Part of Energy Queensland

Substation Standard

Standard for Selection of Surge Arresters

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Abstract: The aim of this document is to establish procedures for selecting gapless metal-oxide surge arresters connected between phase and earth for alternating current systems with the objective of providing protection for electrical plant against voltage surges due to lightning and circuit switching.

Keywords: Surge arrester, protection, standard, substation

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			Section 7.7.1 Arrester classes changed to reflect the latest changes to IEC 60099-4 Sections 8 and 9 regarding insulation coordination removed. Refer to STNW3034. Annex D Added including updated Surge Arrester Selection Guide (EQL SS-1-8.3 Selection of Surge Arresters)

Document approvals

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1 Overview

1.1 Purpose

This document defines methods, parameters and procedure in selecting gapless metal-oxide surge arrester connected between phase and earth for alternating current systems for the protection of electrical plant against voltage surges due to lightning and circuit switching.

This document does not cover specific aspects of the application of surge arresters and the required mechanical strength.

2 References

2.1 Ergon Energy controlled documents

Document number or location (if applicable)	Document name	Document type

2.2 Energex controlled documents

Document number or location (if applicable)	Document name	Document type

2.3 Other documents

Document number or location (if applicable)	Document name	Document type
AS 1307.2	Metal-oxide surge arresters without gaps for A.C. systems	Australian Standard
AS 4436	Guide for the selection of insulators in respect of polluted conditions	Australian Standard
IEC 60099-1	Surge Arresters – Part 1: Non-linear Resistor Type Gapped Surge Arresters for A.C. Systems	International Standard
IEC 60099-3	Surge Arresters – Part 3: Artificial Pollution Testing of Surge Arresters	International Standard
IEC 60099-4	Surge Arresters - Part 4: Metal-oxide Surge Arresters Without Gaps for A.C. Systems	International Standard
IEC 60099-5	Surge Arresters - Part 5: Selection and Application Recommendations	International Standard
IEC 60099-7	Surge Arresters - Part 7: Glossary of Terms and Definitions from IEC publications 60099-1, 4, 5	International Standard
IEEE Std C62.22-2009	IEEE Guide for Application of Metal-Oxide Surge Arresters for Alternating-	International Standard

Document number or location (if applicable)	Document name	Document type
	Current Systems	
ABB Buyer's Guide, Edition 5, 2003 - 2010	High Voltage Surge Arresters Buyer's Guide	Industrial Technical Publication
SESWG/A-2310 E Edition 2, 1995-2010	Application guidelines for station protection, ABB	Industrial Technical Publication

3 Legislation, regulations, rules, and codes

This document complies with the legislation in the following documents:

Legislation, regulations, rules, and codes
(Queensland Electrical Safety Act, 2002) (Queensland Government)
(Queensland Electrical Safety Regulation, 2013) (Queensland Government)
(Queensland Electricity Act, 1994) (Queensland Government)
(Queensland Electricity Regulation, 2006) (Queensland Government)
(Queensland Work Health and Safety Act, 2011) (Queensland Government)
(Queensland Work Health and Safety Regulation, 2011) (Queensland Government)
(National Electricity Rules, 2018) (AEMC)

4 Definitions, acronyms, and abbreviations

4.1 Definitions

For the purposes of this standard, the following definitions apply:

Term	Definition
Actual continuous operating voltage (U_{ca})	The maximum r.m.s power frequency voltage which is applied continuously (≥ 2 hours) between the arrester terminals.
Arrester or Surge Arrester (SA)	A protective device for limiting surge voltages on equipment by diverting surge current and returning the device to its original status. It is capable of repeating these functions as specified.
Arrester protective characteristic	A combination of its residual voltages for different current impulses. For good protection the arrester characteristic should lie well below the protected equipment insulation withstand characteristic at all points.
Coefficient of earthing (COE) or Coefficient of grounding (COG)	The ratio U_{LE}/U_{LL} (express as percentage) of the highest r.m.s line-to-ground power frequency voltage U_{LE} on a sound phase, at a selected location, during a fault to ground affecting one or more phases to the line-to-line power frequency voltage U_{LL} that would be obtained at the selected location with the fault removed. COE is equal to Earth fault factor multiplied by $100/\sqrt{3}$.
Continuous current	The current flowing through the arrester when energised at continuous operating

(I_c)	voltage.
Continuous operating voltage (U_c)	(Often abbreviated as COV or MCOV) is the designated permissible r.m.s value of power frequency voltage may be applied continuously between the arrester terminals. Thus $U_c > U_{ca}$.
Critical flashover voltage (CFO)	The amplitude of voltage of a given waveshape that, under specified conditions, causes flashover through the surrounding medium on 50% of the voltage applications (IEEE C62.22, 2009).
Discharge current	The impulse current which flows through the arrester.
Discharge voltage	Refer to Residual voltage.
Disruptive discharge	The sudden and large increase in current through an insulating medium due to the complete failure of the medium under electrical stress (IEEE C62.22, 2009).
Duty cycle voltage	Refer to Rated voltage.
Earth fault factor (ke)	At a selected location of a three-phase system is the ratio of the highest r.m.s phase-to-earth power frequency voltage on a sound phase during a fault to earth (affecting one or more phases at any point) to the r.m.s phase-to-earth power frequency voltage which would be obtained at the selected location with the fault removed. If ke ≤ 1.4 the system at that location is referred as effectively earthed, otherwise non-effectively earthed. In a system with a resonant earthed neutral or isolated neutral ke = 1.73.
Equipment insulation withstand characteristic	Is a general term for the equipment insulation withstand voltage and comprises: **Withstand level** — **Voltage waveshape** Chopped (steep) wave withstand level (CWW) Lightning impulse withstand level (LIWL or BIL) — 1.2/50 Switching impulse withstand level (SIWL) — 250/2500 Power frequency withstand level (PFWL) — 50 or 60 Hz sinusoidal
Impulse	A surge of unidirectional polarity.
Impulse (of current or voltage)	Impulse is a unidirectional wave, which rises rapidly to a maximum and falls, a little less rapidly, to zero. Its waveshape is expressed by two numbers (T1/T2). T1 refers to the virtual front time and T2 to the virtual time to half value of the tail; both expressed in microseconds. Some important current impulses are: **Impulse** — **Waveshape (T1/T2)** Steep current impulse — T1 = 1 µs — T2 ≤ 20 µs Lightning current impulse — T1 = 8 µs — T2 = 20 µs Switching current impulse — T1 ≥ 30 µs — T2 ≥ 60 µs High current impulse — T1 = 4 µs — T2 = 10 µs A special impulse is the rectangular current impulse, which is the shape of a rectangle. A common duration is 2000 µs.
Insulation co-ordination	The selection of the dielectric strength of equipment in relation to the voltages, which can appear on the system for which the equipment is intended and taking into account the service environment and the characteristics of the available protective

	devices.
Lightning current impulse	A 8/20 µs current impulse.
Lightning impulse protection level (LPL)	The LPL of an arrester is the residual voltage for the nominal discharge current.
Lightning impulse withstand voltage (LIWV) or Basic insulation level (BIL)	The electrical strength of insulation expressed in crest value of a standard lightning impulse under standard atmospheric conditions (IEEE C62.22, 2009).
Nominal discharge current (I_n)	The peak value of lightning current impulse which is used to classify an arrester.
Pressure relief capability	The ability of an arrester, in the event of its overloading due to any reason, to conduct the resulting system short circuit current through it without a violent explosion (IEEE C62.22, 2009). After the operation of the pressure relief, the arrester must be removed
Prior duty	In order to test if an arrester is capable of functioning during and after successive faults, prior duty testing is conducted where the thermal energy W_{th} is injected into the arrester over a nominated duration (typically 3 minutes) before residual voltage tests are conducted (IEC 60099-4, 2014). Residual voltages after application of prior duty are typically 5-10% lower than those without prior duty.
Protective margin	The protective ratio minus one and expressed as percentage.
Protective ratio	The ratio of the equipment insulation withstand level to the corresponding protection level of its arrester.
Rated voltage (U_r)	The maximum permissible r.m.s value of power frequency voltage between its terminals at which it is designed to operate correctly under temporary overvoltage conditions as established in the operating duty tests. **Note**: As per AS 1307.2 the arrester must withstand its rated voltage for at least 10 s after being both preheated to 60°C and subjected to a high energy injection as defined in the standard. Hence, the TOV capability for 10 s has to be minimum U_r. Continuous application of this voltage will damage the arrester.
Residual voltage (U_{res})	The peak value of voltage that appears between the terminals of an arrester during the passage of discharge current.
Surge impedance (Z)	The surge impedance of a conductor is a mathematical constant, approximately equal to the square root of the quotient of the inductance of the conductor and the capacitance between the conductor and ground (AS/NZS 4436, 1996).
Switching impulse withstand voltage (SIWV) or Basic switching insulation level (BSL)	The electrical strength of insulation expressed in crest value of a standard switching impulse (IEEE C62.22, 2009).
Temporary overvoltages (TOV)	Temporary overvoltages as differentiated from surge overvoltages, are oscillatory overvoltages of relatively long duration and which are undamped or only weakly damped.
Temporary	The TOV capability of the arrester expressed in multiple of U_r or U_c.

overvoltage withstand factor (T_r or T_c)	
Virtual front time of a current impulse (T1)	The time in microseconds equal to 1.25 multiplied by the time in microseconds for the current to increase from 10% to 90% of its peak value.

4.2 Acronyms and abbreviations

The following abbreviations and acronyms appear in this standard.

Term, abbreviation or acronym	Definition
CFO	Critical flashover voltage
COE/ COG	Coefficient of earthing/ coefficient of grounding
EQL	Energy Queensland Limited
I_c	Continuous current
I_n	Nominal discharge current
ke	Earth fault factor
LIWV/ BIL	Lightning impulse withstand voltage/ basic insulation level
LPL	Lightning impulse protection level
U_{res}	Residual voltage
SA	Surge arrester
SIWV/ BSL	Switching impulse withstand voltage/ Switching insulation level
TOV	Temporary overvoltage
T_r	Temporary overvoltage withstand factor
U_c	Continuous operating voltage
U_{ca}	Actual continuous operating voltage
U_r	Rated voltage
Z	Surge impedance

5 Background

Two broad categories of surge arresters have been used in the network:

1. Metal-oxide surge arresters (MOSA) consisting of highly non-linear stable zinc oxide (ZnO) value blocks.
2. Gap type arresters consisting of a series connection of a spark gap and a non-linear resistor made of silicon carbide (no longer purchased but exist on the network).

Metal oxide arresters fall into three broad design types, namely: gapless arresters, shunt-gapped arresters and series-gapped arresters. Gap-less arresters are purchased by Energy Queensland.

The principle of operation of the gapless SA could be briefly explained as follows. The volt-ampere characteristic exhibit a very non-linear behaviour that may be approximately by the relationship $I = kV^{\alpha}$. Alpha (α) values will normally vary from 10 to 50, depending on the metal-oxide formulation and current range being studied. Typically, at higher current values and wider ranges will yield lower values of α. For example, α may be 50 over a current range of 1-600 A and may average 26 over a wide range of 1-10 000 A. Figure 1 shows a typical voltage-current characteristic of a gapless arrester. In service there is a permanent current flow through the valve blocks. At the continuous operating voltage this current is small. As soon as the applied voltage exceeds 1.1 times the continuous rating there will be a significant increase in the current flow.

Additionally, the arrester discharge voltage is a function of the rate of rise of the current surge, with higher voltage occurring for faster rates of rise and vice versa. Typically, for the same current magnitude, the voltage occurring for a current cresting in 1 µs is 8-12% higher than occurring for a standard 8/20 µs lightning current wave. The voltage occurring for a current cresting in 45-60 µs is 2-4% lower than that for the 8/20 µs wave.

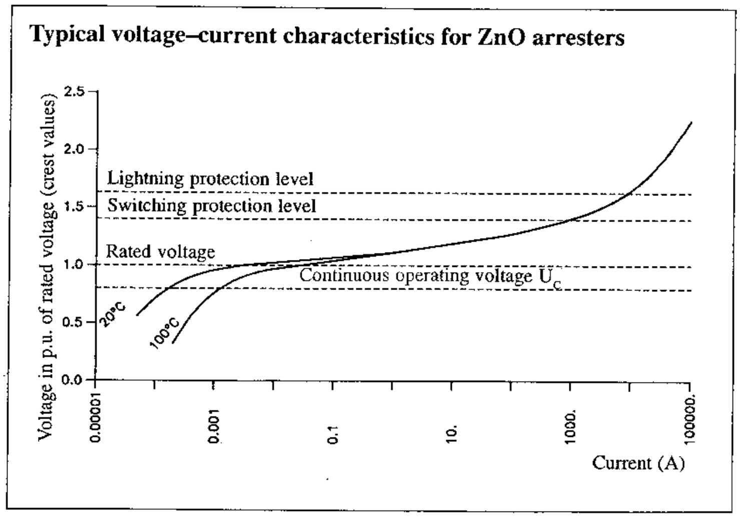


Figure 1: Typical voltage-current characteristic for ZnO arresters (IEEE C62.22, 2009). (Do not use for applications)

6 General procedure for selection of gapless surge arresters

The general procedure for the selection of arresters in relation to the insulation to be protected comprises in a series of steps, which are elaborated in subsequent clauses.

a. Select surge arrester ratings
b. Determine protective levels of arrester
c. Determine equipment insulation strength
d. Evaluate insulation coordination
e. In the event that (d) indicates that adequate protection cannot be achieved, evaluate alternatives, a re-evaluation may be required.

7 Selection of surge arrester ratings

Characteristics and performance of a SA are determined by the following parameters:

a. Continuous voltage (U_c)
b. Rated voltage (U_r)
c. Nominal discharge current (I_n)
d. Specific energy
e. Line discharge class
f. Pressure relief class (porcelain housing only)
g. External insulation level
h. Pollution performance

7.1 Step 1: Obtain system parameters

The following data are required to determine arrester parameters:

a. System nominal voltage, U_n and maximum voltage, U_m
b. Earthing of system neutral
c. Positive and zero sequence impedances at the SA location
d. Possible causes of overvoltages
e. Length of the longest line to which SA will be connected
f. Line surge impedance, Z, and/or line capacitance, C
g. Prospective fault levels at arrester location

7.2 Step 2: Check for abnormal service conditions

Abnormal service conditions are listed in Appendix A of AS 1307.2. Some of the most important conditions that may lead to selection of higher U_c and/or U_r are:

a. Temperatures below -10°C or above +50°C
b. Frequencies under 48 Hz or above 52 Hz (for 50 Hz systems)
c. Presence of heat sources near the arresters
d. High system capacitance or electrical proximity to capacitor banks, long cables and long or over-insulated transmission lines.

7.3 Step 3: Determine Continuous Voltage (U_c)

In a 3-phase system, for arresters connected phase-earth, actual continuous voltage is:

$$U_c = U_m / \sqrt{3} \quad \text{– Equation 1}$$

This applies for effectively earthed and non-effectively earthed systems where the clearing time for phase to ground faults is less than 10 seconds.

7.3.1 Recommended Continuous Voltage

The following **minimum** values of U_c in **normal** conditions are recommended.

	System voltage (kV)						
Nominal, Un	11	22	33	66	110	132	220
Highest voltage, Um	12	24	36	72.5	123	145	245
System earthing	**SA continuous operating voltage, U_c (kV)**						
Effectively and non-effectively earthed	8	15	22	44	75	88	150

7.4 Step 4: Determine Temporary Overvoltage capability and Rated Voltage (U_r)

7.4.1 Check for maximum TOV

It is essential that the arrester itself is stable under all system operating conditions. The system behaviour must be known, especially under TOV conditions. The TOV level has become a determining parameter for the rated voltage of the SA. The SA must be selected with a sufficient safety margin.

The main causes of TOV are:

- Single-phase faults
- Single-phase open circuit
- Loss of neutral earth in a normally earthed system
- Sudden loss of load or generator overspeed or both
- Loss of load at the end of transmission line
- Ferro-resonance
- Accident contact with conductors of a higher voltage system

Generally the TOV arising at earth faults and at load rejection are of interest. Certain network configurations can give resonance overvoltages, which should be avoided by system design and should not be the basis for selection of the arrestor TOV capability.

7.4.2 Earth fault conditions

The most common known TOV is that at single-phase faults. During a single-phase fault, the sound phases exhibit significant voltage rises. The magnitude of the voltage rise on the sound phase during a phase to ground fault is dependent on:

- Positive sequence impedance
- Zero sequence impedance
- Fault resistance

The calculations used to determine the voltage rise, coefficient of earthing and earth fault factor can be found in Appendix A. These calculations can be used in site specific assessments for surge arrester ratings.

7.4.3 Other cases

In some cases, efforts are made to reduce the earth fault current by selectively earthing the neutrals of only a few transformers yet maintaining an effectively earthed system overall. However, there is a possibility that some parts of the system may become non-effectively earthed for some periods when one or more of the earthed neutral transformers taken out of services. An earth fault during this period may lead to higher TOV and arrester failure if this contingency is not taken into account. Since such occurrence is rare, it may be justified to accept risk of arrester failure instead of selecting an arrester with higher TOV capability and thus a higher protective level. This is also equally applicable to the case of accidental contact with conductors of higher voltage systems.

7.4.4 Select suitable TOV capability and Rated Voltage (Ur)

The following procedure is used in general cases for selecting SA with sufficient TOV capability.

Known make and type

a. Determine the ke, fault duration and prior energy/duty requirements from Table 1 depending on the U_m and earthing of the system.

Table 1: IEEE C62.22 recommends that the arresters be selected basing on the following assumptions.

Assumptions	Directly earthed neutral systems		Resonant earth and isolated neutral systems
	$U_m \leq 123\ kV$	$U_m > 123\ kV$	
TOV in p.u of U_m / $\sqrt{3}$	1.4 [1]	1.4 [1]	1.73 [1]
Fault duration	1 s	1 s	10 s and 2 h [2]
Prior energy [3]	Rated	Rated	Rated

Note 1: These values are to be used for general cases. For site specific values, calculated values for TOV from 7.4.2 may be used.

Note 2: 10 seconds is the assumed maximum duration for earth faults in the EQL network.

Note 3: TOV is calculated using the rated prior energy curves to account for multiple faults.

b. Using this information, calculate TOV using Equation 2:

$$\boldsymbol{TOV = ke \times U_m / \sqrt{3}} \quad \text{– Equation 2}$$

c. Using the TOV capability curve of the arrester and the TOV value calculated, determine the corresponding T_r. Figure 2 shows the TOV capability curve of Siemens 3EL arresters.

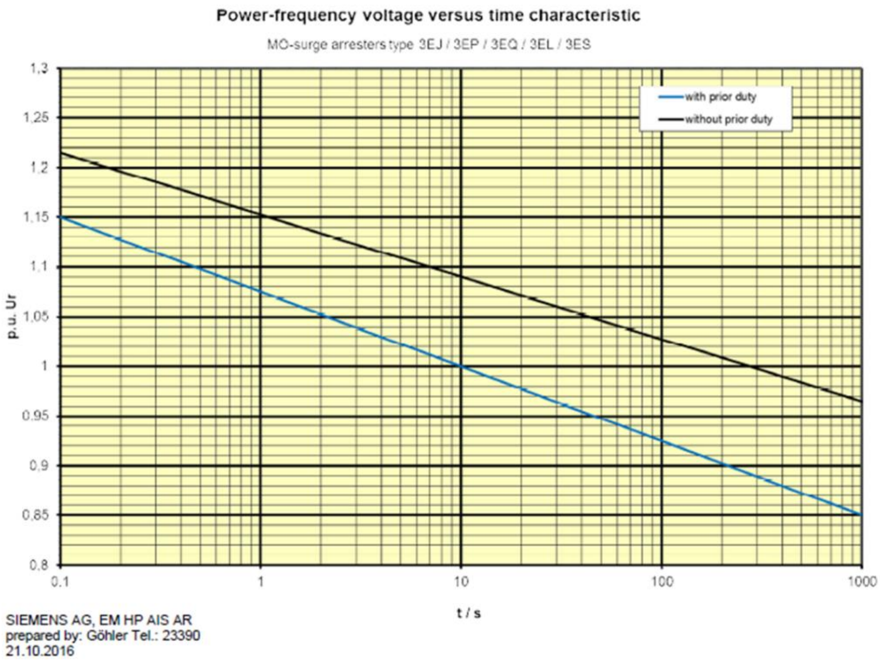


Figure 2: An example of a TOV capability expressed in p.u. Ur.

d. Finally determine the rated voltage using Equation 3 and round the result up to the next highest standard rating according to Table 2.

$$\boldsymbol{U_r = TOV / T_r} \quad \text{– Equation 3}$$

Table 2: Preferred values of rated voltages (IEC 60099-4, 2014).

Range of rated voltage kV r.m.s.	Steps of rated voltage kV r.m.s.
3 to 30	1
30 to 54	3
54 to 96	6
96 to 288	12

<u>Example</u> – the system highest voltage is 72.5 kV and neutral is directly earthed.

$TOV = 1.4 \times 72.5 \div \sqrt{3} = 58.60\ kV\ for\ 1\ s$

Assuming the arrester has TOV capability shown in Figure 2. At 1 s with prior rated energy, the curve gives $T_r = 1.07$ then

$U_r \geq 58.60 \div 1.07 \geq 54.77\, kV$

The next higher standard rating is $U_r = 57\, kV$.

Unknown make and type

It is recommended that the **rated voltage, U_r at least 1.25 times U_c** should be selected when possible. If this is a non-standard rating, choose the next highest rating.

7.5 Step 5: Determine nominal discharge current, I_n

Standard In values stipulated by IEC 60099.4 are 5 000 A, 10 000 A and 20 000 A.

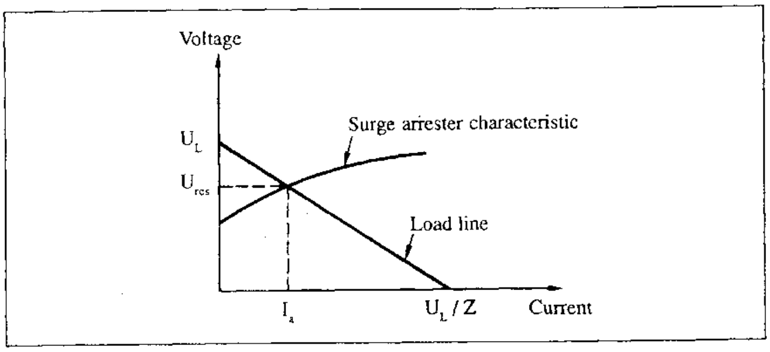
It is recommended a **minimum nominal discharge current of 10 kA** should be used for protection of equipment in substations. This corresponds to Substation SL & SM class in IEC 60099.4.

7.6 Step 6: Determine energy withstand capability and specific energy

7.6.1 General

Switching overvoltage represents the most severe stress for arresters because of the very large energies involved. The most onerous case is the stress caused by switching-in against a trapped charge on a transmission line on arresters installed at the open far end of the line.

The current through the arrester and its residual voltage at this current are given by the intersection of the arrester volt-ampere characteristic and the load line and can be determined by plotting the load diagram as in Figure 3.



U_L = Prospective overvoltage

Z = Line surge impedance

I_a = Surge arrester current

U_{res} = Surge arrester residual voltage

Figure 3: Load diagram (SESWG/A-2310, 1990-05)

TOV will always occur on switching-in a capacitor bank, but will only occur on switching-out if restrikes occur in the switching device. Arresters installed in a substation to protect transformers and other equipment from overvoltages may be subjected to severe energy absorption during capacitor switching because of large energy ($CV^2/2$) stored in the capacitor bank. In this case the arrester energy should also be checked.

7.6.2 Line switching parameters

In the absence of site specific information the following switching parameters can be used (SESWG/A-2310, 1990-05).

Table 3: Line switching surge impedances.

System max voltage U_m (kV)	OH Line Surge impedance Z (ohm)	UG Cable Surge impedance Z (ohm)	Prospective overvoltage without arrestor U_L (p.u)
Under 145	450	20	3.0
145 to 345	400	20	3.0
362 to 525	350	20	2.6

7.6.3 Calculate the arrester energy

Known surge arrester volt-ampere characteristics

The discharge energy (W), given in kilojoule (kj), absorbed by the arrester is given by the equation:

$$\boldsymbol{W = [(U_L - U_{res}) / Z] \times U_{res} \times 2\,l / v \times n}$$ – **Equation 4**

Where

U_L = Prospective switching surge overvoltage or line changing overvoltage (kV)

U_{res} = Switching residual voltage of the arrester (kV), determined from load characteristic

Z = Line surge impedance (ohm)

l = Length of line (km)

v = Velocity of propagation (km/ms)

300 km/ms for aerial lines and GIS bus

For cables much lower around 150 km/ms dependent on cable insulation

n = Number of consecutive discharges

Arrester volt-ampere characteristic not known

The energy W in (kJ) can also be calculated from the following equation:

$$\boldsymbol{W = {}^{1}/_{2}\, C\left[(a \cdot U_m)^2 - \left(\sqrt{2} \cdot U_c\right)^2\right] / 10^3}$$ – **Equation 5**

Where

a = per unit switching overvoltage factor (taken as 3 for Um ≤ 345 kV) times √2/√3

= 2.45

C = line capacitance (μF)

U_m = system highest voltage (kV)

U_c = continuous operating voltage of arrester (kV)

7.6.4 Determine specific energy

$$Specific\ energy\ W' = Arrester\ Energy\ \div Arrester\ U_r \quad (kJ\ \div kVrated)$$ – **Equation 6**

7.7 Step 7: Arrester class

7.7.1 Determine arrester class

Following IEC 60099-4, the class of surge arrester must be selected by considering the I_n and specific energy required for system safety. The specific energy can be calculated using Equations 4, 5 and 6 and Table 4 used to select the correct class of arrester.

Table 4: Arrester class selection characteristics. Note: L = low, M = medium, H = high.

Arrester class		I_n (kA)	Switching impulse discharge current (kA)	Q_{rs} (C)	W_{th} (kJ/kV)	Q_{th} (C)
Substation	SL	10	0.5	≥ 1	≥ 4	NA
	SM	10	1	≥ 1.6	≥ 7	NA
	SH	20	2	≥ 2.4	≥ 10	NA
Distribution	DL	2.5	NA	≥ 0.1	NA	≥ 0.45
	DM	5	NA	≥ 0.2	NA	≥ 0.7
	DH	10	NA	≥ 0.4	NA	≥ 1.1

7.7.2 Recommended minimum class

In general, it is recommended that **SM** class should be selected for substation applications, however **SL** class may be acceptable for voltages up to 66kV.

7.8 Step 8: Determination of protective characteristics

Refer to Section 8.

7.9 Step 9: Pressure relief (applicable to porcelain housed SA only)

7.9.1 Pressure relief current

Pressure relief current limits should exceed the system's available short circuit current and duration at the arrester location. The device is chosen on the basis of the prospective symmetrical short circuit current in the system at the arrester location or calculated from the formula:

$$I = Pk\ \div \left(\sqrt{3} \times U_m\right)$$ – **Equation 7**

I = Prospective symmetrical short circuit current (kA)

Pk = Prospective 3-phase short circuit power at the arrester location (MVA)

U_m = The maximum system voltage (kV)

A minimum level of **40 kA** is recommended.

7.9.2 Pressure relief class

It is recommended that pressure relief class **NS** should be selected.

7.10 Step 10: External insulation levels

According to AS 1307.2, the arrester housing shall withstand the following voltages:

- LIWV = 1.3 x lightning impulse protection level of the arrester
- PFWV = 1.06 / √2 x switching impulse protection level for a duration of 1 minute

- SIWV = 1.25 x switching impulse protection level for arresters having Ur ≥ 200 kV.

7.11 Step 11: Mechanical characteristics

Strong wind and pull of conductor increase the horizontal loading on the arrester. Wind pressure can be calculated from wind velocity.

$$q = 0.36 \times V^2 \text{ on cylindrical surface} \quad – \quad \text{Equation 8}$$

Where

q = wind pressure (Pa)

V = wind velocity (m/s)

The wind force acting on the arrester is:

$$Fw = q \times l \times d \quad – \quad \text{Equation 9}$$

Where

Fw = force due to wind on arrester (N)

l = length of arrester (m)

d = mean diameter of arrester (m)

Assuming this force acts at the middle of the arrester, bending moment (N.m) at the arrester base will be:

$$Mw = l \times Fw \div 2 \quad – \quad \text{Equation 10}$$

The cantilever strength (bending moment) of the arrester must be sufficient for pull of conductor and wind force. Wind speed up to 72 m/s should be allowed for.

7.12 Step 12: Pollution performance

Refer to Table I and Table II of AS 4436, which are shown in Appendix D, for pollution severity levels and relation between the pollution level and the specific creepage distance.

Due to possible being deployed in polluted area it is recommended that **Level IV – Very High** and corresponding minimum nominal specific creepage distance of **31 mm/kVrated or higher** should be selected, where kVrated is the system highest voltage.

8 Determination of protective levels of an arrester

The following protective levels should be considered.

- Steep (or front of wave) current impulse residual voltage (FOW)
- Lightning impulse protection level (LPL)
- Switching impulse protection level (SPL)

If arrester parameters are not available, refer to columns (1), (2) and (3) of Table K1 of AS 1307.2 (for arresters with I_n = 10 kA).

When the make and type of the arrester is known, refer to the manufacturers data and use a coordinating current of 10 kApk.

8.1 Evaluating insulation co-ordination

Insulation coordination is evaluated on the basis of the margin between the insulation strength of the surge voltage at the equipment terminals, which may be estimated by use of either Simplified Method or method presented in Annex C of IEEE Std C62.22-1997, which is shown in Appendix B.

In general there are two methods of portraying insulation coordination

a. The tabulation of protective ratios or margins, and
b. The graphical presentation of coordination.

Regardless of the method, the same minimum protective ratios and margins apply. The graphical presentation is shown in Figure 4.

The graphical method requires the test results of the equipment as well as the protective levels of the arrester.

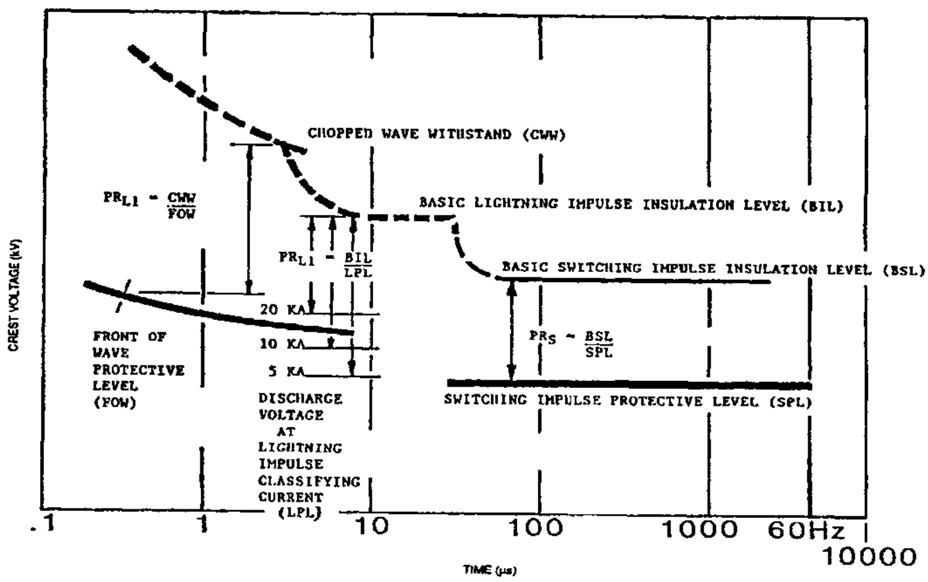


Figure 4: Typical volt-time curve for coordination of arrester's protective levels with insulation withstand strength for liquid filled transformers.

8.2 Arresters at terminals of protected equipment

For arresters installed at the terminals of the protected equipment, the effect of separation distance will be negligible, depending on the equipment highest voltage range the acceptable protective ratios and margins should be as follows:

Protective ratios	Protective margins
$PR_{L1} = CWW \div FOW \geq 1.2$	$PM_{L1} = (PR_{L1} - 1)100\% \geq 20\%$
$PR_{L2} = LIWV(or\ BIL) \div LPL$ $\geq 1.4\ for\ Range\ A$ $\geq 1.2\ for\ Range\ B\ \&\ C$	$PM_{L2} = (PR_{L2} - 1)100\%$ $\geq 40\%\ for\ Range\ A$ $\geq 20\%\ for\ Range\ B\ \&\ C$
$PR_s = SIWV\ (or\ BSL) \div SPL \geq 1.15$	$PM_s = (PR_s - 1)100\% \geq 15\%$

Range A: above 1 kV to less than 52 kV

Range B: from 52 kV to less than 300 kV

Range C: 300 kV and above.

8.3 Arresters at some distance away from protected equipment

For arresters installed at some distance away from the protected equipment, the voltage at the equipment V_T should be calculated by the simplified method.

In this method separation distance and incoming surge steepness are used.

When there are connection leads and a distance between arrester and plant, the protected plant will be subjected to a higher overvoltage. Voltage increase due to distance effects is given in the formula:

Equation 11

$$\boldsymbol{U = U_{res} + (2 \times S \times D) \div v}$$

Where

U = voltage at protected plant (kVpk)

U_{res} = residual voltage of the arrester (kVpk)

S = rate of rise or steepness of the incoming voltage wave (kV/µs)

D = distance between arrester and protected plant including connection leads, arrester tail to the earth grid, and arrester height (m)

v = velocity of wave propagation (m/µs)

(Approximately equal to velocity of light 300 m/µs, except for cables for which 150 m/µs may be used)

Steepness of incoming surge can be calculated from the formula given by IEEE Std C62.22-1997. Rate of rise or steepness (kV/µs) = 11*Arrester MCOV or Uc, and maximum value is 2000 kV/µs.

The acceptable protective ratios and margins are as same as those for arresters at terminals of protected equipment.

9 Evaluation of alternatives

If acceptable coordination cannot be achieved, the following measures may be evaluated;

a. Increase the equipment LIWV and SIWV
b. Decrease the separation distance.
c. Add additional arresters
d. Use arrester with lower protective characteristics.

10 Documentation required

Documentation on the selection of SA shall take the form of a design report and is to include, but not be limited to the following:

1. Values for the design inputs such as system voltage, system impedances, system earthing, etc. Refer to section 7.1.
2. Calculations to determine SA ratings
3. Evaluation of protective ratios / margins
4. Insulation coordination studies
5. Evaluation of alternatives (as applied).

Annex A Coefficient of earthing (COE) and earth fault factor (ke)

A.1. Coefficient of earthing

Table 5: Equations for calculating the coefficient of earthing.

Fault resistance not included	Fault resistance (R_f) included
Applicable when $Z_1 = Z_2$	Fault resistance tends to reduce COE
Single phase-to-earth fault (P-E) at phase a: $COE\ (phase\ b) = -[\sqrt{3}(3k) \div (2+k) + j1] \div 2$ $COE\ (phase\ c) = -[\sqrt{3}(3k) \div (2+k) + j1] \div 2$	For P-E fault: $k = \left(R_0 + R_f + jX_0\right) \div (R_1 + R_f + jX_1$
Double phase-to-earth fault (P-P-E) on phase b and c: $COE\ (phase\ a) = \sqrt{(3k)} \div (1+2k)$	For P-P-E fault: $k = (R_0 + 2R_f + jX_0) \div (R_1 + 2R_f + jX_1)$
Where: $k = Z_0 \div Z_1 = (R_0 + jX_0) \div (R_1 + jX_1)$	

A.2. Earth fault factor (ke)

$$\boldsymbol{ke = \sqrt{3}COE}$$

The network is defined as effectively earthed when COE < 1.4.

Annex B Annex C of IEEE Std C62.22-1997

Calculations of surge arrester separation distances

C.1 Purpose

The purpose of this annex is to provide a relatively simple method for calculating maximum allowable separation distances between surge arresters and equipment to be protected.

C.2 Introduction

The most effective location for any surge arrester is at the terminals of the equipment to be protected. For a variety of reasons, surge arresters sometimes have to be located some distance away from the equipment, or sometimes one set of surge arresters may be used to protect more than one piece of equipment.

Locating a surge arrester remote from the equipment to be protected reduces the protective margin. Depending on a number of factors, the transient voltage at the equipment can easily be more than twice the surge arrester protective level. An analysis has to be made to determine how far a surge arrester can be located away from the equipment and still provide adequate protection.

C.3 Study method

This annex provides a simplified procedure for calculating acceptable separation distances for simple substation configurations. The procedure is illustrated in this annex using two examples as follow:

a) A substation consisting of a single overhead line terminated with a single transformer
b) A multiline two-transformer substation

A reduction process is used in the second example to derive a single-line single-transformer substation that can be analyzed as shown in the first example.

The procedure uses the curve shown in Figure C.8, which was generated from studies using the Electromagnetic Transients Program (EMTP). Equation (C.1) represents the curve plotted in Figure C.8 and may be used instead. All the computer studies were made on single-line single-transformer substations with system voltages ranging from 69 kV to 765 kV.

The curve on Figure C.8 is an average curve using the results from EMTP studies as indicated above. The curve includes the effect of the power frequency voltage and is valid for separation distances not exceeding 300 ft (91 m). Transformer surge capacitance values of 1000 pF to 5000 pF do not materially affect the separation effects.

Special studies are required for complex substations using analytical tools such as the EMTP. It is not the intent of this annex to provide guidance in selecting cases for study or in interpreting the results obtained when using the EMTP or other analytical tools.

C.4 Definitions of symbols

The symbols used to calculate surge arrester separation distances are defined in Figure C.1 and as follows:

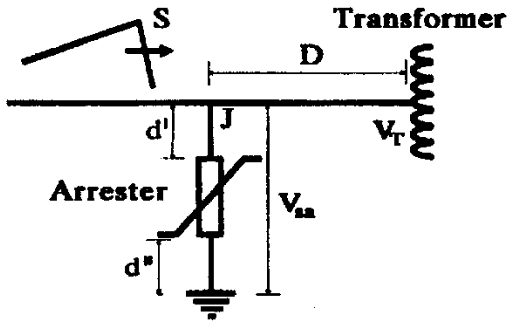


Figure C.1—Definition of symbols

BIL	is Basic Lightning Impulse Insulation Level of the transformer (in kilovolts)
C	is surge propagation rate in overhead conductors (in feet per microsecond or meters per microsecond)
CWW	is Chopped Wave Withstand of transformers (in kilovolts) (1.10 × BIL) (IEEE Std C57.12.00-1993; Anderson [B4]; Table 5)
d'	is conductor length between junction *J* and surge arrester terminal (in feet or meters)
d"	is conductor length between surge arrester and ground (in feet or meters)
d	is total surge arrester lead, *d' + d"* (in feet or meters)
D	is maximum allowable separation distance between junction *J* and transformer terminal (in feet or meters)
di/dt	is rate of rise of surge current = 2(*S*)/*Z* (in kiloamperes per microsecond)
J	is common point among transformer lead, surge arrester lead, and surged line
L	is inductance of surge arrester lead *d* (in microhenries) (Assume 0.4 µH/ft or 1.3 µH/m)
N	is number of transmission lines, including the surged line
S'	is rate of rise of incoming surge on the transmission line (kV/µs) (Use 11 kV/µs per kV MCOV rating to a maximum of 2000 kV/µs—IEEE Std C62.11-1993)
S	is rate of rise of incoming surge at junction *J* (in kilovolts per microsecond)
V_a	is surge arrester FOW protective level at 0.5 µs (in kilovolts) (See Table 1)
V_{sa}	is voltage across the surge arrester, from junction *J* to ground (in kilovolts)
V_T	is maximum voltage stress allowable at the transformer (in kilovolts): V_T is CWW/1.15 if time to crest voltage is less than 2 µs V_T isBIL/1.15 if time to crest voltage is more than 2 µs This assumes a 15% protective margin (See Figure 4)
Z	is surge impedance of transmission line (in ohms) (Refer to Table 5 in IEEE Std C62.11-1993)

C.5 Single-line single-transformer substation, example 1

Refer to Figure C.1. Parameters in this example for a 115 kV system are as follows:

BIL	is 350 kV
C	is 984 ft/µs (300 m/µs)
d	is *d' + d"* = 25 ft (7.6 m)
S'	is 11 × MCOV rating = 11 × 70 = 770 kV/µs

S	is S' in this example
V_a	is 226 kV for MCOV = 70 kV
	Time to crest voltage: (226/770) < 2 μs
	Use $V_T = CWW/1.15$
Z	is 450 Ω

Calculate the following:

CWW	is $1.1 \times BIL = 1.1 \times 350 = 385$ kV
di/dt	is $2\ S/Z = 2(770)/450 = 3.42$ kA/μs
L	is $(d' + d'') \times 0.4$ μH/ft $= 25 \times 0.4 = 10$ μH
	$(d' + d'') \times 1.3$ μH/m $= 7.6 \times 1.3 = 10$ μH
V_{sa}	is $V_a + L(di/dt) = 226 + 10(3.42) = 260$ kV
V_T	is $CWW/1.15 = 385/1.15 = 335$ kV
V_T/V_{sa}	is $335/260 = 1.29$

The abscissa value corresponding to $V_T/V_{sa} = 1.29$ on the curve of Figure C.8 is $D(S)/(C \times V_{sa}) = 0.068$.

Solving for: D is $0.068(C \times V_{sa})/(S)$

is $0.068(984 \times 260)/770 = 23$ ft (7 m)

This is the maximum allowable distance between the surge arrester and the transformer.

C.5.1 Calculated allowable separation distances

Allowable separation distances have been calculated using the above procedure for system voltages from 69 kV through 765 kV based on the following:

- Typical values of BILs
- Station class surge arresters
- Minimum MCOV ratings
- Maximum value for the 0.5 μs FOW protective level from Table 1

The allowable separation distances are given in Table 4.

C.6 Multiline two-transformer substation

Figure C.2 shows a substation with three transmission lines, two transformers, and one set of surge arresters. Allowable surge arrester separation distances should be calculated for each transformer, assuming the incoming surge on each of the three lines, to determine the surge-protection adequacy of both transformers with one set of surge arresters.

To use the method of this annex, the multiline two-transformer substation of Figure C.2 has to be reduced to a single-line single-transformer substation similar to that of Figure C.1. The following procedure shows the reduction method. The procedure should be repeated for each transformer, while assuming the incoming surge to travel on each line separately. Line-out conditions may also be investigated to identify the most severe case.

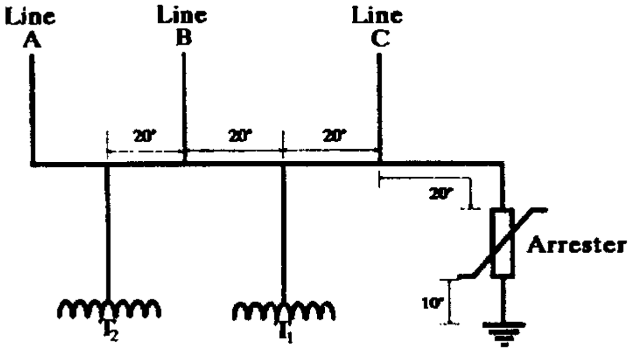


Figure C.2—An example of multiline two-transformer substation

C.6.1 Step-by-step procedure for reduction process

Step 1: Remove the transformer not being considered and identify the transmission line with the incoming surge.

Step 2: Identify parameters.

a) Identify junction J, which is the common point among the transformer lead, surge arrester lead, and the surged line.

b) Identify the separation distance D as the connection between junction J and the transformer terminal that would include the bus-bar length, if applicable.

c) Identify the surge arrester lead d' as the connection between junction J and the surge arrester that would include the bus-bar length, if applicable.

Step 3: Remove all lines connected to d' (connection between junction J and surge arrester).

Step 4: The rate of voltage rise at junction J is $S = (S') \times 3(N + 2)$, where N equals the total number of lines (including the surged line) remaining after Step 3.

The multiline two-transformer substation has been reduced, and the maximum allowable separation distance, D, can be calculated using the procedure used in Section C.5.

C.6.2 Multiline two-transformer substation—example 2

Refer to Figures C.2 and C.3. Parameters used in this example for a 138 kV system follow:

BIL	is 450 kV;
C	is 984 ft/µs (300 m/µs);
d'	is 40 ft (12 m);
d"	is 10 ft (3 m);
S'	is 11 × MCOV rating = 11 × 84 = 924 kV/µs;
Va	is 273 kV for MCOV = 84 kV; and Time to crest voltage: (273/924) < 2 µs Use V_T = CWW/1.15
Z	is 450 Ω.

C.6.2.1 Reduction of Figure C.2—incoming surge on line A

Step 1: Remove transformer not being considered, T2 in this case, and assume the incoming surge is on Line A. See Figure C.3.

Step 2: Identify parameters.

a) Identify junction *J*, where the dashed lines meet in Figure C.3;

b) Identify the separation distance *D*; and

c) Identify the surge arrester lead *d'*; *d'* = 40 ft (12 m) in this example (See Figure C.2), and $d = d' + d''$ = 40 + 10 = 50 ft (12 + 3 = 15 m).

Step 3: Remove all lines connected to *d'*; Line C in this case

Step 4: Calculate the voltage rate of rise at junction J.

$S\ (S1) \times 3/(N + 2);\ N = 2$ (see Figure C.4)

$= (924) \times 3/(2 + 2) = 693$ kv/μs (see Figure C.4)

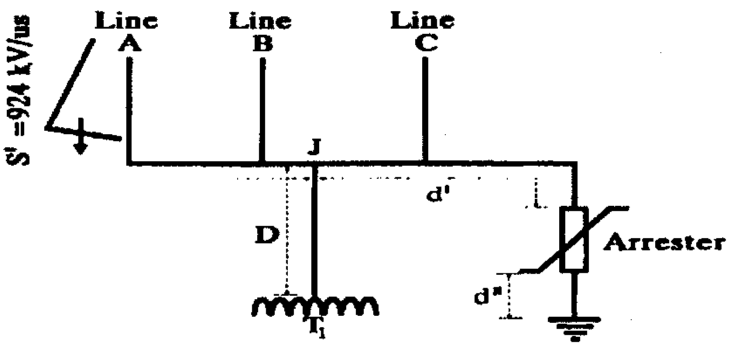


Figure C.3—Example 2—multiline two-transformer substation with an incoming surge on line A—transformer T2 not being considered is removed

The reduced single-line single-transformer substation to be analyzed is shown in Figure C.5. Calculate the following:

$CWW = 1.1 \times BIL = 1.1 \times 450 = 495$ kV

$di/dt = 2(S)/Z = 2(693)/450 = 3.08$ kA/μs

$L = (d' + d'')\ 0.4\ \mu H/ft = (50)0.4 = 20\ \mu H$

$(d' + d'')\ 1.3\ \mu H/m = (15)1.3 = 20\ \mu H$

$V_{sa} = V_a + L(di/dt) = 273 + 20(3.08) = 335$ kV

$V_T = CWW/1.15 = 495/1.15 = 430$ kV

$V_T/V_{sa} = 430/335 = 1.28$

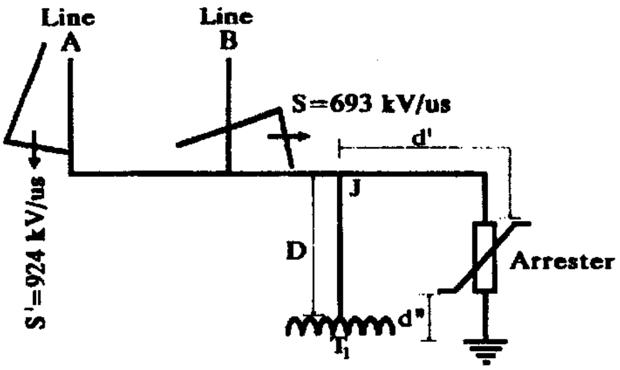


Figure C.4—Example 2—multiline two-transformer substation with an incoming surge on line A—simplified to a single-line single-transformer substation

The abscissa value corresponding to $V_T/V_{sa} = 1.28$ on the curve of Figure C.8 is $D(S)/(C \times V_{sa}) = 0.066$.

Solving for D $= 0.066\ (C \times V_{sa})/(S)$
$= 0.066\ (984 \times 335)/(693) = 31$ ft (9.4 m)

This is the maximum allowable distance between the surge arrester and the T1 transformer if Line A is the surged line.

Repeat the procedure with the incoming surge on each of the other lines. C.6.2.2 shows the incoming surge on Line C.

C.6.2.2 Reduction of Figure C.2—incoming surge on line C

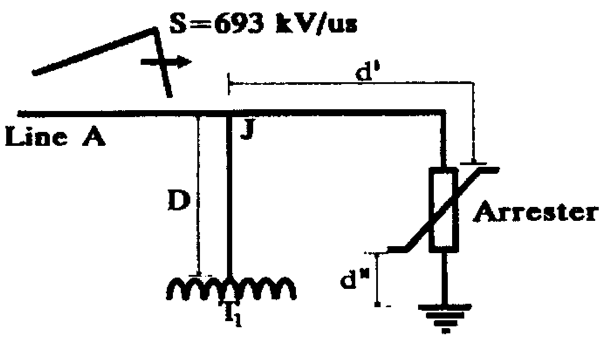


Figure C.5—Example 2—multiline two-transformer substation with an incoming surge on line C—transformer T2 not being considered is removed

Step 1: Remove transformer not being considered, T2 in this case, and assume the incoming surge is on Line C. See Figure C.6.

Step 2: Identify parameters.

a) Identify junction J, where the dashed lines meet in Figure C.6;

b) Identify the separation distance D; and

c) Identify the surge arrester lead d'; d' = 20 ft (6m) in this example (see Figure C.2), and d = d' + d" = 20 + 10 = 30 ft (6 + 3 = 9 m).

Step 3: Remove all lines connected to d'; none in this case.

Step 4: Calculate the voltage rate of rise at junction J.

$S = (S') \times 3/(N + 2)$; N = 3 (see Figure C.6)

$= (924) \times 3/(3+2)$

$= 554$ kV/µs

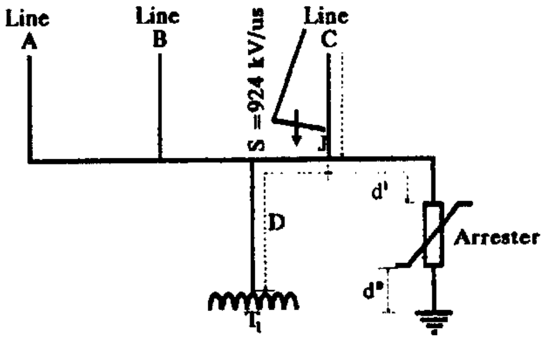


Figure C.6—Example 2—multiline two-transformer substation with an incoming surge on line C—reduced to a single-line single-transformer case

The reduced single-line single-transformer substation to be analyzed is shown in Figure C.7.

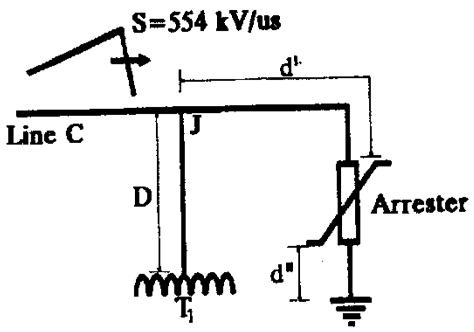


Figure C.7—Example 2—multiline two-transformer substation with an incoming surge on line C—reduced to a single-line single-transformer case

Calculate the following:

$CWW = 1.1 \times BIL = 1.1 \times 450 = 495$ kV

$di/dt = 2(S)/Z = 2(554)/450 = 2.46$ kA/µs

$L = (d' + d'')\ 0.4\ \mu H/ft = (30)0.4 = 12\ \mu H$

$(d' + d'')\ 1.3\ \mu H/m = (9)1.3 = 12\ \mu H$

$V_{sa} = V_a + L(di/dt) = 273 + 12(2.46) = 302\ kV$

$V_T = CWW/1.15 = 495/1.15 = 430\ kV$

$V_T/V_{sa} = 430/302 = 1.42$

The abscissa value corresponding to $V_T/V_{sa} = 1.42$ on the curve of Figure C.8 is $D\ (S)/(C \times V_{sa}) = 0.108$.

Solve for: $D = 0.108(984 \times 302)/(554) = 58$ ft (17.7 m)

An incoming surge on Line A is more critical than one on Line C (D = 31 ft versus 58 ft or 9.4 m versus 17.7 m).

Repeat the procedure with the incoming surge on Line B, and determine the maximum allowable separation distance D for transformer T1.

A similar procedure should be followed to determine the maximum allowable separation distance D for transformer T2.

C.7 Equation representation for Figure C.8

The following equation may be used to calculate the maximum allowable separation distance (D). The equation closely approximates the curve in Figure C.8.

$$D \le \left[\frac{0.385(CV_{sa})}{S}\right] \times \left[\frac{0.957BIL - V_{sa}}{2.92V_{sa} - 0.957BIL}\right] \qquad (C.1)$$

Summary of maximum voltage at transformer (VT) expressed as ratio to maximum voltage at surge arrester (VSA) at junction *J*.

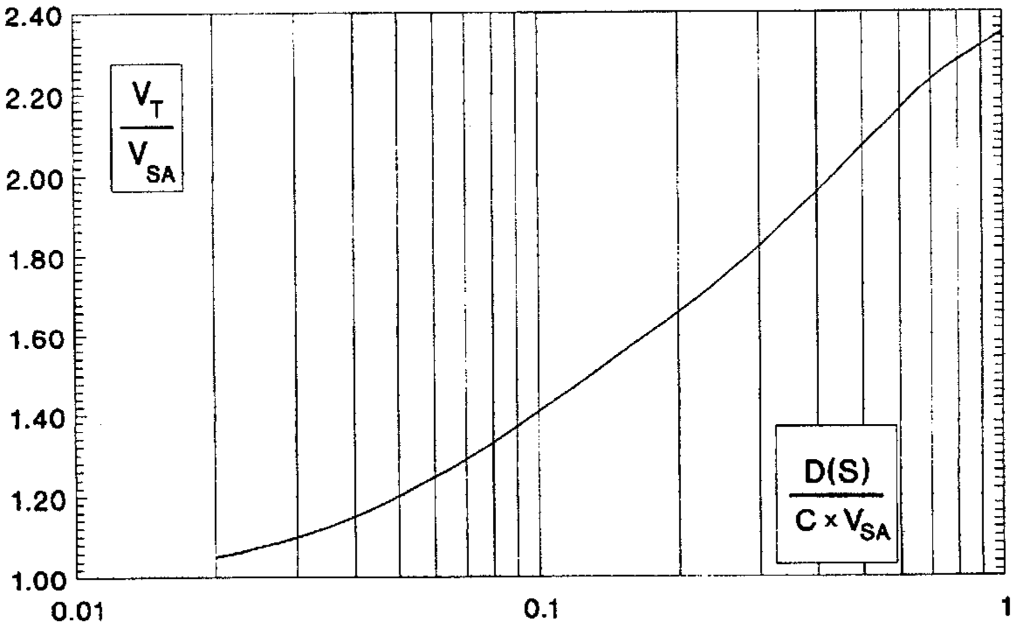


Figure C.8—Curve for graphical determination of acceptable separation distance of surge arrester from a transformer

Annex C Pollution severity levels and minimum creepage distance

Table 6: Table I and Table II from AS 4436-1996.

Pollution level	Examples of typical environment	Minimum nominal specific creepage distance [1] (mm/kV) [2]
I. Light	- Areas without industries and with low density of houses equipped with heating plants. - Area with low density of industries or houses but subjected to frequent winds and/or rainfall - Agricultural areas [3] - Mountainous areas - All these areas shall be situated at least 10 km to 20 km from the sea all shall not be exposed to winds directly from the sea.	16 [4]
II. Medium	- Areas with industries not producing particular polluting smoke and/or with average density of houses equipped with heating plants. - Area with high density of houses and/or industries but subjected to frequent winds and/or rainfall - Areas exposed to the sea but not too close to the coast (at least several kilometres distance)	20
III. Heavy	- Areas with high density of industries and suburbs of large cities with high density of heating plants producing pollution. - Areas close to the sea or in any case exposed to relatively strong winds from the sea. [5]	25
IV. Very heavy	- Areas generally of moderate extent, subjected to conductive dusts and to industrial smoke producing particularly thick conductive deposits. - Areas generally of moderate extent, very close to the coast and exposed to sea spray or to very strong and polluting winds from the sea. - Desert areas, characterised by no rain for long periods, exposed to strong winds carrying sand and salt, and subjected to regular condensation.	31 [6]

Notes:

1. For the actual creepage distance, the specific manufacturing tolerances are applicable. (See IEC Publication 273: Dimensions of Indoor and Outdoor Post Insulator Units for Systems with Nominal Voltage Greater than 1000 V, IEC Publication 305: Characteristics of String Insulator Units of the Cap and Pin Typ, IEC Publication 433: Characteristics of string Insulator Units of the Long Rod Type, and IEC Publication 720: Characteristics of Line Post Insulators.
2. Ratio of the leakage distance measured between phase and earth over the r.m.s phase-to-phase value of the highest voltage for the equipment (see IEC Publication 71-1).
3. Use of fertilisers by spraying, or burning of crop residues, can lead to higher pollution level due to dispersal by wind.

4. In very lightly polluted areas, specific nominal creepage distances lower than 16 mm/kV can be used depending on service experience, 12 mm/kV seems to be a lower limit.
5. Distances from sea depend on the topography of the coastal area and on the extreme wind conditions.
6. In the case of exceptional pollution severity, a specific nominal creepage distance of 31 mm/kV may not be adequate. Depending on service experience and/or on laboratory test results, a higher value of specific creepage distance can be used, but in some instances the practicability of washing or greasing may be considered.

Annex D How to use EQL Selection of Surge Arresters Workbook:

To assist with the selection of appropriate surge arresters, a selection tool has been created based on the information in this standard. The tool is made up of seven sheets containing useful information and formulas, prefilled data, input data and calculations. In order to complete SA evaluation, only the two green coloured sheets need to be accessed as these contain the input data and calculated answers. A brief description of each sheet will be provided below.

D.1. Title

The title sheet contains the revision history of the document and a table of contents describing each sheet of the workbook.

D.2. Useful Information

This sheet provides information about the standards used to develop the spreadsheet and a number of other pieces of background information which were used in the calculations in sheets 4 and 5. These include descriptions of appropriate insulation levels for different voltages, surge arrester characteristics, insulation coordination, system overvoltage, pollution levels and other miscellaneous information.

D.3. Useful Formulae

The useful formulae sheet contains several formulae that have been used to calculate results in sheets 4 and 5 as well as some that were not used but could be useful if further calculations were required to select an appropriate SA. These formulae include impedance, velocity of surge propagation, coefficient of earthing, phase-to-earth faults, earth fault factor and the energy generated in an arrester.

D.4. Input Data

This sheet contains linked cells for the input of key pieces of information about the SA's and the systems they will be used in. Any cells which are coloured pink are to be used to select a value, dark-yellow cells are for values to be entered into and the light-yellow and light-green cells are linked cells which auto-populate based on the pink and dark-yellow cells (fig. 7). Many cells also contain prompts based on standard values about what to enter if you do not know some specifications of the system you are designing for. For example, the lead lengths from the line terminal to the connection point and from the earth terminal to earth have been suggested to be 1 m and 4 m respectively while the lead length from the connection point to the protected equipment varies significantly based on the nominal voltage and space so a table of maximum lengths has been included in table 9.

Input cell   Linked input cell   Cell with formula   Selected value

Figure 5: Colour code for cells in the Input Data and Summary of SA Performance sheets.

Table 7: Maximum lead length based on the nominal voltage and lightning impulse withstand voltage of the equipment.

Nominal voltage, Un (kV)	LIWV equipment rating (kVpk)	Maximum lead length, D (m)	
		Effectively earthed	Non-effectively earthed
11	60	24.24	-0.13
	75	42.54	12.05
	95	66.89	28.25
22	95	12.15	-10.37
	125	31.36	1.78
	150	47.33	11.91
33	145	9.89	0.11
	170	20.02	8.54
	200	32.15	18.71
66	325	27.65	
110	450	20.30	
	550	35.01	
132	450	7.10	
	550	18.93	
	650	30.70	
220	650	3.25	
	750	11.22	
	850	19.20	
	950	27.22	
	1050	35.20	

The tab colour of this sheet as been set to green as it contains important information which must be entered in order to evaluate the SA's.

D.5. Summary of SA Performance

This sheet contains the calculations used to evaluate the SA's performance against required system minimums. The parameters evaluated include continuous operating voltage, rated voltage, nominal discharge current, class, specific energy, protective ratio, creepage distance, LIWV and cantilever strength. It should be noted that EQL have recently specified that all SA's must be evaluated to a level four/very heavy pollution level.. Although no values need to be entered in this sheet, it contains the summarised SA evaluation so its tab colour has also been set to green.

D.6. Supplier Data

The supplier data sheet contains information relevant to the selection of SA's under the current contract 883 with Siemens. This includes data like the arrester class, Ur, Uc, In, residual voltages, specific energy and arrester dimensions which was obtained from a variety of documents provided during the contract evaluation process. It also includes the TOV curves for each type of arrester in the contract with this information being used to assist in evaluating the suitability of the arresters Ur.

D.7. Lookup Tables

The final sheet contains information which is used in sheet 4 to create the drop-down menus in the pink cells. It does not need to be accessed unless changes need to be made to the spreadsheet or there is an issue with what is being displayed.

D.8. Example analysis

In order to explain the new changes to the spreadsheet, an example analysis has been performed on a 33 kV, non-effectively earthed system with a longest overhead line connection of 100 km and the SA's located on the transformers to be protected.

First, the Un, 33 kV, was entered via a drop-down menu. This resulted in the Um automatically updating to 36 kV. Next, 'NON-EFFECTIVELY EARTHED' was selected as the system neutral earthing as the impedances of the system were not known. If they were known, these should be entered in the appropriate cells and the blank option should be selected from the drop-down menu in row 18. If the future fault level is known this should also be entered.

7	**INPUT DATA**					
8	Input cell	Linked input cell	Cell with formula		Selected value	
9						
10	**System**					
11	System nominal voltage (also Base voltage), Un (or Ubase) =				33	
12	System/equipment highest voltage, Um				36	kV
13	System Impedances at arrester location in pu/ohm. Select				Ohm	
14	Leave blank if unknown	Z0 =		+ j		ohm
15		Z1 =		+ j		ohm
16	If impedances are in pu, enter base MVA, otherwise leave blank					MVA
17	System neutral earthing (if impedances are known)					
18	If impendances are unknown, select				NON-EFFECTIVELY EARTHED	
19	Possible future fault level				15	MVA
20						

Following this, the protected equipment section was filled in with the location of the arresters selected from the drop-down menu in row 22. In order to select an appropriate LIWV/BIL, the light-green cells in row 24 automatically populate according to the LIWV/BIL values that correspond to the Un value selected above. From the values provided, choose the appropriate value for the equipment being protected and type into the dark-yellow cell in row 25.

21	**Protected Equipment**						
22	Location of arresters	Transform					
23	Note: SA installed at line entrance mainly protect VT, CT & open CB on the feeder						
24	Potential protected equipment LIWV/BIL based on Un	145	170	200	NA	NA	kVpk
25	Protected equipment LIWV/BIL. Select appropriate value above	200	kVpk				
26							

The incoming transmission line option was then selected from the drop-down menu with this selection automatically populating the surge impedance and surge speed of propagation. The length of the longest line, 100 km, was then input along with the number of consecutive discharges, 2. This is nominally set to two as during switching surges, twice the surge energy is seen by the SA so the system should be designed for this occurrence.

27	**Transmission line / Cable**		
28	Incoming overhead line or cable. Select	Line	
29	Surge impedance, Z	450	ohm
30	Length of connected longest line/cable, l	100	km
31	Surge speed of propagation, v	300	km/ms
32	Number of consecutive discharges, n	2	
33	Note: n = 2 is required to design for switching surges		
34			

In this section no values were selected or input as they are linked to the system earthing and Um values. If the system was effectively earthed and Um below 123 kV, the TOV would be 1.4 and the fault duration 1 s. If the Um was above 123 kV the TOV would be 1.4 with a fault duration of 1 s. All the systems should be rated for prior energy so this is taken into account during calculations involving TOV.

35	**Temporary Overvoltage (TOV) conditions**				
36	These TOV values are in p.u. of Um/sqrt(3).				
37	TOV for effectively earthed, Um ≤ 123 kV	NA			
38	Rated for prior energy	NA	Fault duration	NA	s
39	TOV for effectively earthed, Um > 123 kV	NA			
40	Rated for prior energy	NA	Fault duration	NA	s
41	TOV for non-effectively earthed	1.73			
42	Rated for prior energy	Yes	Fault duration	10	s
43					

Using the system parameters selected above as a guide, the SA that was estimated to be the most appropriate was selected using the drop-down menu in row 46. This selection automatically populated the light-yellow cells in rows 47 to 69 with data that is located in the Supplier Data sheet.

44	**Surge arrester from current contract**					
45	(For checking performance of an existing arrester or selecting arrester with known make & type)					
46	Contract item				33 kV NEI	
47	Make				Siemans	
48	Type				3EL1 036-1PE31-4XA1	
49	Standard. (AS is same as IEC)				IEC	
50	Class (IEC std)				SL	
51	Rated Voltage/Duty cycle voltage, Ur				36	kV
52	Continuous operating voltage/MCOV, Uc				28.8	kV
53	Nominal Discharge Current, In				10	kApk
54	Is TOV capability curve available?				Yes, figure	1
55	TOV capability 10s, TOV				36	kV
56	Residual Voltages					
57		Lightning current	(8/20 µs)	@ 2.5 kApk	80.5	kVpk
58				@ 5 kApk	85.4	kVpk
59				@ 10 kApk	91.8	kVpk
60		Switching current	(30/60 µs)	@ 0.5 kApk	61	kVpk
61				@ 1 kApk	63	kVpk
62				@ 2 kApk	66	kVpk
63	Specific Energy, W'				6	kJ/kVrated
64	Housing	LIWV			170	kVpk
65		PFWV			123	kV
66	Creepage distance,				1400	mm
67	Height of SA, lsa				445	mm
68	Mean diameter, dsa				200	mm
69	Cantilever strength, F				1880	N
70						

Finally, the installation and environmental conditions were set according to standard values and table 2 although other values may be chosen depending on the system and installation environment. EQL has established that the minimum pollution level should be 'IV (Very Heavy)' so this cell should not be changed.

71	**Installation Conditions**		
72	SA connection	Phase-Earth	
73	Length of lead from SA line terminal to connection point, d'	1	m
74	Length of lead from SA earth terminal to earth, d"	4	m
75	Note: Standard lengths of d' (1 m) and d" (4 m) have been used.		
76	Length of lead from SA connection point to protected equipment, D	10.00	m
77	See maximum length of D in the Manual for the Surge Arrester Selection Tool		
78			
79	**Environmental Conditions**		
80	Polllution level. IV Very Heavy is minimum	IV (Very Heavy)	
81	Corresponding specific creepage distance	31	mm/kVrated
82	Pull of conductor at line terminal,	500	N
83	Wind velocity, V	210	km/h
84			

Following the completion of the Input Data sheet, the SA selected can be checked against the system requirements using the Summary of SA Performance sheet. In the summary, the continuous operating voltage, rated voltage, nominal discharge current, class, specific energy, protective ratio, creepage distance, LIWV and cantilever strength of the arrester are compared to that required for the system to operate safely. This outcome of this comparison is displayed visually in the suitability column with any unsuitable parameters identified with a red "NOT SUITABLE" cell. If a parameter is unsuitable, some reasons may be that the wrong surge arrester was selected for the system or that the length of the lead from the SA connection point to the protected equipment was incorrectly selected. If the summary still displays an unsuitable value after these changes have been made then a larger surge arrester may be required.

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