# Electrical engineering in general: Design and construction. Insulation coordination and over voltage protection

# 1 Purpose and scope

The purpose of this clause is to optimize all electrical installations in the infrastructure so that faults due to arbitrary or atmospheric over-voltages are minimized. The clause is relevant for all electric facilities in the infrastructure.

Insulation coordination includes coordination with the grounding system, the determination of the level of insulation, isolation distances and the use of surge protection. Requirements for earthing of the facilities is given in kapittel 6.

This clause is also accompanied by the annex Vedlegg 7a giving a summary of the requirements to insulation coordination in [FEF] and in international standards. The annex is informative as the requirements are duplicated in this clause.

# 2 Requirements for insulation

a) On the secondary side of high voltage transformers the conductors shall either be protected or the conductors shall be installed to be proof of short-circuit event (see definitions in [NEK]) up to the first protection device.

## 2.1 High voltage facilities

a) Moveable relaxed lines and associated equipment in contact line systems with 15 kV *shall* be according to the requirements for insulation in [FEF § 8-3].

1. Regarding insulation distances see requirements in clause 2.1.3.

b) Fixed relaxed lines and associated equipment in contact line systems with 15 kV *shall* be according to the requirements for insulation in [FEF § 4-2].

c) High voltage facilities with other voltages than 15 kV *shall* be according to requirements for insulation in [FEF § 4-2].

> In [FEF] it is stated that railways are not included in the scope of § 4-2 – that is: the moveable relaxed lines and associated equipment are excluded.

### 2.1.1 Insulation level in facilities with 15 kV

Requirements for voltage variations ($U_n$, $U_{max1}$, $U_{min1}$, $U_{max2}$ og $U_{min2}$) are contained in Banestrømforsyning/Prosjektering/Energiforsyning, according to the TSIs and specified in [EN 50122-1].

> The nominal operating voltage is defined as $U_n$ in the standard, and for Jernbaneverket $U_n$ equals 15 kV.

a) All equipment within the fixed 15 kV facilities shall as a minimum be dimensioned for 17,25 kV ($U_{max1}$) continuous voltage phase-earth.

1. If the insulation level for the equipment is given as phase-phase values, the corresponding

phase-earth value shall be used in the dimensioning.

See also Vedlegg 7a.

b) Short time withstanding voltage ($t \leq 60$ s) with operating frequency (r.m.s. value):

1. Insulation for equipment and components shall be 70 kV.
2. Air gap in circuit breakers shall have a withstanding voltage that is one level higher than for insulation, e.g. 95 kV.

See also Vedlegg 7a.

c) Withstanding voltage for lightning pulse (maximum value), $U_{Ni}$, for equipment and lines shall be:

- minimum 170 kV outdoors (over-voltage class OV4).
- minimum 145 kV indoors, if over-voltage protection is installed at the building entrance (over-voltage class OV3, refer to table A-2 in [EN 50124] for the value $U_{Nm}$= 24 kV).

### 2.1.2 Insulation level in the traction network return circuit

The traction network return circuit is a part of the contact line system and hence depicted in this clause, though the insulation level is not the same as for the high voltage facility.

a) The traction network return circuit shall have an insulation level of 1000 V between the return conductor and earth. The requirement applies for all of the return circuit except for the running rails and the termination bar within the lid of the filter impedances.

b) For protection against arbitrary touching of the return circuit (suspended line or cable) the insulation level shall be $U_0$ / U = 600 / 1000 V.

$U_0$: r.m.s. value of the voltage between the insulated conductor and earth, U: r.m.s. value of the voltage between to conductors in a multi-conductor cable or in a system with single-conductor cables, [EN 50264-1].

c) The insulation level for equipotential bonding to the track shall be minimum $U_0$ / U = 450 / 750 V. Requirements for dielectric strength and insulation distances shall be in accordance to <nowiki>[EN 50124] and [IEC 60664].

### 2.1.3 Insulation distances in moveable relaxed lines and associated equipment in contact line system with 15 kV

a) For planning and building of contact line system the facility shall be designed with a minimum of 250 mm static and a minimum of 150 mm dynamic insulation distances, refer to [IEC 60913], table II.

The minimum requirement in [EN 50119] is increased to cope with particular difficult climatic conditions in Norway (wind, snow and ice).

Definition of dynamic insulation distance: The minimum distance that can occur between a voltage-carrying part and a none-live part when one or both parts are moving.

Definition of static insulation distance: The minimum distance that can occur between a voltage-carrying part and a none-live part when none of the parts is moving.

Dynamic and static insulation distances have impact on the design of insulators and pathway systems, particular at narrow places with limited space, e.g. in cuttings and tunnels.

1. Requirements for minimum static insulation distance shall be fulfilled at all places with unloaded systems.
2. requirements for dynamic insulation distance shall be fulfilled at all places with the impact from forces that are likely to appear.
3. For the contact line the requirements for dynamic insulation distance shall be fulfilled at all places with a force of minimum 200 N between the current collector and the contact wire.
4. For planning and refurbishment of the contact line in existing tunnels, on bridges, in snow sheds etc. a request for an exemption may be forward to the owner of the facilities for a minimum insulation distance of 220 mm (static) and 120 mm (dynamic) between the contact wire/live parts and fixed/grounded parts.
5. For separation of sections the insulating distance between live parts and disconnected/earthed parts shall be at a minimum of 150 mm [NEK EN 50122-1].

Fixed constructions above the railway, e.g. bridges, buildings, culverts etc. should not be closer than 400 mm from live parts in the contact line system due to possible future adjustments.

c) For insulating distances in autotransformer systems the requirements in annex 5.d to [540], Kontaktledningssystemer shall apply.

## 2.1.4 Insulation distances in fixed relaxed high voltage facilities

a) Other high voltage facilities than those in clause 2.1.3 shall fulfil the requirements for insulation distances given in table A.3 in [EN 50124-1].

b) For auto transformer (AT) system the minimum requirements for distances in the line system given in Tabell 1 shall apply.

c) For circuit breakers in AT system and at the entrance to the auto transformers the distances in Tabell 2 shall apply.

AT systems is characterized as a two-phase system ($U_{PL}$-$U_{NL}$= ±15 kV) and hence the voltage between the two different sections of the contact line may accidentally be with direct opposite phase.

Tabell 1: Minimum requirements to distances between fixed relaxed lines for AT system

| Distance between | Minimum requirement |
|---|---|
| Positive conductor (PL) and earth | 250 mm |
| Negative conductor (NL) and earth | 250 mm |
| Positive conductor (PL) and negative conductor (NL) | 400 mm |
| Negative conductor (NL) and contact line (KL) | 400 mm |
| Positive conductor (PL) and contact line (KL) | 250 mm |

Tabell 2: Minimum requirements to distances at circuit breakers and for the entrance to transformers in AT systems

| Distance between | Minimum requirements |
|---|---|
| Positive conductor | 250 mm |
| Negative conductor (NL) and earth | 250 mm |
| Positive conductor (PL) and negative conductor (NL) | 320 mm |
| Negative conductor (NL) and contact line (KL) | 320 mm |
| Positive conductor (PL) and contact line (KL) | 250 mm |

Requirements to distances in Tabell 1 and Tabell 2 are found in the report ”Autotransformatorsystem for norske forhold” (EK800118-000).

### 2.1.5 Creepage distances for insulators and circuit breakers

a) Insulators and circuit breakers in fixed installations shall have a creepage distance in accordance with [EN 50124-1, clause 6.3.2]. See </nowiki>Tabell 3.

1. The standard presents the requirements in [mm/kV]. For railways with 15 kV the maximum continuous operating voltage shall be (U</nowiki>$_{max1}$ = 17,25 kV).

Tabell 3: Minimum requirements to creepage distance according to [EN 50124-1]

| Degree of contamination | Minimum creepage distance | Minimum creepage distance for 17,25 kV |
|---|---|---|
| Adverse conditions (pollution, 10-20 km from the sea, natural sink) | 40 mm/kV | 690 mm |
| Extremely unfavourable conditions (heavy pollution, industry, salt water, urban areas, natural sink) | 48 mm/kV | 828 mm |
| Extremely unfavourable conditions (tunnel, not natural sink) | 52 mm/kV | 897 mm |

## 2.2 Low voltage facilities

### 2.2.1 Insulation level in lov voltage facilities

a) Facilities, equipment and components shall be constructed with insulation levels according to Tabell 4.

1. The values apply for systems with 230/400 V, and the requirements for dielectric strength apply as well for phase-to-phase as for phase-to-earth.

The requirements to insulation level apply for a dielectric strength for a 1,2/50 µs pulse and for a 8/20 µs pulse.

Tabell 4: Nominal insulation level for low voltage facility according to table 44B [NEK 400:2006]

| Impulse withstand voltage, $U_{Ni}$ | Description of facility | Jernbaneverket's notes |
|---|---|---|
| 6 kV | Main distribution, energy entrance, meter included | Entrance from energy supplier, entrance from auxiliary transformer |
| 4 kV | Fixed installation with cables and outlets | |
| 2,5 kV | Common equipment | Signalling circuits, low voltage installations |
| 1,5 kV | Electronics | Signal- and telecommunications |

### 2.2.2 Insulation distances in low voltage facilities

a) According to values for the impulse withstand voltage in Tabell 4 the insulation distances in air shall be as depicted in Tabell 5.

The distances depends on the position and the degree of contamination, Refer to table A3 in [EN 50124-1].

Tabell 5: Minimum distance in air for different impulse withstand voltage in low voltage facilities depending on position,

| Impulse withstand voltage | Minimum insulation distance |
|---|---|

| $U_{Ni}$ | [mm] | | |
|---|---|---|---|
| | Indoor in closures | Indoor without closure | Outdoor |
| 6 kV | 5,5 | 10,0 | 19,0 |
| 4 kV | 3,0 | 7,0 | 15,0 |
| 2,5 kV | 1,5*) | 5,5 | 11,5 |
| 1,5 kV | 0,5**) | 5,5 | — |

*) 1,6 mm in PD4

**) 0,8 mm in PD3

# 3 Requirements for over-voltage protection

In addition to the use of over-voltage protection a better protection against over-voltage results from appropriate earthing and sufficient isolation as depicted earlier in this clause and in kapittel 6.

a) Facilities with over-voltage protection should have protection for multiple lightnings.

This can be achieved by doubling all protection devices, e.g. by installing two equal protection devices in parallel as a mutual backup.

b) Protection for specific important and exposed facilities should have an alarm-circuit to report any defects.

## 3.1 Over-voltage protection

### 3.1.1 Functional requirements

a) Normal operation: The surge arresters shall have a high impedance and not show any harm at the nominal voltage.

The condition defines the properties of the arresters, see comments to Tabell 6.

b) For over-voltage: The arresters shall be the slightest point in the facility. e.g. the arrester shall deteriorate the over-voltage before the insulation get damaged.

The condition defines the properties of the arresters, see comments to Tabell 6.

c) At break-down: Damaged arresters shall present a visual sign to ease any inspection.

1. Damaged arresters shall be replaced immediately.

d) Surge arresters in the contact line system shall have properties that do not upset the rules for disconnections and connection depicted in [546] – both at normal operation and at break-down.

### 3.1.2 Position of the voltage arresters

a) The over-voltage protection shall be installed in front of and as close as possible to the object to be protected.

b) An earth electrode with good high frequency performance shall be provided to serve the surge arresters.

1. The distance between the surge arresters and the earth electrode shall be as short as possible.
2. The earth resistance for the earth electrode should be as low as possible, see kapittel 6.

c) The routing between the live conductor and the arrester and between the arrester and the earth electrode shall be as straight and short as possible – any change of direction should be made with a large radius (> 30 cm). Conductors shall not have any sharp bend.

d) Surge arresters (metal oxide arresters) in the contact line system should have insulated conductors all the way to the earth electrode. See also requirements for earthing arrangement in clause 3.2.1.

# 3.2 Requirements for over-voltage protection in facilities of 15 kV

a) Surge arrester (metal oxide) shall be installed at places in the network where damage to equipment and cables may arise due to over-voltages.

1. As a minimum over-voltage protection shall be installed at the places depicted in the following clauses 3.2.2 to 3.2.5.

Other needs for over-voltage protection should be accompanied with the possibility to achieve a low resistance to earth at the catenary supports. See relevant requirements in kapittel 6.

b) Surge arresters in the 15 kV facilities shall be selected by the dimensioning voltages given in Tabell 6.

Tabell 6: Dimensioning voltages for selection of over-voltage arrestors in 15 kV facilities

| **15 kV facilities** 1) | **Max. continuous operating voltage** 2) | **Static insulation voltage** 3) | **Impulse insulation voltage ($U_{Ni}$)** 3) | **Lowest $U_{res}$** 4) | **Highest $U_{res}$** 5) |
|---|---|---|---|---|---|
| OV 4 outdoor/unprotected | 17,25 kV | 24 kV | 170 kV | 29,3 kV | 85 kV |
| OV 3 indoor/protected | 17,25 kV | 24 kV | 145 kV | 29,3 kV | 72,5 kV |

Notes to the table:

1) grouped by over-voltage categories (OV) according to [EN 50124-1].

2) $U_{max1}$, according to [EN 50163].

3) According to [EN 50124-1].

4) Lowest protection level ($U_{res}$) should be greater than maximum operating voltage (amplitude value) + 20 %.

5) Highest protection level ($U_{res}$) should be less than half of the insulation level of the facility.

Surge arresters are often denoted by its marked voltage ($U_r$) or the continuous operating voltage ($U_C$). Hence the product specification is consulted to find suitable values for $U_r$ or $U_C$ giving $U_{res}$ (protection level / residual voltage).

### 3.2.1 Preparation of earthing for over-voltage protection

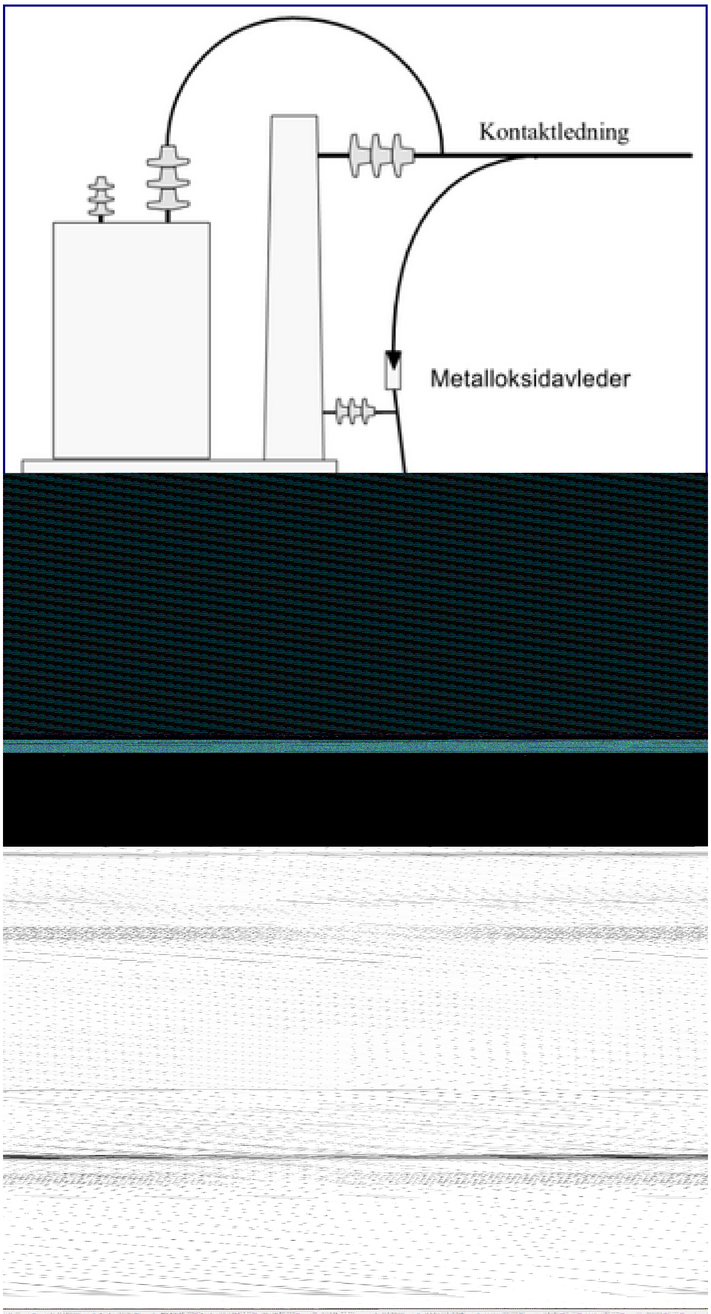
a) Surge arresters shall be installed insulated from the catenary support, see Figur 1.

1. There shall be a designated protection conductor (yellow/green, minimum 25 mm²) from the surge arrester to the earth electrode.
2. The pathway shall be as short as possible with hardly any arcs (recommended radius > 50 cm).
3. There shall be a separate insulated protection conductor (yellow/green, minimum 25 mm²) from the earth electrode to the catenary support.

The primary function of the earth electrode is functional protection of equipment (booster transformer, auxiliary transformer etc.) from lightning. Recommended resistance to earth is less than 100 ohms.
With this lay-out most of the energy in a fast transient (lightning pulse) will be directed to earth rather then back to the return circuit. A lightning pulse don't follow sharp bends.

b) Catenary support shall be bonded to the traction return circuit in one of the following ways:

1. If a parallel earth conductor is installed the bond connects to it.
2. Where there is no track circuit installed (exception for possible axle counters) the bond connects to the rail(s).
3. Alternatively the bond connects to the rails via an impedance bond.




Figur 1: Over-voltage arrestor at booster transformer, auxiliary transformer and cable end sleeve

### 3.2.2 Over-voltage protection at booster transformer

a) Over voltage protection shall be installed at both sides of a booster transformer between the contact line and a common earth electrode.
Exception: For booster transformers in tunnels the over-voltage protection shall be installed in the contact line system at both ends of the tunnel.

### 3.2.3 Over-voltage protection at auxiliary transformer

a) Similarly as for the booster transformer the over-voltage protection shall be installed at the auxiliary transformer between the contact line and an earth electrode.

1. The over-voltage protection should be connected to the contact line system between a possible disconnector to ease the replacement of a defective surge arrester, see alsokapittel 8.

See guidance in clause 3.2.2 when auxiliary transformers are installed in tunnels.

### 3.2.4 Over-voltage protection of high voltage cables

a) For high voltage cables longer than 70 m over-voltage protection shall be installed in both ends.

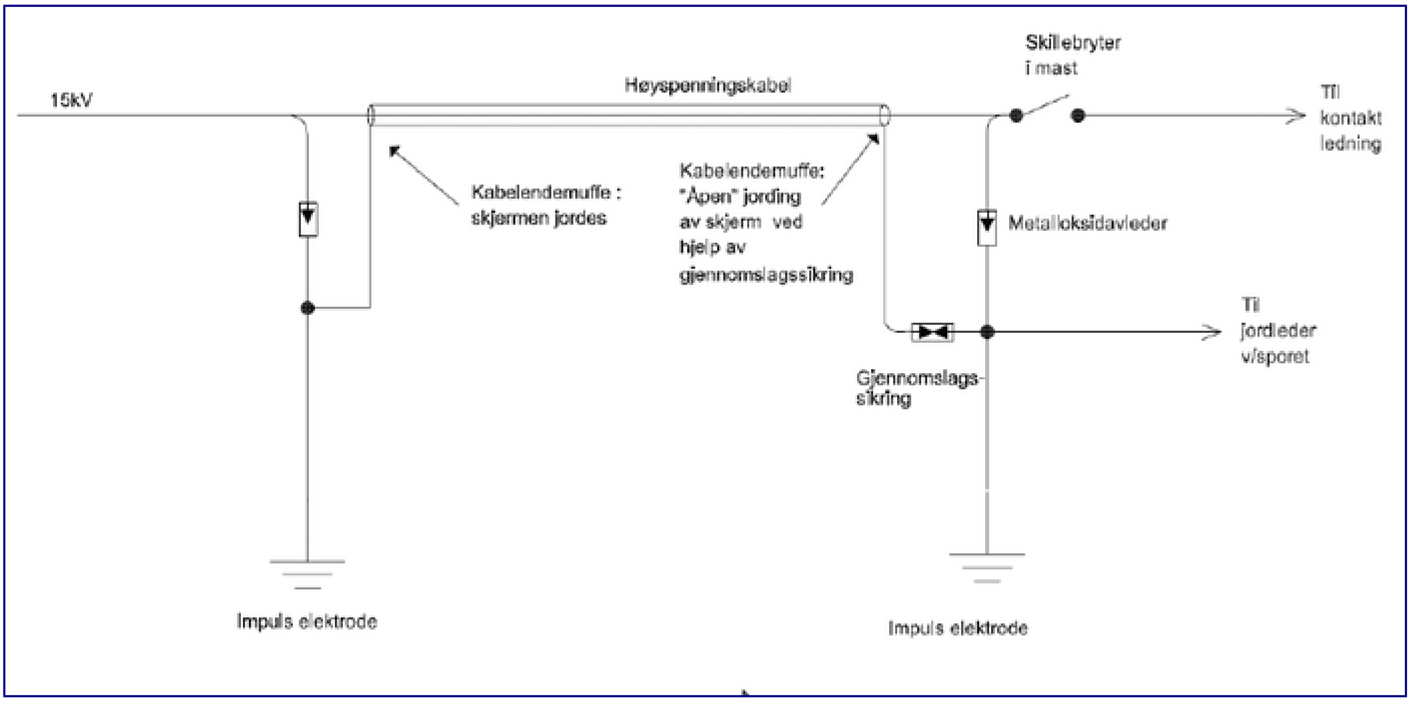
1. Cables installed along the track, or leading to the track, shall be earthed according to kapittel 6. In such cases there shall be a voltage limiter in the open-earthed end – between the cable shield and earth. See Figur 2 and Figur 3.
2. Voltage limiter is installed closely together with the over-voltage protection.

Observe also guidance to "Forskrift om elektriske forsyningsanlegg" [FEF, §4-4] about "Koplingspunkter og avslutninger for kabler" for the open-earthed cable shield.
The voltage limiter is important to avoid over-voltages exceeding the protection level (residual voltage). The voltage between conductor and shield at the cable end sleeve in the open end can in worst case (without any protection) rise to the doubled of the protection level.
Figur 2 and Figur 3 depicts examples of over-voltage protection for longer high voltage cables (feeder cables, bridging cables etc.). The cable shield is earthed in the source end, and in the other end the cable shield is connected to earth via a voltage limiter. The figures depicts only the schematic principals at the voltage protection. See kapittel 6 for additional details regarding earthing.
Components like voltage limiters with low activating voltage and high performance in accordance with EN 5022-1 do exist. Recommended terms for searching are: "overvoltage protection", "railway", "EN 50122-1:2010" etc..

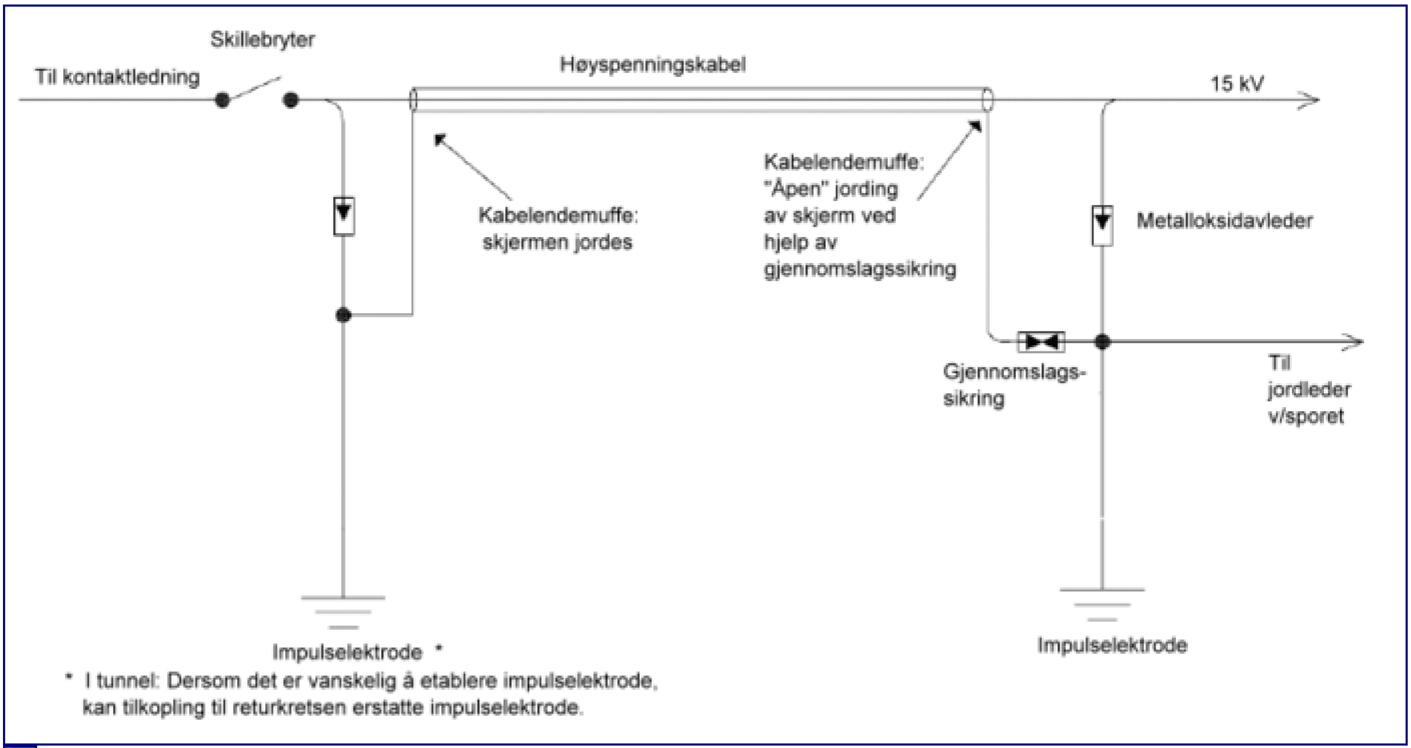
b) For short cable lengths (≤70 m) ( bridging cables by bridges and similar) it is sufficient with over-voltage protection in one end only depending on length and local conditions.

c) It shall be documented that the cable can tolerate the voltages that can be present without installed over-voltage protection.

d) For short cables where the one end is terminated without any connection to the shield, the shield may be folded back over the outer sheath and insulated with a sleeve so it will be possible at a later event to get access to the shield.




Figur 2: Examples of over-voltage protection of feeding cable, with over-voltage protection and voltage limiter / voltage limiter between feeder cable and contact line, and over-voltage protection in the source end




Figur 3: Examples of over-voltage protection of feeding cable, with over-voltage protection between feeder cable and contact line / voltage limiter in the source end - alternative solution

### 3.2.5 Over-voltage protection at auto transformers

Cable is used between auto transformers and connection to aerial feeding with NL and PL.

a) In mast with connection of aerial feeders to cables over-voltage protection shall be installed, see Figur 1 and Figur 2:

1. NL shall have its own over-voltage protection.
2. PL shall have its own over-voltage protection.
3. Earth connection of both surge arresters shall – with as short as possible connection with hardly any arcs – be connected to a local (common) earth electrode.
4. The cable shields of both NL and PL shall be bonded to the earth connection on the surge arresters.
5. The earth electrode shall be bonded to a connecting point in the mast.

With this lay-out most of the energy in a fast transient (lightning pulse) will be directed to earth rather then back to the return circuit. A lightning pulse don't follow sharp bends.

b) In the AT kiosk bonding shall be established between: local earth, ring earth, any possible earth electrode), protection earth, and operative earth (track return circuit = mid tap on the auto transformer).

1. Cable shield of NL and cable shield of PL shall be insulated (not connected).

c) In the AT kiosk:

1. If the cables for NL and PL are longer than 70 m the auto transformer shall be protected with over-voltage protection between both the NL connection and the mid tap of the auto transformer and the PL connection and the mid tap of the auto transformer.
2. If over-voltage protection is installed in the AT kiosk an earth electrode shall be installed in addition to the ring earth.

# 3.3 Requirements to the over-voltage protection in low voltage facilities

This clause depicts over-voltage protection at the source side of the primary supply for technical equipment. The class designation states the stresses to be applied when testing, refer to [REN blad 8021].
The primary protection divert the greater portion of the over-voltage. The secondary protection divert the residual over-voltage passed by the primary protection and attenuated in the feeding cables.

a) The dimensioning voltages in Tabell 7 shall be used when selecting surge arresters for low voltage installation.

b) Primary protection (klasse 1) shall be installed at the branching from the energy provider to Jernbaneverket.

1. The surge arresters should be duplicated.

c) Secondary protection (“mellomvern”) (klasse 2) shall be installed in main distribution (“omformerrom”) at all incoming supplies lines/cables.

1. The surge arresters should be duplicated.

d) Secondary protection (klasse 3) shall be installed at the secondary distribution cabinets for signalling, remote control, telecommunications, see also clause 3.3.1.

e) Secondary protection shall at a minimum have at least 5-10 % higher protection level than the primary protection, but the primary protection shall have better performance related to diverted energy.

f) Over-voltage protection shall be installed to avoid hazards (IP20) by touching and damage to equipment.

g) Care shall be taken for the lay out the facility to have necessary separation between source arresters and other electric parts to avoid damage due to arcing from the protection devices.

h) Pluggable protectors with highly visible warning at failure should be used. Protection devices for specific critical facilities should have alarm circuit for remote monitoring of failure events.

i) Alarm circuits should also be installed for any fuses in front of the protection devices. If the fuses disconnect any indication from the protection devices only do not catch the lack of power.
It is important that any fuses in front of the surge arresters are selective to avoid disconnection of the whole facility.

Tabell 7: Dimensioning voltage for the selection of protective devices in low voltage facilities

| | **Nominal voltage, $U_{n,phase-phase}$** | **Lightning impulse residual voltage, $U_m$ 1)** | **Continuous operating voltage, $U_c$, nominal voltage, $U_r$ 2)** | **Recommended voltage for protection devices, $U_p$ 3)** |
|---|---|---|---|---|
| Category 1: Electric equipment with electronics signal/telecom | TN 400 V<br>TT 230 V<br>IT 230 V 4) | 1500 V | 280 V<br>280 V<br>320 V or 420 V | < 1200 V |
| Category 2: Electric equipment | TN 400 V<br>TT 230 V<br>IT 230 V 4) | 2500 V | 280 V<br>280 V<br>320 V or 420 V | < 2000 V |

| | | | | |
|---|---|---|---|---|
| signal/electric | | | | |
| Category 3:<br>Low voltage<br>fixed<br>cable, plug ++ | TN 400 V<br>TT 230 V<br>IT 230 V [4)] | 4000 V | 280 V<br>280 V<br>320 V or 420 V | < 3200 V |
| Category 4:<br>Low voltage<br>network | TN 400 V<br>TT 230 V<br>IT 230 V [4)] | 6000 V | 280 V<br>280 V<br>320 V or 420 V | < 4800 V |

Notes to the table:

[1)] according to [NEK 400:2006], table 44B, and [REN blad 8021].

[2)] For low voltage facility $U_c = U_r$ according to [REN blad 8021]. The values are the stated corresponding phase-to-earth voltage + 10 %. [3)] According to [REN blad 8021] it is recommended to use devices with a diverting voltage that is 20 % lower then the lightning impulse residual voltage.

[4)] For IT distribution it is recommended that $U_c$ is higher to allow for moderate over-voltages from a single phase inductive earthing failure.

### 3.3.1 Over-voltage protection for communication and signalling equipment

a) In addition to over-voltage protection of the primary power supply of the equipment, appropriate protection devices shall be installed on incoming and outgoing cables for signalling facilities, telecommunication lines and remote controls as depicted in the respective books of Teknisk regelverk [5xx].

b) In general over-voltage protection should be installed at the termination of all incoming and outgoing conductors/pairs for cables that is:

- installed along the railway track and is exposed to inductive voltages from the traction line supply
- connected equipment in cabinets/closures with connection to the track return circuit (see kapittel 6)
- connected to aerial lines/cables close to the termination
- connected to equipment exposed to lightning (antenna masts and similar)

c) Over-voltage protection shall be installed also on unused conductors/pairs.

# 4 Annexes

Vedlegg 7a - Isolasjonskoordinering 15 kV, installasjoner og luftlinjer