IEC 60270 : 1981 Partial discharge measurements	IS/IEC 60270 : 2000 High-voltage test techniques — Partial discharge measurements	Identical

The Committee has reviewed the provisions of the following International Standards referred in this adopted standard and has decided that they are acceptable for use in conjunction with this standard. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies:

International Standard	*Title*
IEC 60099-1 : 1970	Lightning arresters — Part 1: Non-linear resistor type arresters for a.c. systems

(*Continued on third cover*)

CONTENTS

Indian Standard

Line Traps for A.C. Power Systems

(Second Revision)

SECTION ONE - GENERAL

1. Scope

This standard applies to line traps inserted into high voltage a.c. transmission lines to prevent undue loss of carrier signal power, typically in the range 30 kHz to 500 kHz, under all power system conditions and to minimize interference from carrier signalling systems on adjacent transmission lines. It does not apply to inductors which are connected to high voltage transmission lines for other purposes.

Line traps associated with a.c./d.c. converter stations require to operate under power system conditions which are not defined in this standard.

The information which has been provided in Appendix B to assist in the specification of such line traps is of an advisory nature only and does not form part of this standard.

2. Object

The object of this standard is to establish definitions, requirements, methods of testing and ratings for line traps.

3. Symbols used in this standard

Please note that the symbols used only in the appendixes are not included.

α	=	temperature coefficient
A_t	=	tapping loss
A_{tR}	=	tapping loss based on blocking resistance
C_r	=	self-capacitance
Δf_1, Δf_2	=	bandwidth based on blocking impedance
Δf_{1R}, Δf_{2R}	=	bandwidth based on blocking resistance
f_c	=	centre frequency
f_{cR}	=	centre frequency based on blocking resistance
f_{pN}	=	rated power frequency
I_N	=	continuous rated current
I_{km}	=	asymmetrical peak value of first half cycle of short-circuit currents
I_{kN}	=	steady state component of short-circuit currents

J	=	short-circuit current density
L_p	=	power-frequency inductance of the main coil
L_t	=	true inductance of the main coil
L_{tN}	=	rated inductance of the main coil
R_b	=	blocking resistance
T	=	inverse of temperature coefficient
U	=	voltage developed across the line trap at rated power frequency by the rated short-time current
U_m	=	maximum system voltage
Z_b	=	blocking impedance
θ	=	temperature

4. Service conditions

4.1 *Standard conditions*

The standard conditions shall be those for outdoor service. A line trap shall be capable of carrying out its required function whether exposed to sunshine, rain, fog, frost, snow, ice, etc. Cases arising from severe atmospheric conditions such as salt spray, industrial pollution, etc., shall be covered by special agreement between manufacturer and purchaser.

4.2 *Altitude*

A line trap shall not be used at an altitude greater than 1 000 m above sea-level without special agreement with the manufacturer and measure being taken to ensure its suitability.

4.3 *Ambient temperature*

Unless otherwise agreed between manufacturer and purchaser, a line trap shall not be used beyond an air temperature range of -40 °C to +40 °C.

4.4 *Power frequency*

This standard applies only to power system frequencies between 15 Hz and 60 Hz inclusive.

4.5 *Wave shape*

For the purpose of this standard, power-frequency currents and voltages shall be considered to have wave shapes which are approximately sinusoidal.

4.6 *Unusual service conditions*

In the event that the requirements of Sub-clauses 4.2 and 4.3 cannot be met, reference should be made to Clause 8 and Sub-clause 10.3.

SECTION TWO - DEFINITIONS

For the purpose of this standard, the following definitions shall apply. Other terms used have the meanings attributed to them in IEC Publication 50, unless otherwise stated.

5. General

A line trap, consisting of a main coil in the form of an inductor, a tuning device and a protective device, is intended for insertion in a high voltage power transmission line between the point of connection of carrier-frequency signals and adjacent power system elements such as busbars, transformers, etc. The tuning device connected across the main coil ensures, with proper adjustment, that the line trap presents a relatively high impedance at one or more carrier frequencies or carrier-frequency bands, whereas the impedance of the line trap at power frequencies is negligible. A line trap may also be used to limit the loss of carrier-frequency at a power system tee point.

Untuned line traps are sometimes used where there is a requirement for a wideband coupling. However, attention is drawn in Sub-clause 5.4 to the possibility of series resonance occurring under certain power system conditions, leading to an unacceptable shunting effect of the carrier-frequency signal path.

Figures 1a and 1b show the circuit diagrams of typical line traps.

5.1 *Main coil*

An inductor which carries the power-frequency current of the high voltage transmission line.

5.1.1 *Apparent inductance*

The reactance of the main coil divided by the angular frequency at which the reactance was determined, uncompensated for the effect of self-capacitance.

5.1.2 *Power-frequency inductance*

The inductance L_p at power-frequency.

5.1.3 *True inductance*

The self-inductance L_t of the main coil at a specified frequency compensated for the effect of self-capacitance.

5.1.4 *Rated inductance*

The value of true inductance L_{tN} at 100 kHz.

5.1.5 *Self-capacitance*

The capacitance C_r which, together with the true inductance, causes the main coil to resonate at self-resonant frequency. The self-capacitance is a function of the design of the main coil.

5.1.6 *Self-resonant frequency*

The frequency at which the combination of true inductance and self-capacitance becomes resonant.

5.1.7 *Resistance of main coil*

The value of resistance at d.c. current.

5.1.8 *Temperature coefficient*

The ratio α of the change in resistivity due to a change in temperature of 1 °C relative to the resistivity at 0 °C.

5.1.9 *Rated power frequency*

The frequency f_{pN} of the high voltage power transmission system to which the line trap is connected.

5.2 *Tuning device*

The combination of capacitors, inductors and resistors connected across the main coil. All of these components may not be present at any one time, depending on the carrier-frequency requirements of the line trap.

5.3 *Protective device*

The device connected across the main coil and tuning device which prevents the line trap from being damaged by transient overvoltages which may occur across it. Additional protective devices may be fitted to protect individual components of the tuning device.

5.4 *Carrier-frequency characteristics*

Power system elements such as transformers, busbars, lines, etc., represent an impedance connected beyond the line trap between line and earth. This impedance, in series with the impedance of the line trap, may shunt the carrier-frequency signal path. The loss in signal power resulting from this shunt depends upon the vectorial sum of the two impedances.

In the most unfavourable case, the reactive components of the two impedances may neutralise each other thus reducing the total shunt impedance to an unacceptably low value.

In order to eliminate this possibility and the further possibility of varying shunting effects arising out of power system switching, the blocking impedance of the line trap should always include a resistive component. The line trap performance can therefore be assessed in terms of its resistive component only.

5.4.1 *Blocking impedance*

The complex impedance Z_b of the complete line trap within a specified carrier-frequency range.

5.4.2 *Blocking resistance*

The resistive component R_b of the blocking impedance.

5.4.3 *Tapping loss*

The loss A_t sustained by a carrier-frequency signal due to the finite blocking ability of the line trap. It is defined in terms of the ratio of the signal voltages across an impedance equal to the characteristic impedance of the transmission line with and without the shunt connection of the line trap and is expressed in decibels.

5.4.4 *Tapping loss based on blocking resistance*

The loss A_{tR}, expressed in decibels, sustained by a carrier-frequency signal due to the shunt connection of the resistive component of the line trap impedance.

5.4.5 *Bandwidth based on blocking impedance*

The carrier-frequency bandwidth Δf_1 or Δf_2 within which the module of the blocking impedance does not fall below a specified value or the tapping loss A_t does not exceed a specified value (see Figures 2a and 2b).

5.4.6 *Bandwidth based on blocking resistance*

The bandwidth Δf_{1R} and Δf_{2R} based on the resistive component expressed in terms of the blocking resistance (see Figures 2a and 2b).

5.4.7 *Centre frequency*

The geometric mean frequency f_c of the bandwidth limit frequencies.

5.4.8 *Centre frequency based on blocking resistance*

The geometric mean frequency f_{cR} derived from the bandwidth limit frequencies based on blocking resistance. For band-tuned line traps f_c is equivalent to f_{cR}.

5.4.9 *Q factor*

The ratio of reactance to resistive component of the main coil at a specified frequency.

5.5 *Currents*

5.5.1 *Continuous rated current*

The maximum r.m.s. value of the current I_N flowing continuously through the main coil at specified power frequency which does not cause the specified temperature rise limits to be exceeded.

5.5.2 *Rated short-time current*

The r.m.s. value of the steady state component of the short-circuit current I_{kN} flowing through the main coil for a specified time without causing thermal or mechanical damage. The asymmetrical peak value I_{km} of the first half-cycle of the short-circuit current shall be assumed to be 2.55 times the r.m.s. value.

5.5.3 *Emergency overload current*

The amount of current which the main coil can sustain for a specified period without suffering permanent damage or a significant reduction in useful life.

SECTION THREE - REQUIREMENTS

6. General requirements

6.1 *Main coil*

The rated inductance of the main coil shall be chosen from the recommended values given in Clause 20 and shall not be less than 90% of the stated value.

Where there is a requirement for interchangeability, a suitable upper limit shall be agreed between manufacturer and purchaser. Otherwise, an upper limit does not require to be specified.

Note.- For calculations of blocking resistance or bandwidth based on blocking resistance, the lower tolerance should be used.

6.1.1 *Self-resonant frequency*

This frequency shall always be higher than 500 kHz except for line traps having a rated inductance greater than 0.5 mH where it may not be possible to achieve such a high frequency because of the physical construction of the main coil.

6.1.2 *Q factor*

Where interchangeability is of prime importance, a Q factor of not less than 30 at 100 kHz must be assured. The physical construction of the main coil can have an influence on the Q factor.

6.1.3 *Current ratings*

The continuous and short-time current ratings shall be in accordance with Clauses 21 and 22.

6.2 *Tuning device*

The tuning device shall be so arranged as to permit interchange without removing the line trap. It shall be so designed that neither significant alteration in the line trap blocking requirements nor physical damage shall result from either the temperature rise or the magnetic field of the main coil at continuous rated current, rated short-time current or emergency overload current.

6.3 *Protective device*

It is recommended that non-linear resistor type arresters for a.c. systems in accordance with IEC Publication 99 or an equivalent national standard, whichever is more appropriate, be used for insulation co-ordination and that the nominal discharge current be equal to or greater than that of the station arresters installed behind the line trap. In no case shall this current be taken as less than 5 kA.

The protective device shall be so designed and arranged that neither a significant alteration in its protective function nor physical damage shall result either from the temperature rise or the magnetic field of the main coil at continuous rated current, rated short-time current or from emergency overload current. It shall neither enter into operation as a result of the power-frequency voltage developed across the line trap by the rated short-time current nor shall it remain in operation after a response to a transient overvoltage which is immediately followed by the power-frequency voltage developed across the line trap by the rated short-time current.

7. Blocking requirements

Specification of the blocking impedance and the tapping loss are for agreement between manufacturer and purchaser. This standard does not give any detailed guidance on the permissible variation of these two quantities within the bandwidth of the line trap.

Attention is, however, drawn to Clause A3 of Appendix A where the relationship between rated inductance, blocking resistance and bandwidth is discussed.

For the purpose of stating the bandwidth, a maximum loss of 2.6 dB is suggested for both tapping loss and tapping loss based on blocking resistance. This corresponds to a line trap blocking resistance of 1.41 times the characteristic impedance of the transmission line. A typical case is that of a line trap of 570 Ω blocking resistance connected to a transmission line of 400 Ω characteristic impedance, this being a typical value of the phase/earth impedance of a single conductor transmission line.

8. Continuous service requirements

The temperature rise of any part of a line trap under rated continuous current conditions shall not exceed the values given in Table I at altitudes below 1 000 m and the air temperature range given in Sub-clause 4.3. The temperature rise at the hot spot should be measured directly and the average temperature rise calculated from the increase in resistance of the main coil as described in Sub-clause 19.1.

Since a line trap is usually not fully loaded during all its working life, the values given in Table I are higher than those given in IEC Publication 85.

Table I

Limits of temperature rise

Insulation class and reference temperature (°C)	Maximum temperature rise (°C)	
	Hot spot measured by direct methods	Average value measured by increase in resistance
105 (A)	75	65
120 (E)	100	85
130 (B)	110	90
155 (F)	135	115
185 (H)	155	140
220 (C)	200	160

Note.- For certain insulating materials outside these classifications, temperature rises in excess of those given in Table I may be adopted by agreement between manufacturer and purchaser.

If a line trap is intended for service where the air temperature is likely to exceed the upper limit of the range given in Sub-clause 4.3 by not more than 10 °C, the allowable temperature rise shall be reduced by:

- 5 °C if the excess temperature is less than or equal to 5 °C;

- 10 °C if the excess temperature is greater than 5 °C but less than 10 °C.

No recommendations are given regarding the temperature rise where the air temperature exceeds the upper limit given in Sub-clause 4.3 by more than 10 °C.

For a line trap intended for use at altitudes greater than 1 000 m but tested at lower altitudes, the limits of temperature rise given in Table I must be reduced by 2.5% for each 500 m above 1 000 m.

Note.- Certain parts of a line trap may require, or be capable of having, individual temperature specifications depending on their positions relative to the main coil. For bare metallic parts or windings, the temperature rise shall not exceed the limits given for adjacent material. For the dimensions of the terminals, attention is drawn to IEC Publication 129 noting that the terminals of line traps operate at higher temperatures due to eddy currents produced by the magnetic field of the main coil.

9. Ability to withstand rated short-time current

9.1 *Mechanical strength*

The ability of a line trap to withstand the mechanical forces produced by the asymmetrical peak value I_{km} of the short-time current shall be verified by carrying out the tests specified in Item *a)* of Sub-clause 19.4.

9.2 *Thermal behaviour*

The ability of a line trap to withstand the heating effect of the rated short-time current I_{kN} shall be verified by carrying out the tests specified in Item *b)* of Sub-clause 19.4.

10. Insulation level

10.1 *Insulation across a line trap*

The insulation level for the insulation between the terminals of a line trap is governed by the rated voltage of the protective device. The insulation of the main coil and the tuning device shall be adequately rated for:

a) the voltage U developed across the line trap at rated power frequency by the rated short-time current. This voltage U shall be:

$$U = 2\pi \cdot f_{pN} \cdot L_p \cdot I_{kN}$$

where:

f_{pN} = rated power frequency

L_p = power frequency inductance of the main coil measured in accordance with Clause 19.6

I_{kN} = rated short-time current

The rated voltage of the protective device shall be higher than U.

b) the front of wave impulse sparkover voltage or the residual voltage caused by the nominal discharge current of the protective device, whichever is higher.

10.2 *System voltage insulation*

The system voltage insulation of a line trap is provided by insulator strings or post insulators. For these IEC Publication 383 applies. The line trap system voltage insulation shall be consistent with the other equipment in the associated high voltage transmission network.

10.3 *Line traps for use at high altitudes*

In the case of line traps intended for use at altitudes between 1 000 m and 3 000 m, but tested at altitudes below 1 000 m, the test voltage for those insulations which are formed by air distances shall be increased in accordance with IEC Publication 71-1.

11. Radio influence voltage (RIV)

Radio influence voltage may be generated by corona on the line trap. It is therefore recommended that the corona inception voltage be at least 15% higher than the phase to earth voltage ($U_m/\sqrt{3}$) of the transmission network to which the line trap is connected. The maximum system voltages U_m given in Table II are in accordance with IEC Publication 71-1. The test voltages ($1.15 \cdot U_m/\sqrt{3}$ in three-phase supply networks) relating to each power system voltage, are also given in Table II. The maximum radio influence voltage is a matter for agreement between manufacturer and purchaser.

Table II

Relationship between maximum power system voltage and radio influence test voltage

Maximum power system voltage U_m	Radio influence test voltage $1.15\cdot(U_m/\sqrt{3})$ (r.m.s.)
kV	kV
52	35
72.5	48
123	83
145	97
170	113
245	163
300	199
362	242
420	280
525	349
765	508

12. Power losses

Power losses occur in the main coil due to the passage of power-frequency current and the presence of eddy currents. The magnitude of these losses is a function of the design of the line trap and the material used in the windings.

If the purchaser requires the losses to be determined, this should be done by agreement with the manufacturer who should thereafter declare them. It is pointed out that a requirement for low power losses can influence the carrier-frequency performance of the line trap.

Since line traps vary widely in design and construction, it is recommended, for comparison purposes, that the losses should be corrected for a temperature of 75 °C.

A method of correcting power losses with regard to temperature is given in Appendix A, Clause A4, for guidance only.

13. Tensile strength of suspension system

The suspension system of a line trap shall be designed for a tensile stress of at least twice the mass of the line trap in kilograms, multiplied by 9.81 to convert to newtons, plus 5 000 N.

14. Accessories

14.1 *Bird barriers*

The provision of bird barriers is optional. If provided, no entrance to the line trap shall admit a sphere having a diameter of 16 mm.

14.2 *Terminals*

The position and type of terminals used is a matter for agreement between manufacturer and purchaser. Attention is, however, drawn to IEC Publication 518 and NEMA Standard CC1-1975 for details of recommended dimensions.

SECTION FOUR - RATING PLATES

The main coil, the tuning device and the protective device shall be provided with rating plates of weatherproof material fitted so that they are readily visible. The inscriptions shall be indelibly marked and include the following data:

15. Rating plate of the main coil

a) Manufacturer's name and year of manufacture.
b) Type.
c) Serial number.
d) Rated inductance (mH).
e) Power-frequency inductance (mH).
f) Rated continuous current (A).
g) Rated power frequency (Hz).
h) Rated short-time current (kA) and duration (s).
i) Total weight (kg).

16. Rating plate of tuning device

a) Manufacturer's name and year of manufacture.
b) Type.
c) Serial number.
d) Frequency band(s) (kHz).
e) Blocking impedance (minimum value) (Ω).
f) Blocking resistance (minimum value) (Ω).
g) Rated impulse protective level (kV).
h) Belonging to main coil with rated inductance (mH) and serial number (optional).

If additional information is required, this is a matter for agreement between manufacturer and purchaser.

17. Rating plate information for protective device

This should be in accordance with IEC Publication 99-1.

SECTION FIVE - TESTS

18. General conditions

The tests may be made by the manufacturer at any ambient temperature between 0 °C and +40 °C, indoors or outdoors.

For the tests, the line tap shall be mounted in a position similar to what it would be in service unless otherwise stated. The ambient temperature during the tests should be noted.

Some or all of the type tests may be repeated as sampling tests if specially agreed to between manufacturer and purchaser. The tests on the protective device shall be carried out in accordance with IEC Publication 99-1, or an equivalent national standard.

Note.- For some of the following tests, particular methods are suggested in the interests of simplicity. Other methods, including direct read-out instruments which eliminate or reduce computation, can be used providing their accuracy and suitability can be adequately demonstrated. It is important when carrying out carrier-frequency measurements, to ensure that the measuring loop is kept as small as possible in order to exclude extraneous impedances.

Also, all equipment used in such measurements (including the line trap) should be kept clear of metallic surfaces and objects and, where appropriate, the impedance of the test leads taken into account.

19. Tests

The titles of the following sub-clauses will indicate which are type tests and which are routine tests.

19.1 *Temperature rise test (type test)*

This test is designed to prove the thermal behaviour of the line trap at rated continuous current. The temperature rise of the main coil of the line trap (average value measured by increase in resistance and hot spot by direct methods) has to be determined.

The test should be carried out at rated continuous current I_N unless, for any reason, this is impossible, in which case a value I_t which is not less than 90% of the rated value is allowed.

The value of temperature rise θ_n which would have resulted from the rated continuous current is calculated from the formula:

$$\theta_n = \theta_t \left(\frac{I_N}{I_t} \right)^{1.6}$$

where θ_t is the temperature rise measured at I_t.

The test shall be continued until the temperature of any part of the line trap does not increase by more than 2% during two consecutive hourly readings.

a) Determination of the average value of temperature rise measured by increase of resistance:

Since the resistance of the main coil will vary with temperature depending on the temperature coefficient α of the conductor material, the temperature rise resulting from the application of rated continuous current can be ascertained by measuring the resistance immediately before the commencement of the test and calculating what it was immediately after the test. Since it is likely that a period of time will elapse between the completion of the test and the measurement of the resistance of the main coil, it is recommended that at least four measurements be taken at intervals of not more than 3 min and plotted against a time base. By extrapolating the resulting curve as shown in Figure 3, the value of resistance at the moment of completion of the test will be obtained.

Values of temperature coefficient α and $T = 1/\alpha$ are given in Table III for copper, aluminium and aldrey. It is important that the manufacturer specifies the value of either α or T for the conductor material used.

Table III

Values of α and T for aluminium, copper and aldrey

Conductor material	$\alpha = \frac{1}{T}$ (1/°C)	$T = \frac{1}{\alpha}$ (°C)
Aluminium	0.004 44	225
Copper	0.004 26	235
Aldrey	0.003 60	278

The temperature θ_2 of the main coil at the end of the test period shall be calculated from its measured resistance R_2 at that temperature and its measured resistance R_1 at some other temperature θ_1, using the following formulae:

- for aluminium: $$\theta_2 = \frac{R_2}{R_1} \cdot (225 + \theta_1) - 225$$

- for copper: $$\theta_2 = \frac{R_2}{R_1} \cdot (235 + \theta_1) - 235$$

- for aldrey: $$\theta_2 = \frac{R_2}{R_1} \cdot (278 + \theta_1) - 278$$

where θ_1 and θ_2 are measured in degrees Celsius (see IEC Publication 76-2).

The average temperature rise is the difference between the final temperature θ_2 and the ambient temperature.

b) Determination of temperature rise at hot spot:

The hot spot temperature rise is the difference between the highest temperature reading obtained from a number of measuring points (at least 5) located as shown in Figure 4 and the ambient temperature at the completion of the test.

It is possible to use thermocouples, thermometers, thermally sensitive paper or other suitable devices to measure the temperature rise. The measuring device must be embedded in the coils on the surface of the conductor.

Temperature measurements using thermocouples may be difficult to carry out because the voltage across the main coil during the test can affect the readings. Where the axis of the main coil is vertical, the hot spot usually occurs at the top of the coil.

19.2 *Measurement of radio influence voltage (type test)*

The recommended method of determining whether or not radio influence voltage would be generated by the line trap under service conditions is shown in Figure 5. The environment in which the tests are carried out should be clean and dry. Also, the background interference level should not exceed 50 µV (see Clause 11).

The tests should be carried out in accordance with IEC Publication 270 using equipment which is generally approved for the purpose and commercially available.

The equipment should be capable of measuring signals in a quasi-peak mode in the band 0.5 MHz to 1.5 MHz within a 9 kHz bandwidth. The input impedance should be approximately 150 Ω.

19.3 *Insulation tests*

It is only necessary to carry out one of the following tests subject to agreement between manufacturer and purchaser. In certain circumstances and subject to discussion and agreement between the two parties, it may be considered advantageous to carry out both tests.

19.3.1 *Impulse voltage test (type test)*

Method 1:

The test is carried out with the protective device replaced by one having an impulse sparkover voltage at least 30% higher than the protective device which was delivered with the main coil and of the same type and construction. The method of connection should also be similar. The upper limit of the sparkover voltage should be that of the protective device having the next highest rating given in IEC Publication 99-1.

Note.- It may be necessary to use a sphere gap in place of the protective device if the test requirements cannot be met due to the inherent characteristics of the protective device.

A voltage having a wave front of at least 200 kV/µs and an amplitude which ensures front of wave sparkover of the protective device, shall be applied to the line trap terminals. The recommended test circuit is shown in Figure 6, but with the protective device connected instead of the chopping gap.

Test procedure:

The test voltage shall be applied to each terminal with the other earthed.

Oscillographic records should be obtained of all voltages and circuits as shown in Figure 6.

Test sequence:

a) One reduced impulse voltage at approximately 50% of the sparkover voltage of the protective device.

b) Five positive and five negative full impulse voltages as defined previously.

c) Repetition of Item *a)*.

Significant variations in the blocking capabilities of the line trap prior to and after the impulse voltage tests, as well as variations in the oscillographic records, will indicate insulation abnormalities or other damage resulting from the tests.

Method 2:

The test is carried out with the protective device disconnected and the tuning device connected in the manner that it would be in service.

A voltage having a wave shape of 1.2/10-50 µs shall be applied to the line trap terminals. The peak value of the voltage shall be at least 30% higher than the front of wave sparkover voltage or the residual voltage at nominal discharge current, whichever is higher. The recommended test circuit is shown in Figure 6.

Test procedure: see under "Method 1".

Test sequence:

a) One reduced full impulse at approximately 50% of the required peak voltage as defined previously.

b) One 100% full impulse.

c) Two positive and two negative 100% chopped impulses with a maximum time to chopping of 5 µs and a maximum time of voltage collapse during chopping of 0.4 µs.

d) Three positive and three negative 100% full impulses.

e) Repetition of Item *a)*.

Significant variations in the blocking capabilities of the line trap prior to and after the impulse voltage tests, as well as variations in the oscillographic records, will indicate insulation abnormalities or damage resulting from the tests.

Note.- The chopping gap shown in Figure 6 is included for the chopped impulse tests only.

19.3.2 *Power-frequency voltage test on tuning device (type and routine test)*

For the purpose of this test the tuning device is disconnected from the main coil and a test voltage U_t = 1.3 U applied to it for 5 s. The voltage U is evaluated in accordance with Clause 10.

19.4 *Short-time current tests (type tests)*

These tests are designed to prove the mechanical and thermal withstand capabilities of the line trap at rated short-time current I_{kN}, recommended values of which are given in Clause 22. For the purposes of the tests, the line trap must be complete, i.e. the tuning and protective devices must be connected across the main coil.

a) Mechanical strength

The mechanical strength of the line trap shall be proved by applying an asymmetrical short-time current, the first peak of which shall be not less than 2.55 times I_{kN}. The asymmetrical short-time current shall have a duration of at least 5 cycles. Other durations are a matter for agreement between manufacturer and purchaser.

b) Thermal behaviour

The thermal behaviour of the line trap shall be proved by applying a short-time current I_{kN} for a duration of 1 s.

If there are limitations in the test equipment, the thermal behaviour shall be proved by applying a current I for a time t such that I^2t is not less than $I^2{}_{kN} \cdot t_N$, t having a value between 0,5 s and 2 s and t_N a value of 1 s.

The ability of the line trap to withstand this test shall be determined by visual inspection and measurement of the blocking capabilities before and after the tests. If the test cannot be carried out because of insufficient power capacity of the test equipment, the final temperature θ_1 shall be calculated as follows. It shall not exceed the maximum permissible temperature θ_2 as specified in Table V.

$$\theta_1 = \theta_0 + aJ^2t \cdot 10^{-3} \ ^\circ\mathrm{C}$$

where:

θ_0 = initial temperature (°C)

J = short-circuit current density (A/mm²)

t = duration of the test (s)

a = function of $\frac{1}{2}(\theta_2 + \theta_0)$ in accordance with Table IV $\left(\frac{^\circ\mathrm{C} \cdot \mathrm{mm}^4}{\mathrm{A}^2 \cdot \mathrm{s}}\right)$

where:

θ_2 is the maximum permissible average temperature in °C as specified in Table V.

The initial temperature θ_0 shall be the sum of the ambient temperature and the relevant temperature rise measured by change in resistance.

Note.- It is preferable to combine the mechanical strength and thermal behaviour tests for a duration of 1 s.

Table IV

Values of factor a

$\frac{1}{2}(\theta_2 + \theta_0)$ (°C)	a = function of $\frac{1}{2}(\theta_2 + \theta_0)$ $\left(\frac{^\circ\mathrm{C} \cdot \mathrm{mm}^4}{\mathrm{A}^2 \cdot \mathrm{s}}\right)$	
	Copper	Aluminium
140	7.41	16.5
160	7.80	17.4
180	8.20	18.3
200	8.59	19.1
220	8.99	20.0
240	9.38	20.9
260	9.78	21.8

Table V

Maximum permissible values of average temperature of the line trap (°C)

Insulation class temperature (°C)	Values of θ_2 copper & aluminium (°C)
105 (A)	180
120 (E)	200
130 (B)	250
155 (F)	250
180 (H)	250
220 (C)	300

19.5 *Measurement of the rated inductance of the main coil (type and routine test)*

a) For purposes of this measurement, it is recommended that the line trap be installed in such a way that there is at least one diameter separation from any metallic structures, objects or materials. The proximity of metal in any form can affect the accuracy of the measurement. All test leads should be kept as short as possible.

b) The recommended arrangement of test equipment is shown in Figure 7.

L_{tN} = rated inductance of the main coil (H)
C_r = self-capacitance of the main coil (F)
R_x = equivalent resistance of the main coil (Ω)
C_B = variable capacitor
G = carrier frequency signal generator
R_B = variable resistor

C_B and R_B are adjusted for minimum reading on meter M at frequencies f_1 = 140 kHz and f_2 = 70 kHz. Values of $C_B = C_{B1}$ and C_{B2} respectively will be obtained.

$$L_{tN} = \frac{1}{4\pi^2 \cdot (C_{B1} - C_{B2})} \left(\frac{1}{f_1^2} - \frac{1}{f_2^2} \right)$$

also $R_B = R_x$.

19.6 *Measurement of power-frequency inductance of the main coil (type and routine test)*

This is carried out by voltage/current methods at power frequency or any frequency up to 100 Hz.

19.7 *Measurement of blocking resistance and blocking impedance (type and routine test)*

The blocking resistance and blocking impedance of a line trap shall be determined within the specified bandwidth (impedance or resistive components as applicable) by means of the bridge method shown in Figure 8. Equivalent methods of proven accuracy can also be used.

Note.- In the case of line traps utilising simple resonance, it may be a matter for agreement between manufacturer and purchaser not to perform this test on all units of a series. It is then sufficient to determine the impedance at the tuning frequency and, for this purpose, the method of measurement shown in Figure 9 is recommended. This method gives correct results only when the blocking impedance is resistive. At the tuning frequency, the voltage U_R is a minimum. Maintaining voltage U constant and varying R until $U_R = U/2$ will give a value of R which will be equal to the blocking resistance of the line trap. The internal impedance of the generator should be small.

19.8 *Measurement of tapping loss and tapping loss based on the blocking resistance (type and routine test)*

A recommended method of determining the tapping loss is shown in Figure 10. The tapping losses are calculated by the following equations:

Tapping loss (A_t)

$$= 20 \log_{10} \left| \frac{U_1}{U_2} \right| \text{ dB}$$

$$= 20 \log_{10} \left| 1 + \frac{Z_1}{2Z_b} \right| \text{ dB}$$

Tapping loss based on the blocking resistance (A_{tR})

$$= 20 \log_{10} \left| \frac{U_1}{U_2} \right| \text{ dB}$$

$$= 20 \log_{10} \left| 1 + \frac{Z_1}{2R_b} \right| \text{ dB}$$

where:

Z_1 = resistance equivalent to the characteristic impedance of the line

Z_b = blocking impedance

R_b = blocking resistance

U_1 = voltage at terminals 1 and 2 when switch S_1 is open

U_2 = voltage at terminals 1 and 2 when switch S_1 is closed and switch S_2 is in position 3-4 (when measuring tapping loss) or position 3-5 (when measuring tapping loss based on the blocking resistance).

When measuring the tapping loss based on the blocking resistance, the reactive component of the impedance of the line trap shall be compensated for by adjusting capacitance C or inductance L, hence the alternative positions for switch S_2.

Note.- If the measurement of the tapping loss is carried out in this manner, measurement of the blocking impedance and blocking resistance can be omitted and vice versa.

SECTION SIX - RECOMMENDED VALUES

Preferred values are underlined.

20. Rated inductance of main coil (mH)

<u>0.2</u> - 0.25 - <u>0.315</u> - 0.4 - <u>0.5</u> - <u>1.0</u> - <u>2.0</u>

21. Rated continuous current (A)

100 - 200 - <u>400</u> - <u>630</u> - <u>800</u> - 1 000 - <u>1 250</u> - 1 600 - <u>2 000</u> - 2 500 - <u>3 150</u> - <u>4 000</u>

22. Rated short-time current (kA r.m.s.)

2.5 - 5 - <u>10</u> - <u>16</u> - <u>20</u> - 25 - <u>31.5</u> - <u>40</u> - <u>50</u> - <u>63</u> - 80

23. Co-ordination of rated continuous current and rated short-time current

To achieve this co-ordination, two series of line traps are recommended in Table VI, Series 1: for normal requirements (for all values of inductance mentioned in Clause 20) and Series 2: for above normal requirements.

Table VI

Co-ordination of currents

Rated continuous current (A)	Rated short-time currents	
	Series 1 (kA)	Series 2 (kA)
100	2.5	5
200	5	10
400	10	16
630	16	20
800	20	25
1 000	25	31.5
1 250	31.5	40
1 600	40	50
2 000	40	50
2 500	40	50
3 150	40	50
4 000	63	80

Note.- Difficulties may exist in testing some of the larger line traps due to limitations in test facilities.

APPENDIX A

Additional information is given in this appendix to amplify the one already given in the standard and to facilitate its use. It is intended to be of an explanatory nature only and is not to be considered part of the specification.

A1. Definition of the inductance of the main coil

In the previous edition of IEC Publication 353 (1971), the inductance of the main coil was defined as the inductance measured at power frequency or any frequency up to 1 000 Hz. Since this value is only of importance in defining the voltage developed across the line trap by the rated short-time current (Sub-clause 10.1) and has no significance in determining the performance of the line trap at carrier frequencies, it was decided in this edition to define the inductance of the main coil in terms of its inductance at 100 kHz and to call it "rated inductance". It is important to note that the recommended values given in Section Six are now in terms or "rated inductance" and not "power-frequency inductance" as in the previous document. The term "power-frequency inductance" refers to the inductance of the main coil measured at power frequency.

A2. Frequency dependence of the true inductance of the main coil

The total inductance of an air coil, of which a line trap is a particular example, consists of two parts:

a) The outer (external) inductance resulting from the magnetic flux which surrounds the coil and links the windings.

b) The internal inductance resulting from the magnetic flux inside the conductors.

Because of current displacement effects (skin and proximity effects), the internal inductance diminishes as the applied frequency increases. In the case of a line trap, differences of up to 10% are possible between the power-frequency inductance and the rated inductance. An example of the frequency dependence of the true inductance is shown in Figure 11.

A3. Relationship between rated inductance, blocking resistance and bandwidth based on blocking resistance

The following examples demonstrate the two most common forms of tuning circuits, but there are many different arrangements of tuning components which can be used for particular applications.

The circuit of a single frequency-tuned line trap is shown in Figure 1a and that for a band-tuned line trap in Figure 1b. The corresponding blocking characteristics and definitions of bandwidth are shown in Figures 2a and 2b. The following formulae, applicable to either of the two tuning methods, enable theoretical calculations of the bandwidth Δf_{1R} and the limit frequencies f_{1R} and f_{2R} to be made.

It is assumed that the centre frequency f_{cR}, the rated inductance L_{tN} and the blocking resistance R_b have already been specified, including any tolerances.

a) Bandwidth Δf_{1R} based on the blocking resistance:

$$\Delta f_{1R} = f_{cR} \cdot 2b = f_{2R} - f_{1R} \text{ (Hz)}$$

b) Lower band limit frequency f_{1R}:

$$f_{1R} = f_{cR} \cdot (\sqrt{1 + b^2} - b) \text{ (Hz)}$$

c) Upper band limit frequency f_{2R}:

$$f_{2R} = f_{cR} \cdot (\sqrt{1 + b^2} + b) \text{ (Hz)}$$

For a single frequency-tuned line trap:

$$b = \frac{\pi f_{cR} \cdot L_{tN}}{2R_b}$$

For a band-tuned line trap:

$$b = \frac{\pi f_{cR} \cdot L_{tN}}{R_b}$$

It will be seen that a band-tuned line trap offers twice the bandwidth of a single frequency-tuned line trap.

Other arrangements of higher order networks are available, for example, for double frequency-tuned line traps.

A4. Measurement of losses at power frequency

The measurement of total losses at rated frequency current requires special care because of the very low loss angle of a line trap. An appropriate method (e.g. wattmeter, bridge, etc.,) shall be adopted by the manufacturer.

The total losses can be divided into those due to the d.c. resistance of the main coil and those due to eddy current losses in the windings and metallic parts of the line trap. Metallic structures in the near vicinity can also contribute to eddy current losses.

It is recommended that the losses should be measured, where possible, when the temperature of the windings is in the region of a reference temperature of 75 °C. This can be done during the test described in Sub-clause 19.1.

If this is not possible, the losses at the reference temperature can be determined by measuring the losses when the line trap is cold (temperature θ °C) and carrying out the following calculations:

$$P_w = I_N^2 \cdot R \cdot K_1 + (P_c - I_N^2 R) \cdot K_2$$

where:

P_w = calculated total losses at 75 °C

I_N = rated continuous power frequency current

R = d.c. resistance at θ °C

K_1 = factor for correcting d.c. resistance at θ °C to reference temperature

$$= \frac{T + 75}{T + \theta} \quad \text{where} \quad T = \frac{1}{\alpha} \quad \text{(see Table III)}$$

P_c = measured total losses at θ °C (cold state)

K_2 = factor for correcting eddy current losses to reference temperature (data obtained from a type tested line trap of similar construction)

$$= \frac{P_{wt} - I_N^2 \cdot R_t \cdot K_1}{P_{ct} - I_N^2 \cdot R_t}$$

where:

P_{wt} = measured total losses at 75 °C

P_{ct} = measured losses at θ °C

R_t = d.c. resistance at θ °C

A5. Emergency overload capability

The rated continuous current can be exceeded in accordance with Table AI without damaging the line trap or shortening its useful life, on the assumption that the overload is applied after normal operation at rated continuous current.

Table AI should be applied with great care and if it is the intention to subject a line trap to frequent overloads, the advice of the manufacturer should be sought. Table AII shows the absolute maximum temperature for each class of insulation.

Table AI

Emergency overload current as a percentage of rated continuous current

Ambient temperature (°C)	Emergency period		
	15 min	30 min	60 min
+40	140	130	120
+20	145	135	125
0	150	140	130
-20	155	145	135
-40	160	150	140

Table AII

Relationship between insulation class and the maximum temperature to which it can be subjected

Insulation class and reference temperature (°C)	Maximum temperature (°C)
105 (A)	150
120 (E)	175
130 (B)	185
155 (F)	210
180 (H)	235
220 (C)	260

APPENDIX B

LINE TRAPS ASSOCIATED WITH A.C./D.C. CONVERTER STATIONS

The information given in this appendix is intended to inform rather than instruct and is not to be regarded as forming part of this standard which is entirely devoted to line traps used in a.c. power systems.

It is evident from the relatively small amount of information currently available that the design of d.c. line traps is considerably more complex than the design of a.c. line traps.

Consequently, to deal with them adequately, state-of-the-art filter design, transient system behaviour, insulation co-ordination and system non-linearities which result in the production of harmonics, have to be taken into account.

Further research and close monitoring of existing installations are required in order to formulate design guidelines and performance specifications, leading to the preparation of an IEC publication.

B1. Introduction

The process of converting a.c. power to d.c. power and vice versa is accompanied by two effects:

The consumption of reactive power equal to more than half the actual power converted and the generation of harmonics in current and voltage.

These two phenomena require the addition of filtering on both sides of the converter station to reduce the penetration of harmonics into each network. The layout of a typical converter station is shown in Figure 12. On the a.c. side, the impedance of the network, as seen from the converter, is not known accurately and harmonic currents flowing through the network impedance give rise to harmonic voltages. On the d.c. side, voltage harmonics generate current harmonics, the amplitude of which depends on the characteristics of the converter equipment and the impedance of the d.c. network.

In general terms, a converter acts, from the a.c. network viewpoint, as a source of harmonic currents (high internal impedance) and, from the d.c. network viewpoint, as a source of harmonic voltages (low internal impedance).

If the converter is fed from a balanced three-phase source of voltage and if the delay angles are equidistant, the characteristic harmonics are of an order determined by the pulse number p of the converter being $k \cdot p$ ± 1 on the a.c. side and $k \cdot p$ on the d.c. side, where k is an integer. By using converters with a high pulse number, it is theoretically possible to eliminate the lower order harmonics of higher amplitude.

B2. General

Service conditions and performance requirements of line traps associated with a.c./d.c. converter stations differ significantly from those normally associated with conventional a.c. power systems. HVDC converters produce harmonics covering a wide band of frequencies ranging from power frequency to frequencies of the order of a megahertz or more. At the lower end of the spectrum (power frequency to 50th harmonic), radiated signals can cause interference in adjacent telephone circuits and measures have to be taken at the source to reduce this interference to acceptable levels.

Interference can also be produced in power line carrier installations in the range 20 kHz to 500 kHz which may necessitate a judicious choice of carrier frequencies.

Interference in the radio and television bands is not usually a problem because of system attenuation.

Operating experience is limited at present and it is possible that undetected problems may arise in the future.

B3. Characteristics of line traps used in d.c. power stations

The application of line traps to a.c. power systems and how they respond to such application is fully described elsewhere in this document. However, the following considerations also have to be taken into account when line traps are used in d.c. power systems:

a) Because of a different current distribution within the main coil, a line trap designed for use on an a.c. system may have to be derated when used on a d.c. system. This applies mainly to multi-layer coils as distinct from single layer coils.

b) The thermal and mechanical withstand requirements are not so onerous due to lower fault levels.

c) The presence of harmonics has to be taken into account in evaluating temperature rises because of the exaggerated skin effects produced by high frequency currents.

d) Corona and RIV will be different and new guidelines have to be established.

B4. Use of line traps in a.c./d.c. converter stations

Line traps used in conjunction with a converter station may be installed on either the a.c. or d.c. side of the station or both. They may be used for blocking purposes or as part of radio interference (RI) filters to suppress the high frequency noise generated by the converters. In this latter capacity, they may also be required to perform the dual function of suppressing interference and, in conjunction with shunt capacitors in a π-configuration, of providing a means of injecting and receiving carrier frequency signals into and from the associated power system.

B5. RI filter application

The configuration of a typical RI filter is that of a π-network with a line trap forming the series arm with capacitors on each side acting as the legs of the π. To achieve maximum effect, it is usual for the filter to be connected as near the converter as possible.

Since the line trap cannot be considered in isolation in such a situation, its requirements are likely to be more stringent than in conventional applications. It may, for example, have to exhibit a high resistive component over a bandwidth of a megahertz or more which, in turn, would necessitate a higher rated inductance than usual and large values of capacitance and resistance in the tuning device. It is likely therefore that the combination of the line trap and associated capacitors used in this way will impose special demands on the carrier-frequency performance of the line trap.

B6. Insulation co-ordination

A.C. side:

The insulation co-ordination of a conventional line trap as used in a.c. systems is described elsewhere in this document. The short-time current can be of the order of 30 times the rated continuous a.c. current. The ratings of the protective device are calculated accordingly in relation to the maximum voltage drop across the main coil.

However, where there is a possibility of resonances occurring when used as part of an RI filter because of the presence of high frequency currents, it is necessary for such resonances and/or currents to be taken into account for insulation co-ordination purposes.

D.C. side:

Service conditions here are considerably different from those which apply on the a.c. side. For example, the short-time current is in the order of 2 to 5 times the continuous rated current.

This obviously has an effect on the thermal and mechanical requirements of the line trap. Also, the presence of harmonics has to be taken into account in calculating the voltage drop which occurs across the line trap under such conditions.

Generally speaking, the resistive voltage drop during short-time current conditions does not represent a critical operating condition. The maximum voltage drop is determined mainly by the rate of change of current with the time, i.e. di/dt, which, in turn, is dependent on the presence of smoothing reactors and on system parameters, including those of the converter station itself. To ensure proper insulation co-ordination, a "system-determined" di/dt approach is necessary.

Such an approach requires an analysis of transient behaviour and a knowledge of the overvoltages which are likely to occur in order for the maximum overvoltage across the line trap terminals and the rating of the protective device and hence that of the tuning device, to be determined.

B7. Current harmonics

While current harmonics (odd on the a.c. side and even on the d.c. side) are usually significantly attenuated by specially designed filters, their effects may still be evident in the type of RI filter previously described.

For this reason, it is necessary to ensure that a careful analysis is made of the potential presence of harmonics when a line trap is to be used in this manner.

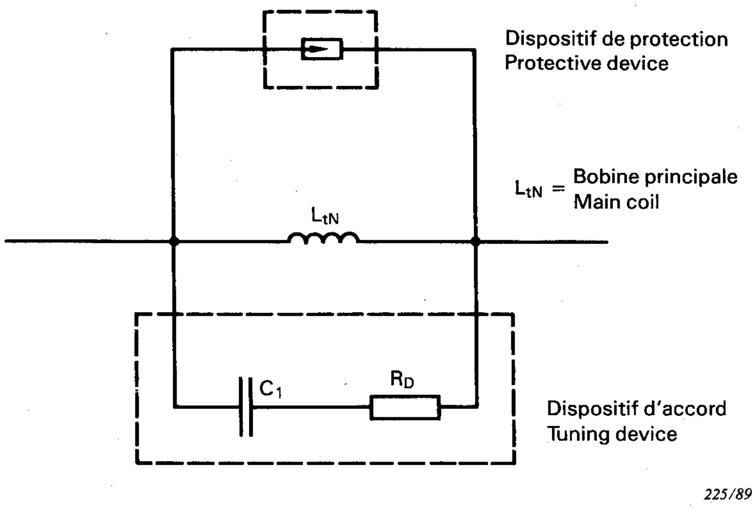


Fig. 1a. - Schéma d'un circuit-bouchon à fréquence unique d'accord.
Circuit diagram of a single frequency-tuned line trap.

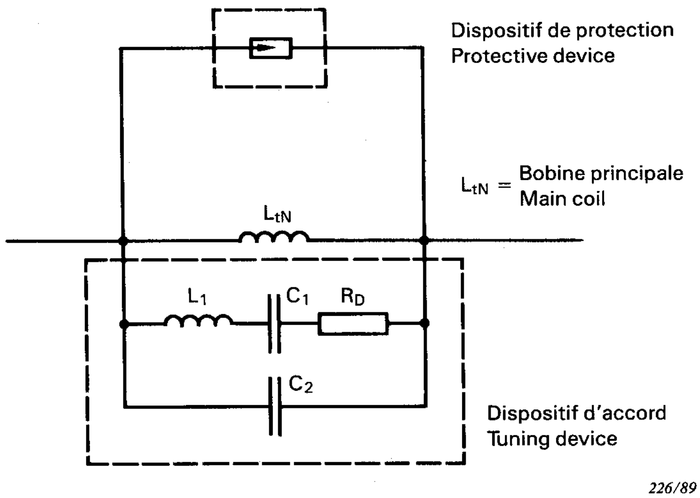


Fig. 1b. - Schéma d'un circuit-bouchon à bande accordée.
Circuit diagram of a band-tuned line trap.

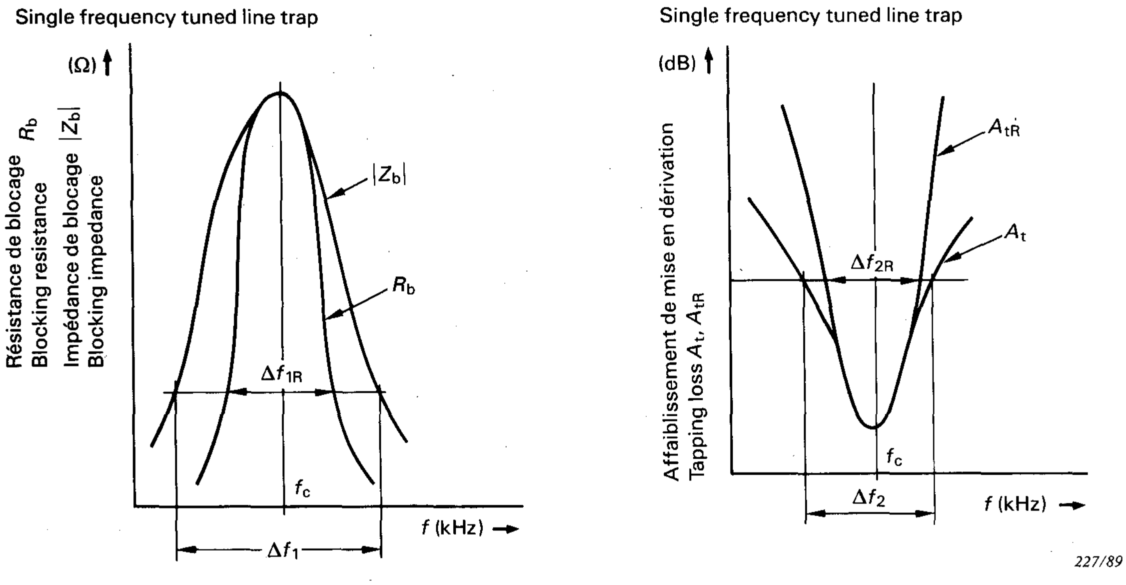


Fig. 2a. -

Definition of the bandwidth of a single frequency-tuned line trap.

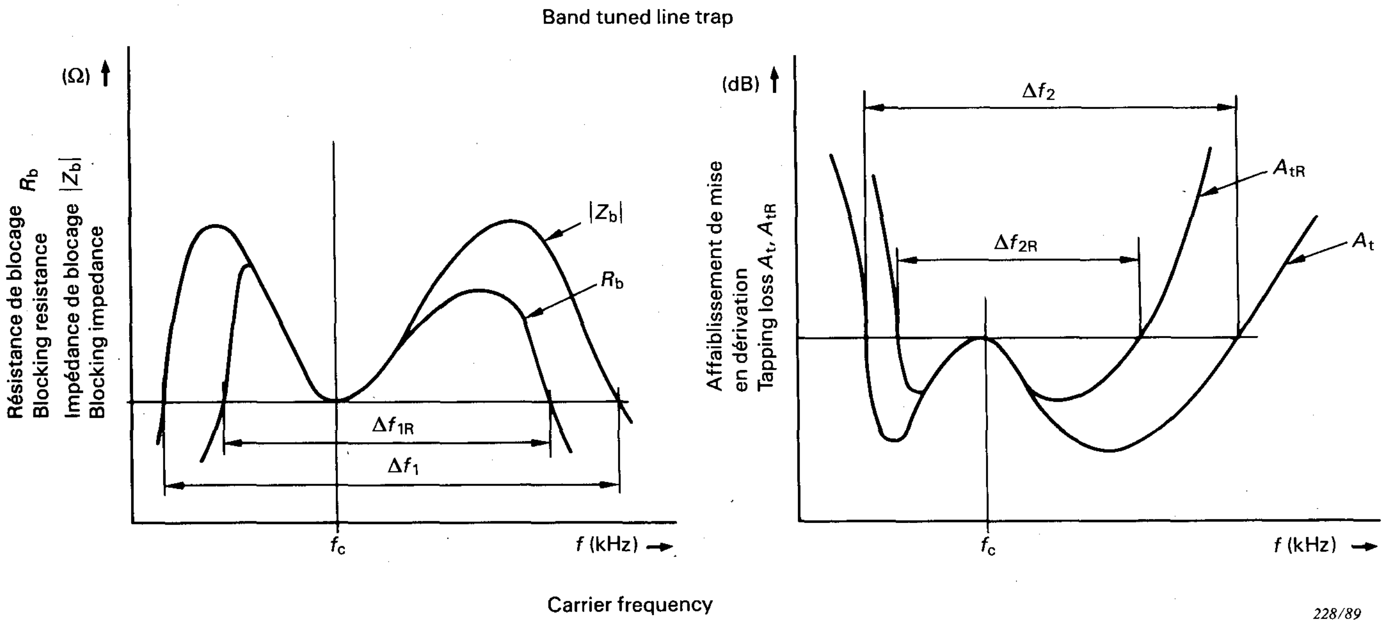


Fig. 2b. -

Definition of the bandwidth of a band-tuned line trap.

Note.- $\Delta f_{1R} = \Delta f_{2R}$ mais but $\Delta f_1 \neq \Delta f_2$.

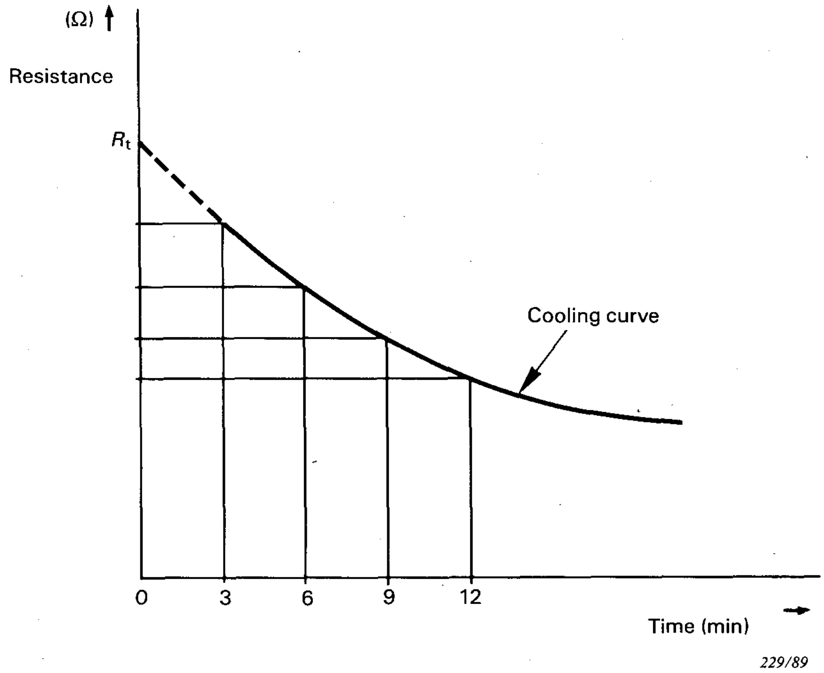


Fig. 3. -

Method for determining the resistance of the main coil, at completion of temperature rise test.

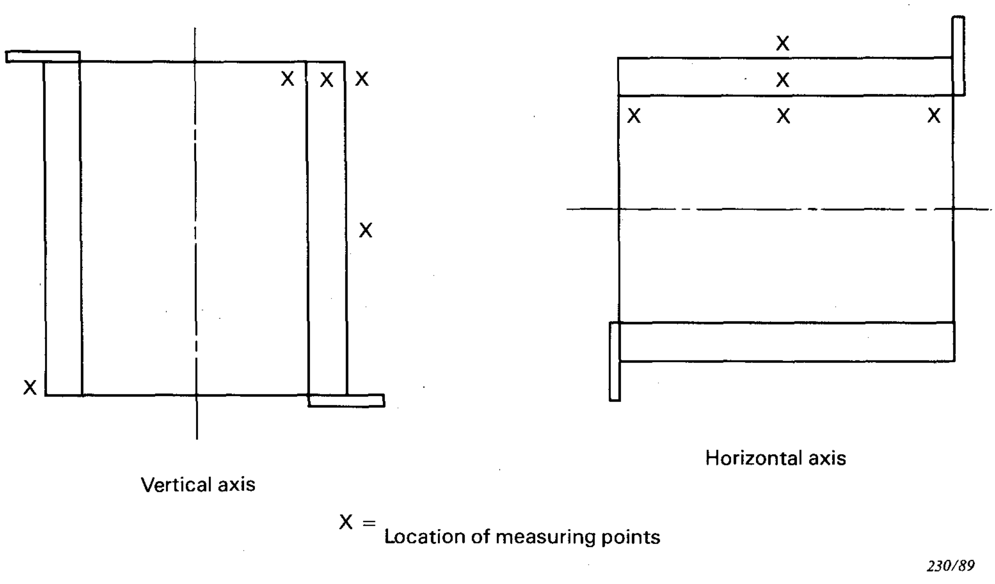
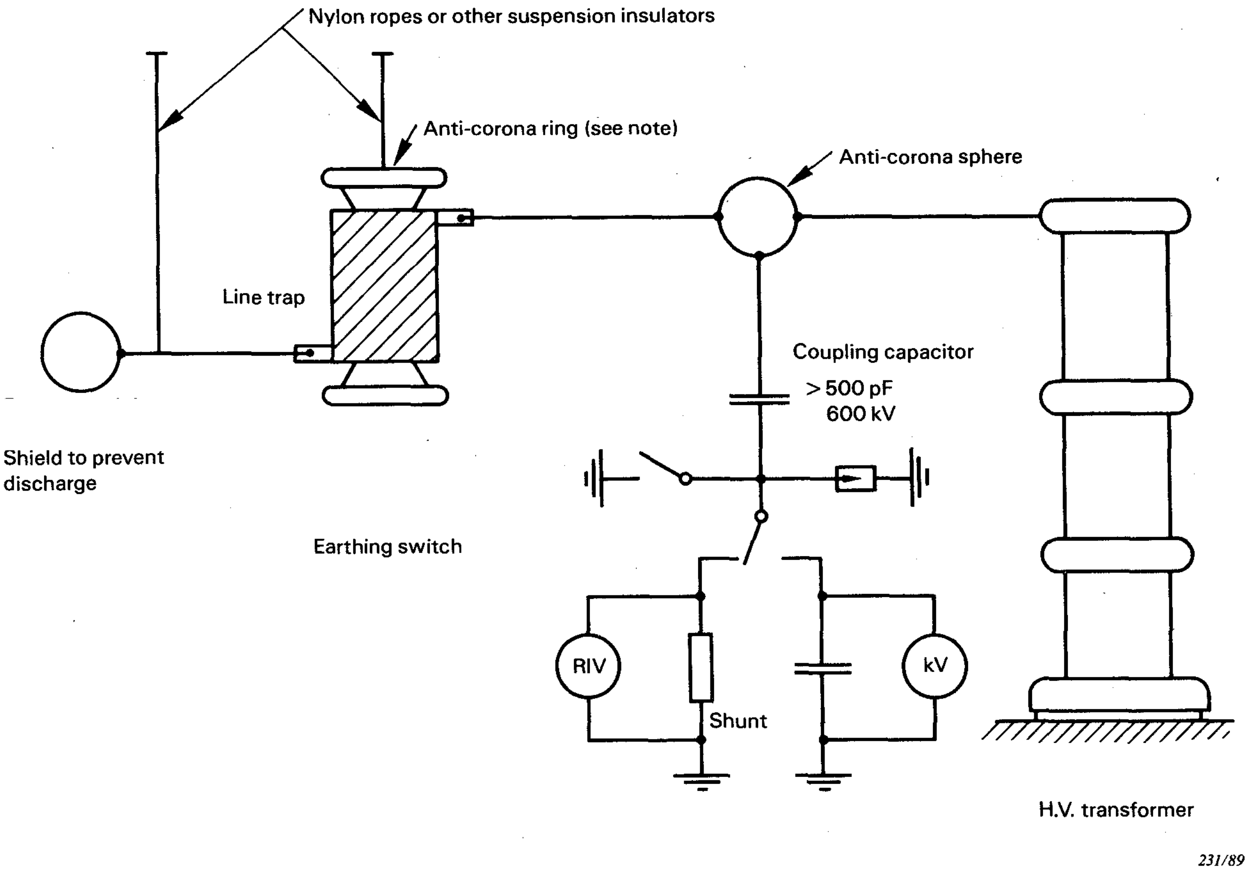


Fig. 4.

Location of measuring points in main coil to determine the temperature at the hot spot.

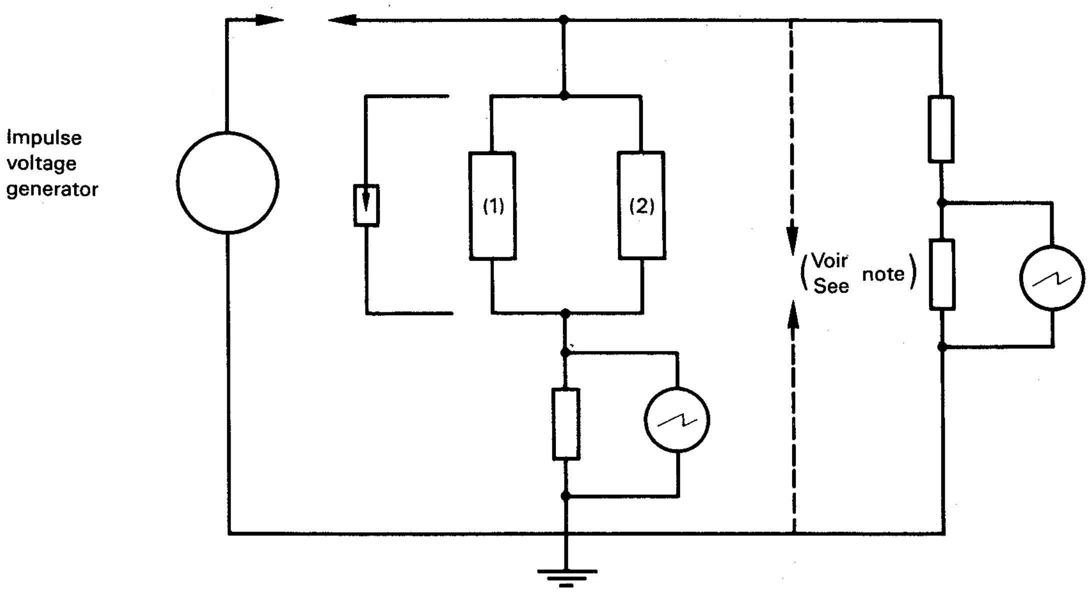


Note.-

Anti-corona rings are only to be used if they are required in service.

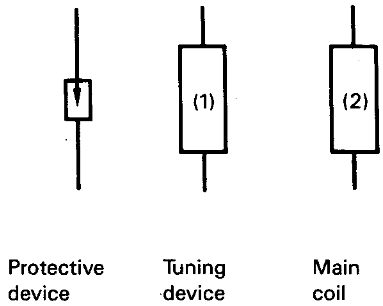
Fig. 5. -

Method of installation for determining the radio influence voltage RIV of a line trap.



Note.-

The chopping gap is included for the chopped impulse test only.



232/89

Fig. 6.

Measuring circuit for the impulse voltage test.

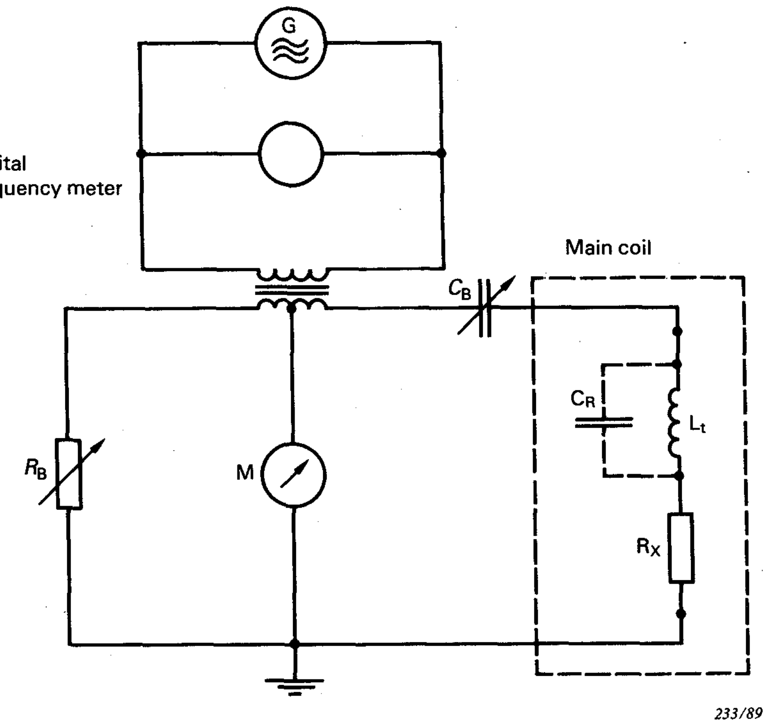


Fig. 7.

Measuring circuit for the determination of the true inductance of the main coil.

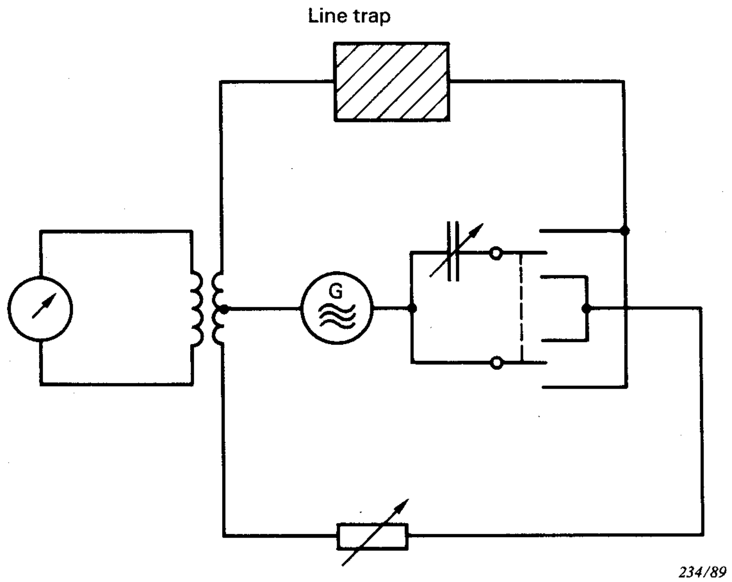


Fig. 8.

Measuring circuit for the determination of the blocking impedance.

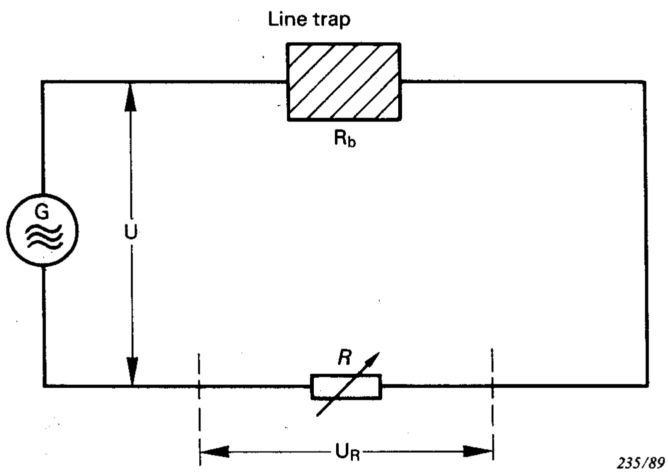


Fig. 9.

Measuring circuit for the determination of the blocking resistance at the tuning frequency in the case of line traps utilising simple resonance.

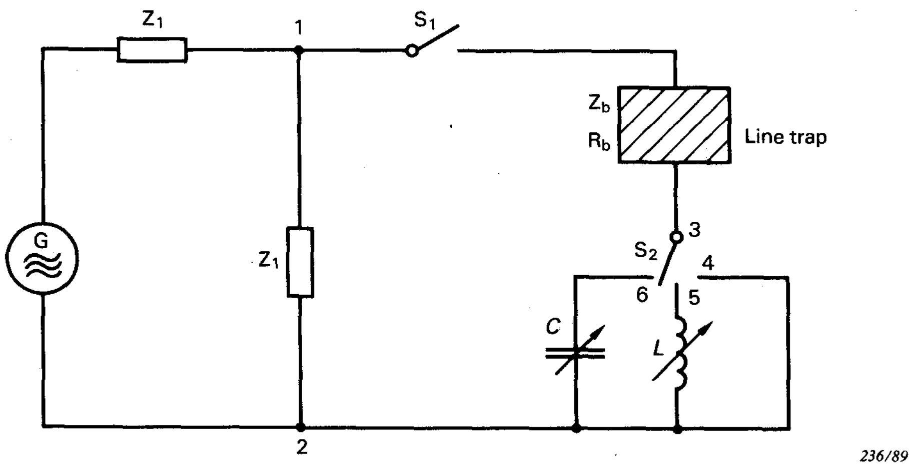
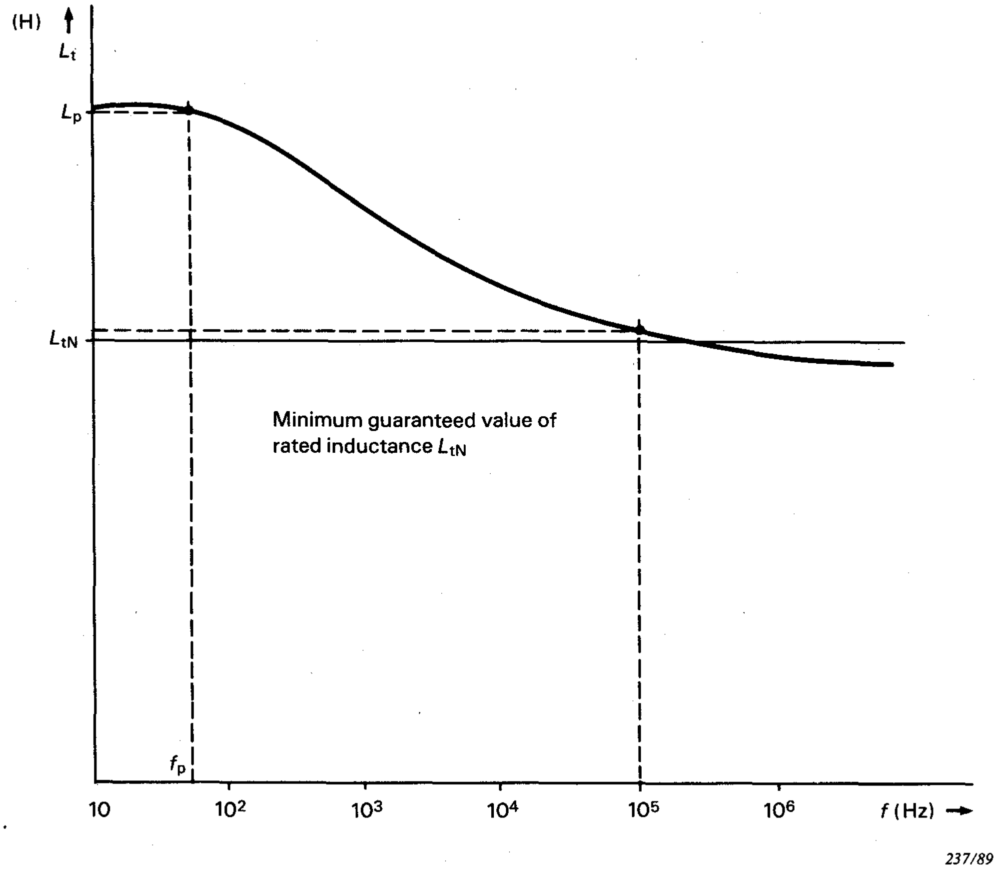


Fig. 10. -

Measuring circuit for the determination of tapping loss.



L_t = True inductance

L_p = Power frequency inductance

L_{tN} = Rated inductance

f_p = Power frequency

Note.-

The difference between power frequency inductance and rated inductance depends on the design of the main coil. No tolerance is specified for power frequency inductance.

Fig. 11. -

Frequency dependence of the true inductance of the main coil.

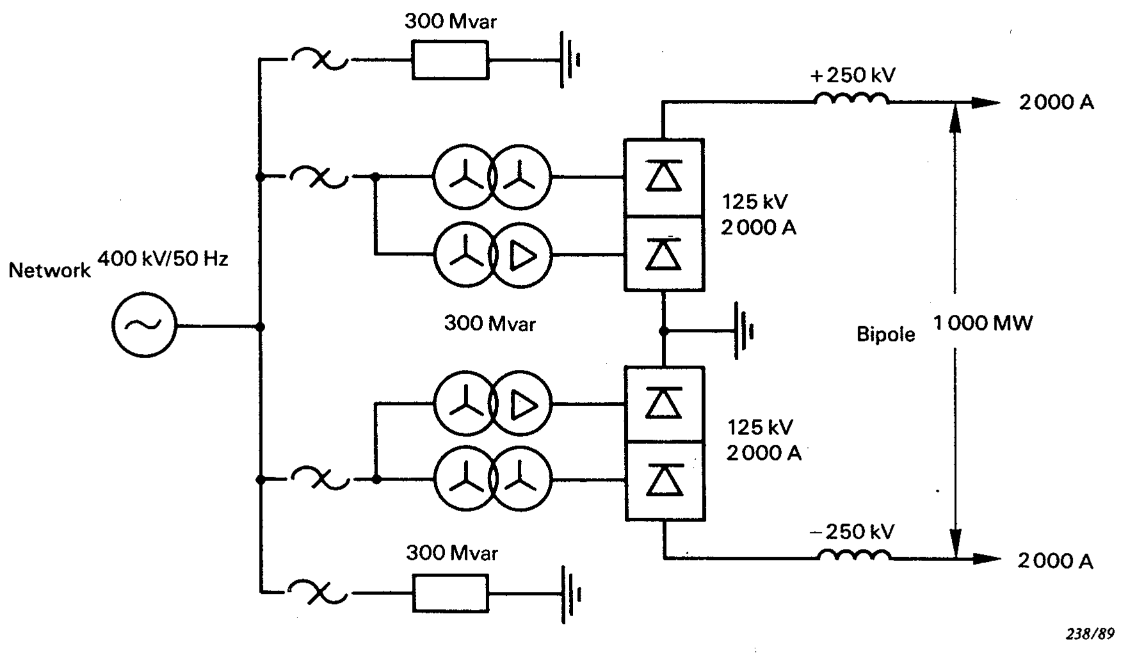


Fig. 12.

Typical converter station.

Amendment 1

Line traps for a.c. power systems

INTRODUCTION

In general, line traps have proven to be very reliable components of power line carrier systems. However, some line trap field problems associated with tuning devices were reported to technical committee 57. This is particularly the case when disconnectors near to line traps are frequently operated to switch unloaded lines on or off. It appears that transient overvoltages created by disconnector switching may be hazardous to the tuning capacitors of line traps even if the design requirements documented in IEC 60353 are fulfilled.

Research in recent years based on testing, was carried out and showed that the breakdown strength of capacitor dielectric material is a function of the material properties and the nature and the duration of the applied dielectric stresses e.g. waveshapes, multiple unipolar and multiple bipolar impulses.

This amendment will address the issue of the transient overvoltages seen by line traps, specifically those related to disconnector operations. Focus is on the consequences as related to the design of the tuning devices.

The tuning elements, other than the capacitors, are usually protected by spark gaps and thus the transient overvoltages are critical for the capacitors only. The capability of the tuning capacitors to withstand the stresses imposed by switching operations should be proved by adequate voltage endurance tests. Therefore the title and the scope of this annex was agreed to be: Dielectric qualification of tuning device capacitors.

Page 69

Add, after appendix B, the following new annex C:

Annex C
(normative)

Dielectric qualification of tuning device capacitors

C.1 General

C.1.1 Scope

Line traps may be designed with or without a tuning device. A critical condition for the application of line traps designed with a tuning device is the high reliability of the tuning device when exposed to dielectric stresses due to lightning strokes, circuit breaker operations and disconnector switching operations.

The basis of the requirements for the dielectric strength of the tuning device is the protective level of the line trap's surge arrester. The voltage withstand levels of the tuning device's capacitor units shall be coordinated, on a worst case basis, for either single unipolar voltage impulses (related to lightning strokes) or repetitive bipolar voltage impulses (related to disconnector switching operations) with the arrester's protective level.

The protective level is defined for the selected metal-oxide (MO) arrester by the residual voltage U_{P1} based on an arrester surge current of 20 kA peak and a waveshape of 8/20 µs.

In this annex, the dielectric requirements for the tuning device are based only on gapless MO arresters, which provide a protective level with negligible dependency on the surge waveshape.

For line traps with tuning devices protected by surge arresters with series gaps the time delay of the breakdown voltage of the spark gaps shall be taken into consideration.

NOTE The time delay of the breakdown voltage of surge arresters with series gaps is a function of the front-of-wave rate of rise of the impulse voltage. Thus, the protective level for the system is determined by the breakdown voltage of the spark gaps.

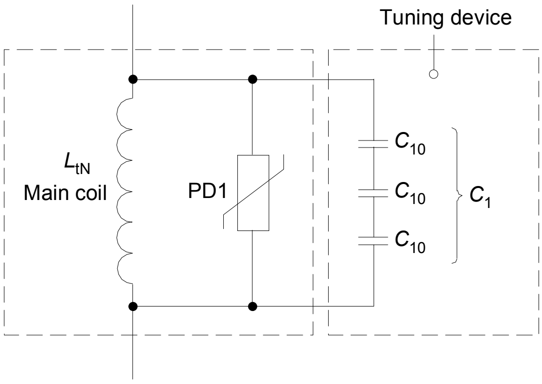
This annex refers in total to four tuning circuits which are predominantly in use.

These circuits are:

- single frequency tuning, figure C.1,
- double frequency tuning, figure C.2,
- damped single frequency tuning, figure C.3 and
- wide band tuning, figure C.4.

The inductor and resistor components of a tuning device are usually protected by an auxiliary spark gap and voltage endurance is therefore not an issue.

This annex only covers the voltage endurance qualification of tuning device capacitor elements. This is a component qualification test only and is not a tuning device type test.

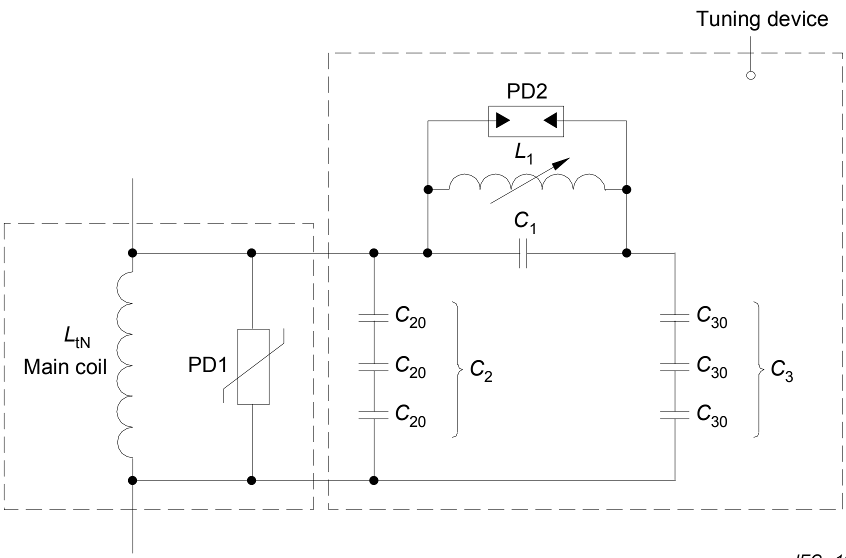


$$C_1 = \frac{C_{10}}{n_1}$$

n_1 = number of capacitor elements in series

IEC 1083/02

Figure C.1 – Circuit diagram of an undamped single frequency tuned line trap



$$C_1 = \frac{C_{10}}{n_1}$$

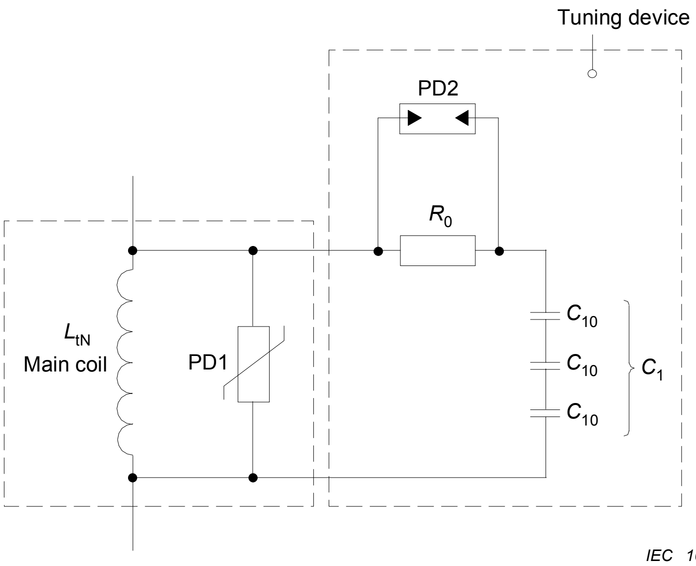
$$C_2 = \frac{C_{20}}{n_2}$$

$$C_3 = \frac{C_{30}}{n_3}$$

n = number of capacitor elements in series

IEC 1084/02

Figure C.2 – Circuit diagram of an undamped double frequency tuned line trap

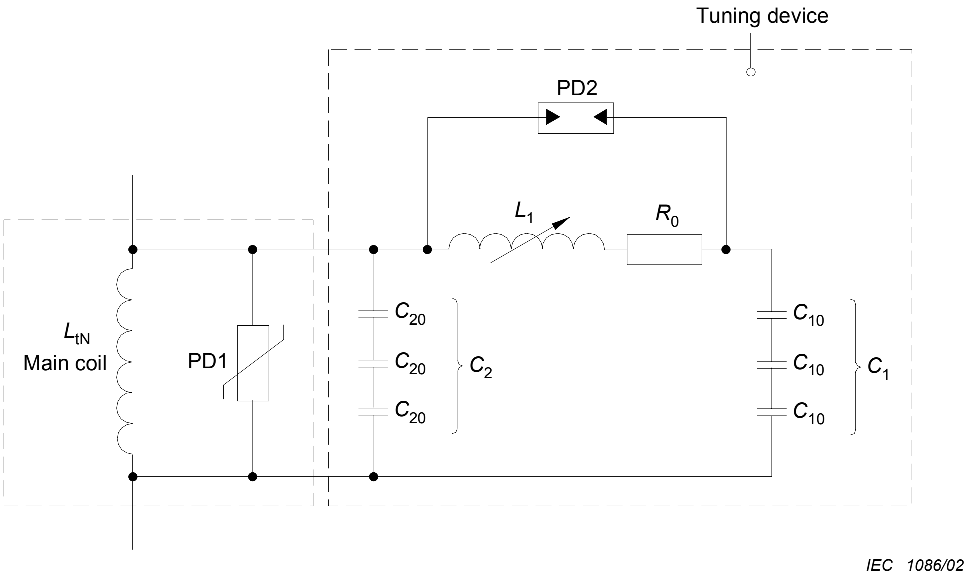


$$C_1 = \frac{C_{10}}{n_1}$$

n = number of capacitor elements in series

IEC 1085/02

Figure C.3 – Circuit diagram of a damped single frequency tuned line trap



$$C_1 = \frac{C_{10}}{n_1}$$

$$C_2 = \frac{C_{20}}{n_2}$$

n = number of capacitor elements in series

Figure C.4 – Circuit diagram of a wide band tuned line trap

C.1.2 Reference documents

IEC 60099-4:1991, *Surge arresters – Part 4: Metal-oxide surge arresters without gaps for a.c. systems*

C.2 Definitions

For the purposes of this annex, the following terms and definitions apply.

C.2.1
protective device PD1
this is a metal-oxide (MO) surge arrester and is the main protective device for the line trap

C.2.2
residual voltage U_{P1}
the voltage that appears between the terminals of the metal-oxide surge arrester PD1 during the passage of discharge current of waveshape 8/20 µs and peak current of 20 kA

C.2.3
spark-over voltage U_{P2}
the breakdown voltage of the protective device PD2 under transient conditions

C.2.4
spark-over voltage (peak value) U_{P20}
the power frequency spark-over voltage of the protective device PD2

C.2.5
individual capacitor elements
the capacitor elements C_{10}, C_{20}, C_{30}…which are connected in series to form the capacitor units C_1, C_2, C_3….. The capacitor elements in each string have the same nominal capacitance value

C.2.6
the number of capacitor elements C_{01}, C_{02}, C_{03}….. connected in series
n_1, n_2, n_3…

C.2.7
protective device PD2
protects the components L_1 plus C_1, R_0 and L_1 plus R_0 at the spark-over voltage U_{P2}

C.2.8
tuning device
a selected tuning circuit to achieve specified high frequency blocking characteristics

C.2.9
tuning inductor L_1
the inductive component in the tuning device used in conjunction with the capacitors to achieve a desired frequency response

C.2.10
resistor R_0
a resistor to provide damping and to meet resistive blocking requirements

C.2.11
safety factors, Sf_1, Sf_2, Sf_3, Sf_4
factors of safety applied to the tuning capacitor units for various voltage requirements

C.2.12
test voltage levels U_1, U_2, U_{BIL}, U_{BP}
Withstand voltage values used in the testing of capacitor units

C.3 Service conditions

Line traps, including tuning devices, are exposed to in-service transient dielectric stresses generated by lightning strokes, circuit breaker operations and disconnector switching operations. As a consequence the tuning device capacitor elements are exposed to both unipolar impulses, which are predominantly the result of lightning strokes and circuit breaker operations, and also to repetitive bipolar impulses, which are generated by the operation of nearby disconnectors.

C.4 Requirements

C.4.1 Metal-oxide surge arresters (PD1)

PD1 should meet the requirements of IEC 60099-4.

The surge arrester self capacitance variation over the PLC frequency range and in-service operating temperature should not compromise the high frequency blocking performance of the line trap; the specified blocking characteristic shall be met.

C.4.2 Protective device (PD2)

PD2 should be a spark gap due to its inherent performance characteristics.

PD2 shall not operate under steady state and short circuit conditions in order not to influence the power line carrier function of the line trap.

The self capacitance of PD2 should be as low as possible and is typically on the order of 5 picofarads.

The long term stability of the protection device is a requirement. The spark-over voltage of PD2 shall be maintained with the design limits for a minimum of 10^5 bipolar impulses (see note in C.5.2).

The spark-over voltage U_{P2} shall be coordinated with the dielectric strength of the resistor R_0 and inductor L_1.

C.4.3 Tuning capacitor units C_1, C_2, C_3...

In the design of the tuning capacitor units consisting of individual capacitor elements C_{10}, C_{20}, C_{30}... allowance shall be made for the capacitance tolerance. This is especially critical for the control of the voltage distribution along the series connected capacitors.

The values of C_1, C_2, and C_3... are established by $C_1 = \frac{C_{10}}{n_1}$; $C_2 = \frac{C_{20}}{n_2}$; $C_3 = \frac{C_{30}}{n_3}$

The tuning capacitor units shall be designed with a certain safety factor *Sf*, to withstand the following test voltage requirements:

a) $Sf_1 : U_1 \geq Sf_1 \cdot 2\pi \cdot f_{pN} \cdot L_p \cdot I_N$ steady state a.c. condition

b) $Sf_2 : U_2 \geq Sf_2 \cdot 2\pi \cdot f_{pN} \cdot L_p \cdot I_{kN}$ dynamic a.c. condition

c) $Sf_3 : U_{BIL} \geq Sf_3 \cdot U_{p1}$ ± standard lightning impulses (see 19.3.1)

d) $Sf_4 : U_{BP} = n \cdot U_{BPD} \geq Sf_4 \cdot U_{p1}$ multiple bipolar impulses

The tangent δ of the capacitor elements is typically in the order of $1 \cdot 10^{-3}$ to provide both adequate dielectric and high (PLC) frequency performance.

The partial discharge level of a individual capacitor element C_{10}, C_{20}, C_{30}... at the a.c. voltage $U_1 = Sf_1 \cdot 2\pi \cdot f_N \cdot L_P \cdot I_N$ divided by the number "*n*" of capacitor elements in series shall be less than 5 pC.

The bipolar withstand voltage U_{BPD} of an individual capacitor element C_{10}, C_{20}, C_{30}... at 10^5 pulses is used for design purposes and shall be equal to or higher than (including safety factors Sf_4) the residual voltage U_{P1} of the surge arrester divided by the number "*n*" of series connected capacitor elements C_{01}, C_{02}, C_{03}...

An example of an endurance graph for a capacitor element is shown in figure C.5.

C.5 Test

C.5.1 Classification of tests

The only test required for the dielectric qualification of tuning device capacitors is a voltage endurance test. This is a type test carried out on capacitor elements which are representative of the range of capacitors used in a tuning device.

C.5.2 Voltage endurance test requirements

The voltage endurance test is performed on capacitor elements of a particular design and manufacturer. Once the capacitor elements are qualified, there is no need to repeat the endurance test program for various production tuning capacitor units. The results of the endurance test program on the capacitor elements are to be documented in a suitable test report.

Requirements for bipolar pulses:

a) Repetition rate: 50 Hz/60 Hz ⇒ 20 ms/16,7 ms

b) Front-of-rise $\frac{\Delta U_{bi}}{\Delta t} \geq 40 \frac{\text{kV}}{\mu\text{s}} = 40 \frac{\text{V}}{\text{ns}}$

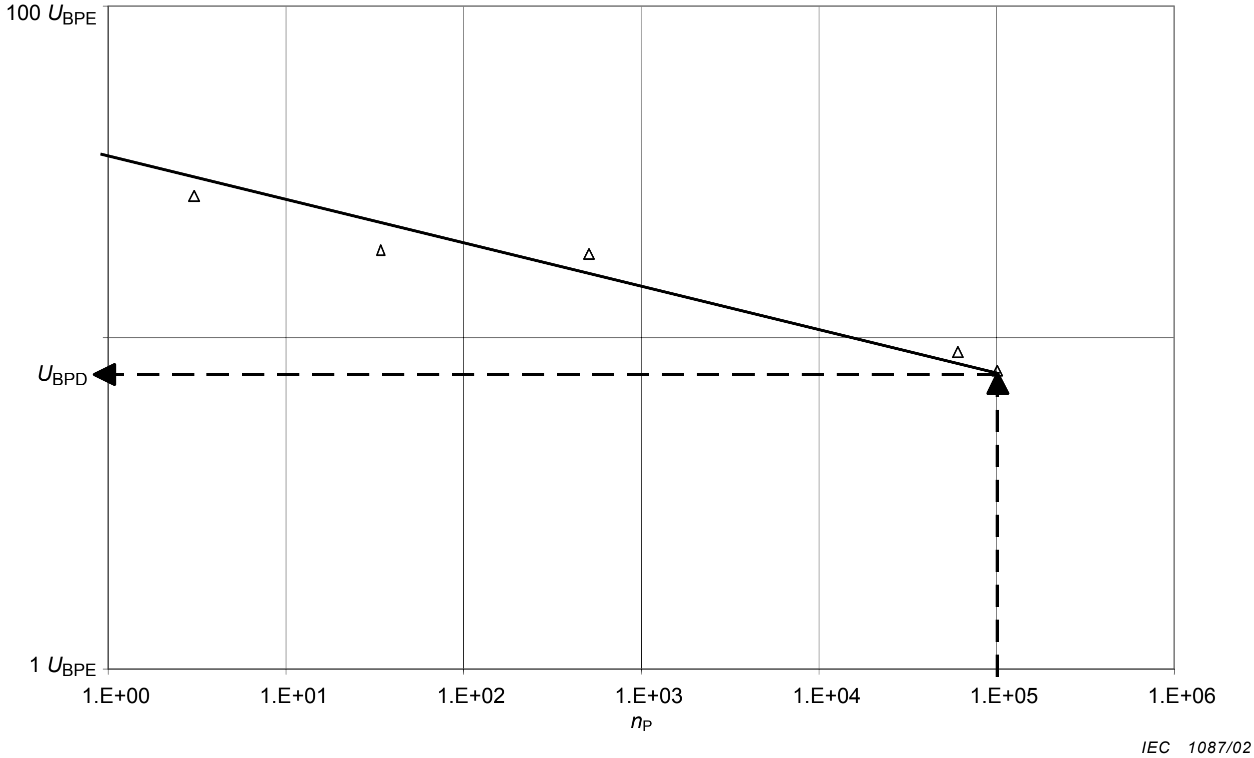
c) Peak voltage of the bipolar pulses is defined between zero and the peak value of the waveshape.

d) A single bipolar pulse consists of a positive and negative peak.

The voltage endurance test shall be carried out at a minimum of four bipolar voltage test levels. An example of the schematic diagram of a test circuit can be found in schematic diagram in figure C.6.

From this data, a voltage endurance curve can be traced using a double log scale resulting in a straight line. See figure C.5 below for an example of a typical voltage endurance life curve of capacitor elements.

NOTE The objective of the voltage endurance test is to determine the peak value of the bipolar impulse voltage, for which the capacitor elements under test will survive 10^5 bipolar pulses. This number of applied bipolar impulses is equivalent to an in-service voltage transient exposure resulting from one isolator operation per day for 30 years, assuming that each switching transient may consist of up to 10 restrikes per operation.



Key

U_{BPD} bipolar withstand voltage (peak value) of a capacitor element to be used for the design of the capacitor units

Δ Lifetime at different withstand voltage test levels

Figure C.5 – Bipolar withstand voltage U_{BPE} of a capacitor element as a function of number impulses n_P

The life time (number of bipolar pulses) at the four breakdown voltage levels shown on the graph are based on a statistically significant number of samples. A minimum of five test samples at each test level is required.

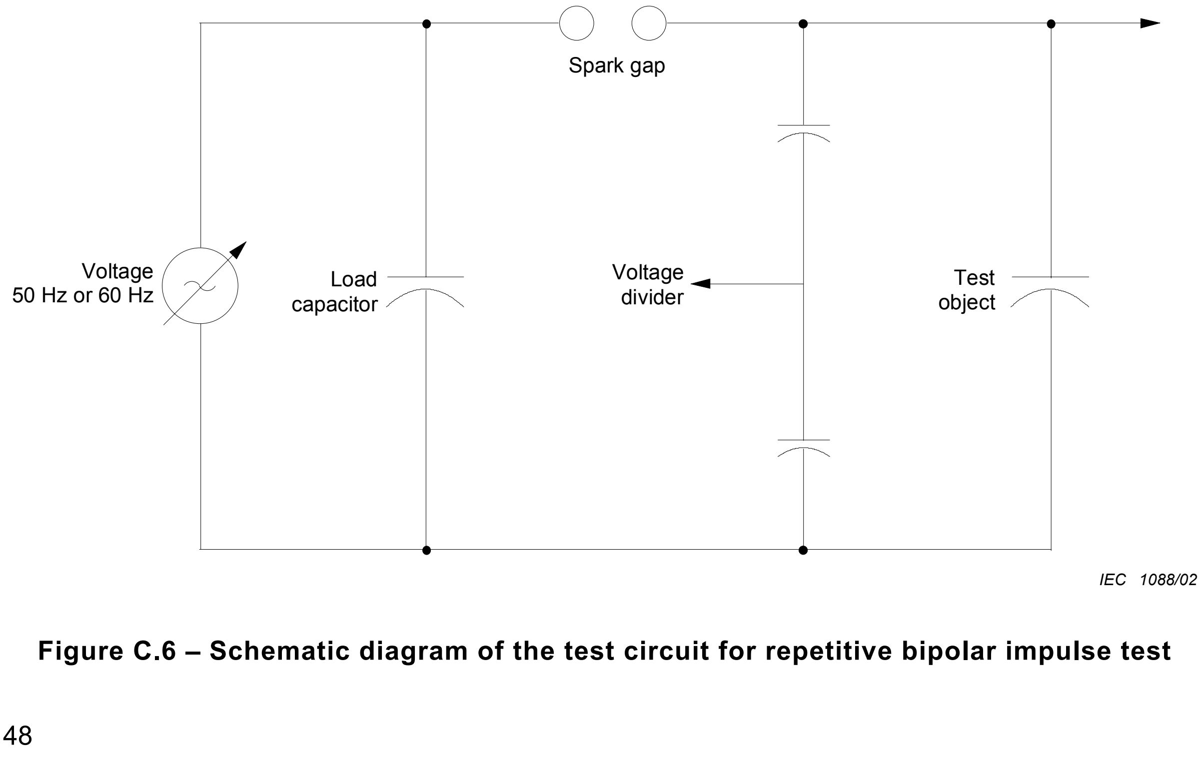


Figure C.6 – Schematic diagram of the test circuit for repetitive bipolar impulse test

C.6 Insulation coordination

C.6.1 Insulation coordination of the MO arrester residual voltage U_{P1} and the bipolar voltage U_{BP}

Insulation coordination is achieved by considering the MO arrester protective level U_{P1} compared to the withstand voltage level U_{BP} (peak) of the tuning device capacitor units under repetitive bipolar impulse test. A capacitor unit consists of "*n*" capacitor elements, each having the bipolar withstand voltage U_{BPD} (peak).

The relationship between U_{BP}, U_{BPD}, and U_{P1} is given in the formula below:

$$U_{BP} = n \cdot U_{BPD} \geq Sf_4 \cdot U_{P1}$$

C.6.2 Examples of insulation coordination

EXAMPLE 1. Capacitor type A

a) Withstand voltage of the capacitor element type A

at 1,2/50 µs (as per IEC 60353) ≥ 15 kV

at 10^5 bipolar pulses ≥ 8 kV

b) Protective level of the MO surge arrester

at 1,2/50 µs impulse voltage
at 20 kA 8/20 µs current surge } ≤ 20 kV

Number (*n*) of capacitor elements in series:

$n \geq 20$ kV/8 kV $n = 3$ capacitors in series

In this case, the safety factor is

$$Sf_4 = \frac{3{,}0}{2{,}5} = 1{,}2$$

EXAMPLE 2. Capacitor type B

a) Withstand voltage of the capacitor element type B

at 1,2/50 µs (as per IEC 60353) ≥ 25 kV

at 10^5 bipolar impulses ≥ 4 kV

b) Protective level of the MO surge arrester

at 1,2/50 µs impulse voltage
at 20 kA 8/20 µs current surge } ≤ 18 kV

Number (*n*) of capacitor elements in series:

$n \geq 18$ kV/4 kV $n = 5$ capacitors in series

In this case, the safety factor is:

$$Sf_4 = \frac{5}{4{,}5} = 1{,}1$$

C.6 Insulation coordination

C.6.1 Insulation coordination of the MO arrester residual voltage U_{P1} and the bipolar voltage U_{BP}

Insulation coordination is achieved by considering the MO arrester protective level U_{P1} compared to the withstand voltage level U_{BP} (peak) of the tuning device capacitor units under repetitive bipolar impulse test. A capacitor unit consists of "*n*" capacitor elements, each having the bipolar withstand voltage U_{BPD} (peak).

The relationship between U_{BP}, U_{BPD}, and U_{P1} is given in the formula below:

$$U_{BP} = n \cdot U_{BPD} \geq Sf_4 \cdot U_{P1}$$

C.6.2 Examples of insulation coordination

EXAMPLE 1. Capacitor type A

a) Withstand voltage of the capacitor element type A
   at 1,2/50 µs (as per IEC 60353) ≥ 15 kV
   at 10^5 bipolar pulses ≥ 8 kV

b) Protective level of the MO surge arrester
   at 1,2/50 µs impulse voltage
   at 20 kA 8/20 µs current surge
   } ≤ 20 kV

   Number (*n*) of capacitor elements in series:
   $n \geq 20$ kV/8 kV $n = 3$ capacitors in series
   In this case, the safety factor is

$$Sf_4 = \frac{3,0}{2,5} = 1,2$$

EXAMPLE 2. Capacitor type B

a) Withstand voltage of the capacitor element type B
   at 1,2/50 µs (as per IEC 60353) ≥ 25 kV
   at 10^5 bipolar impulses ≥ 4 kV

b) Protective level of the MO surge arrester
   at 1,2/50 µs impulse voltage
   at 20 kA 8/20 µs current surge
   } ≤ 18 kV

   Number (*n*) of capacitor elements in series:
   $n \geq 18$ kV/4 kV $n = 5$ capacitors in series
   In this case, the safety factor is:

$$Sf_4 = \frac{5}{4,5} = 1,1$$

Applying the appropriate design criteria, the required number of series capacitor elements for either the lightning impulse voltage stress or the multiple bipolar stress is shown in the table below.

Example	**Lightning stress**	**Multiple bipolar stress**
A	$n \geq 20$ kV / 15 kV; $n = 2$	$n = 3$
B	$n \geq 18$ kV / 25 kV; $n = 1$	$n = 5$

Therefore, the worse case design criteria shall be based on the multiple bipolar impulse stress.

(*Continued from second cover*)

International Standard	*Title*
IEC 60129 : 1975	Alternating current disconnectors (isolators) and earthing switches
IEC 60383 : 1976	Tests on insulators of ceramic material or glass for overhead lines with a nominal voltage greater than 1 000 V
IEC 60518 :1975	Dimensional standardization of terminals for high-voltage switchgear and controlgear

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 2022 'Rules for rounding off numerical values (*second revision*)'. The number of significant places retained in the rounded off value should be same as that of the specified value in this standard.

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Amendments Issued Since Publication

Amend No.	Date of Issue	Text Affected

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