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SERIES K: PROTECTION AGAINST INTERFERENCE

Lightning protection of the dedicated transformer for radio base station

Recommendation ITU-T K.110

ITU-T

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Summary

Recommendation ITU-T K.110 addresses lightning protection of the dedicated transformer for a radio base station (RBS).

RBSs are usually powered by the local power utility with a dedicated power line operating at medium voltage (e.g., from 10 kV to 20 kV). A dedicated transformer is installed at the RBS for transforming the medium voltage (MV) to low voltage (LV) (e.g., 380 V or 240 V), which is then used to power the RBS.

Frequently, the dedicated transformer is installed on a pole, and thus the associated overhead lines (medium and low voltage) have poor earthing conditions. Therefore, these transformers are exposed to lightning effects and, consequently, the power interruptions caused by lightning flashes can severely affect normal operations of the RBS.

The main objective of this Recommendation is to reduce the risk of damage to an RBS dedicated transformer due to lightning flashes, which will improve the safety and reliability of the RBS itself and its related equipment.

This Recommendation includes the following features:

1) need of protection for dedicated transformer;
2) earthing and bonding of transformer and RBS;
3) direct lightning protection for transformers;
4) transformer insulation requirements;
5) MV/LV arresters and LV surge protective devices (SPDs);
6) protection of ancillary facilities.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T K.110	2015-12-14	5	11.1002/1000/12669

* To access the Recommendation, type the URL http://handle.itu.int/ in the address field of your web browser, followed by the Recommendation's unique ID. For example, http://handle.itu.int/11.1002/1000/11830-en.

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Lightning protection of the dedicated transformer for radio base station

1 Scope

This Recommendation addresses the lightning protection of dedicated transformers used to provide electrical power for radio base stations (RBSs). It contains procedures for earthing, bonding and direct lightning protection of the dedicated transformer, including protection methods for the associated power lines, requirements for surge arresters (medium voltage (MV) and low voltage (LV) arresters), and protection procedures for ancillary facilities.

Transformers used for powering an RBS and other components (i.e., shared transformers) are not covered in this Recommendation. The lightning protection of these shared transformers is contained in [b-ITU-T K.111].

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T K.56] Recommendation ITU-T K.56 (2010), *Protection of radio base stations against lightning discharges*.

[ITU-T K.97] Recommendation ITU-T K.97 (2014), *Lightning protection of distributed base stations*.

[ITU-T K.112] Recommendation ITU-T K.112 (2015), *Lightning protection, earthing and bonding: Practical procedures for radio base station sites*.

[IEC 60076-3] IEC 60076-3 (2013), *Power transformers – Part 3: Insulation levels, dielectric tests and external clearances in air*.

[IEC 60076-4] IEC 60076-4 (2002), *Power transformers – Part 4: Guide to the lightning impulse and switching impulse testing – Power transformers and reactors*.

[IEC 60099-4] IEC 60099-4 (2014), *Surge arresters – Part 4: Metal-oxide surge arresters without gaps for a.c. systems*.

[IEC 61643-11] IEC 61643-11 (2011), *Low-voltage surge protective devices – Part 11: Surge protective devices connected to low-voltage power systems – Requirements and test methods*.

[IEC 62305-1] IEC 62305-1 (2010), *Protection against lightning – Part 1: General principles*.

[IEC 62305-2] IEC 62305-2 (2010), *Protection against lightning – Part 2: Risk management*.

[IEC 62305-3] IEC 62305-3, (2010), *Protection against lightning – Part 3: Physical damage to structures and life hazard*.

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 continuous operating voltage of an arrester (Uc) [IEC 60099-4]: Designated permissible r.m.s. value of power-frequency voltage that may be applied continuously between the arrester terminals in accordance with Ur.

3.1.2 non-solidly earthed power distribution systems [b-IEC 60050-601]: System generally refers to neutral point ungrounded via arc suppression coil or high-impedance to ground. When short-current fault occurs, the system can not constitute a current loop, the fault current is very small, also known as small current grounding system.

3.1.3 rated voltage of an arrester (Ur) [IEC 60099-4]: Maximum permissible RMS. value of power-frequency voltage between its terminals at which is designed to operate correctly under temporary overvoltage conditions as established in operating duty tests.

3.1.4 residual voltage of an arrester (Ures) [IEC 60099-4]: Peak value of voltage that appears between the terminals of an arrester during the passage of discharge current.

3.1.5 solidly earthed neutral system [b-IEC 60050-601]: System whose neutral point(s) is (are) earthed directly.

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 arrester disconnector: Device for disconnecting an arrester from the system in the event of arrester failure, to prevent a persistent fault on the system and to give visible indication of the failed arrester.

NOTE – Eliminate the fault current through the arrester during disconnection generally is not a function of the device.

3.2.2 dedicated transformer: Power transformer used exclusively to provide electrical power to a radio base station.

3.2.3 drop-out fuse: Fuse used in MV power line and distribution transformers for overload and short circuit protection.

3.2.4 earthing network: The part of an earthing installation that is restricted to the earth electrodes and their interconnections.

3.2.5 heat-blast disconnector: Device that uses the explosion of a component in order to disconnect a circuit and interrupt the current flow.

3.2.6 high current impulse of an arrester: Peak value of discharge current having a 4/10 impulse shape which is used to test the stability of the arrester on direct lightning strokes.

3.2.7 lightning protection insulator: An insulator body comprising an upper part and a lower part connected series. When subjected to a lightning overvoltage, the nonlinear resistance of the lower part decreases and the overvoltage is concentrated at the upper part, causing a flashover. After the lightning current is over, the nonlinear resistance of the lower part rapidly rises and limits the flow of power frequency current.

3.2.8 metal-oxide surge arrester without gaps: Arrester having non-linear metal-oxide resistors connected in series and/or in parallel without any integrated series or parallel spark gaps.

3.2.9 nominal discharge current of an arrester (In): Peak value of lightning current impulse (8/20 μs current impulse) which is used to classify an arrester.

3.2.10 non-linear metal-oxide resistor: Part of the surge arrester which, by its non-linear voltage versus current characteristics, acts as a low resistance to overvoltage, thus limiting the voltage across the arrester terminals, and as a high resistance at normal power-frequency voltage.

3.2.11 series reactor: Device that limits the lightning current flow through a drop-out fuse, in order to avoid its undesired operation.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

EPR Earth Potential Rise

FTO Forward Transformation Overvoltage

ITO Inverse Transformation Overvoltage

LV Low Voltage

MV Medium Voltage

RBS Radio Base Station

SPD Surge Protective Device

5 Conventions

None.

6 Need for protection

Power utilities usually protect distribution transformers against lightning induced surges, but not against direct lightning flashes. However, a dedicated power transformer used to provide electrical power to an RBS is installed in an environment that is very exposed to direct flashes. The main items that enhance this high exposure include the presence of a tall metallic tower for the RBS, a long overhead power distribution line (feeder) and the RBS placement on a hill. Therefore, the dedicated power transformers for RBS presents a number of aspects that need to be considered:

– earth potential rise (EPR) when lightning strikes the tower;
– induced overvoltages when lightning strikes the tower;
– low voltage (LV) and medium voltage (MV) lines nearby the transformer (within 3 km) may be struck by lightning.

This Recommendation considers two possible earthing configurations:

1) The transformer and the RBS share the same earthing network. This configuration is shown in Figure 1 and should be adopted when the distance between the transformer and the RBS is shorter than 30 m. When the tower is struck by lightning, the EPR may cause flashover of the line insulation at the nearest pole, and the current flowing through the MV arresters would be very high and would damage the arresters. Moreover, other components of the power system could also be damaged.
2) The transformer and the RBS have separated earthing network. This configuration is shown in Figure 2, where the distance between the transformer and the RBS is usually longer than 30 m. When the tower is struck by lightning, the EPR will be applied to the LV side of the transformer and may lead to the breakdown of its insulation. Moreover, if not conveniently specified, the lightning arresters may also be damaged.

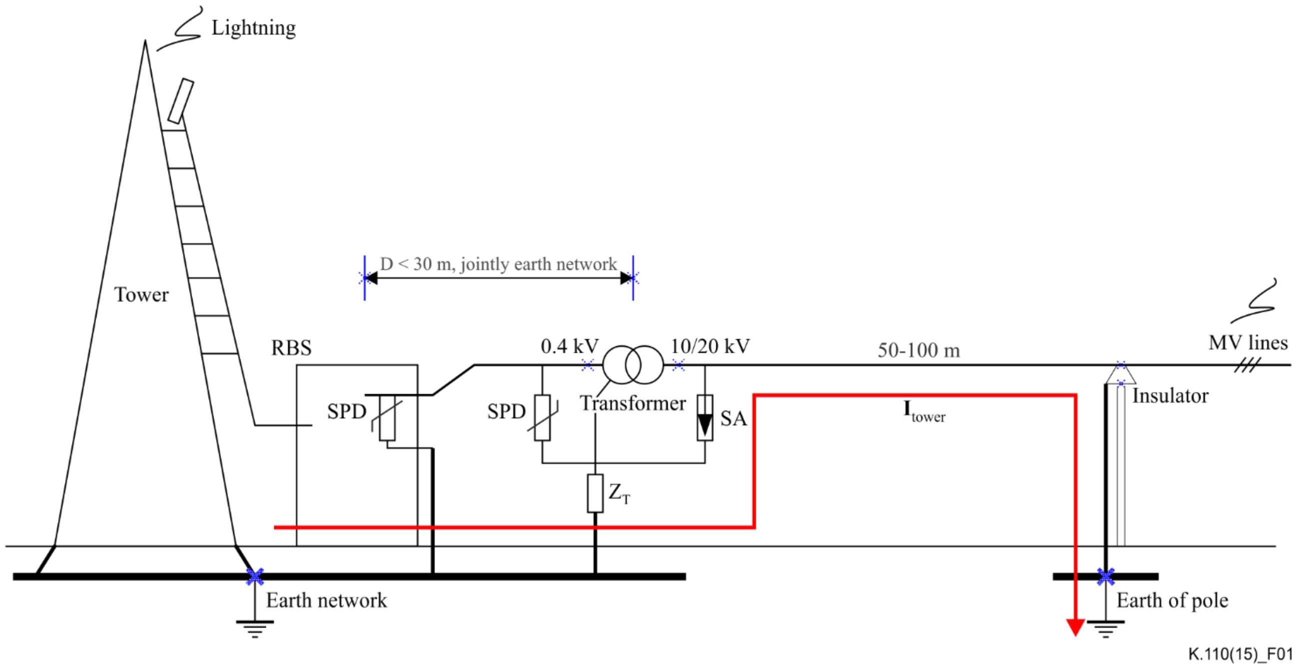

Figure 1 – Reference configuration for earthing network

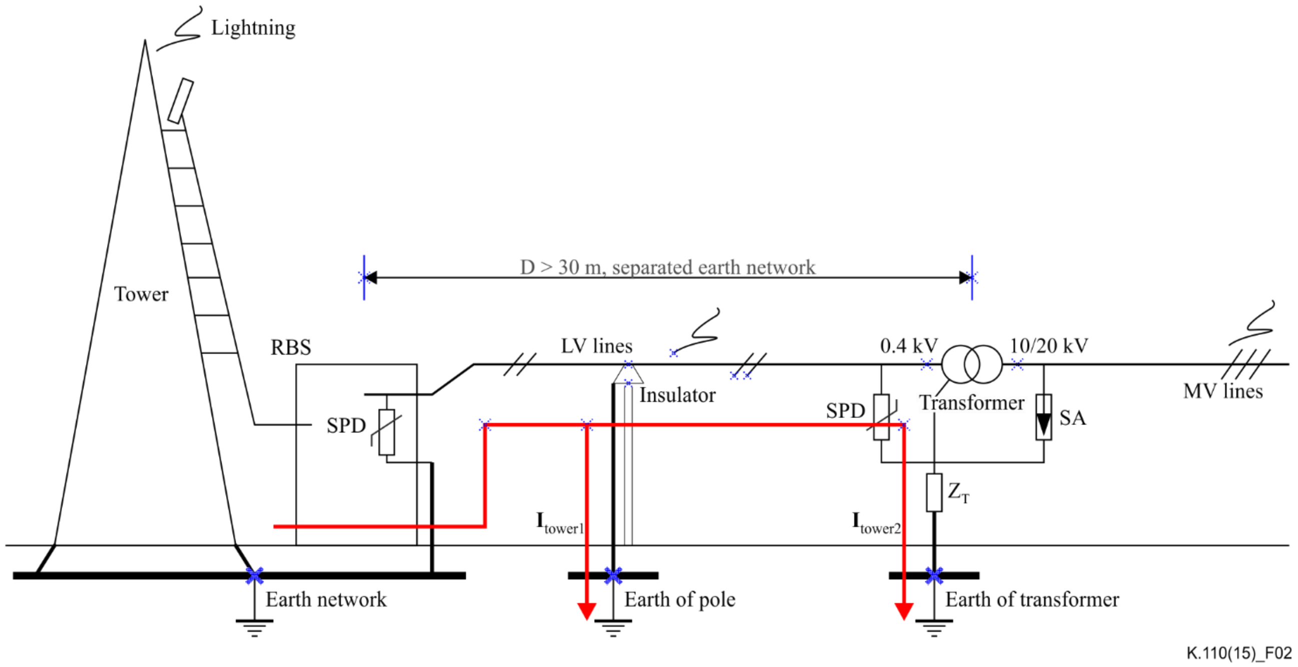

Figure 2 – Reference configuration for separated earthing network

The annual total number of flashes (N) to the RBS site is considered in order to determine the required protection level (Basic, Reinforced, or Special) for the RBS site, as shown in Table 1. Annex A presents the procedure for calculating the total number of flashes (N), as a function of the RBS configuration (common or separated earthing network).

Table 1 – Determination of the protection level

Total annual number of flashes	Protection level
$N \leq 0.5$	Basic
$0.5 < N \leq 1$	Reinforced
$N > 1$	Special

7 Earthing network for transformer and RBS

7.1 Basic principles

A transformer's earthing network should consider the distance between the transformer and the RBS, the site surroundings, geological conditions, soil composition, topography and other factors. The perimeter of the terrain may determine the boundaries of the earthing network.

The depth of earthing electrodes is generally not less than 0.5 m. In rocky hill or gravel soil (thin rocky) situations, the earthing electrode depth should be determined according to the specific circumstances.

The length of vertical earthing rods of the grounding system can be determined by the soil resistivity and presence of rocky layers. The number of vertical earthing rods of the grounding system can be determined by earthing network size and soil resistivity. Vertical earthing rods should be installed at least at the four corners of the earthing network and bonded to it.

More details on earthing networks can be found in [ITU-T K.112].

7.2 Common earthing network

When the transformer and the RBS earthing network are within a range of 30 m, they should share a common earthing network (see Figure 1). The common earthing network should have the shape of a ring conductor, which shall surround the building foundations. The distance between the external walls of the building and the earthing ring should not be less than 0.5 m. The transformer, the RBS and the tower shall be connected to the earthing ring, as well as to the building foundation and other underground facilities, as shown in Figure 3.

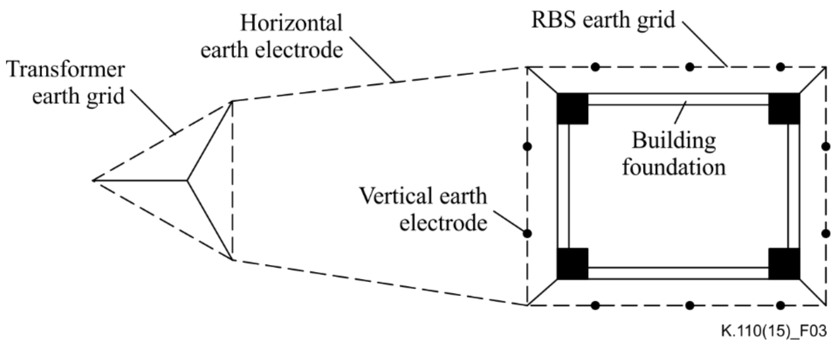

Figure 3 – Ring shape earthing network

7.3 Separated earthing network

When the distance between the transformer and the RBS is greater than 30 m, they shall have separated earthing network. The RBS earthing network is similar to the one described in clause 6.2, excepting that the transformer is not earthed in earthing network. The transformer earthing network shall comply with the following two requirements:

1) A ring electrode in the form of a triangle shall be installed around the transformer and connected to it. This ring shall be made of horizontal electrodes buried at a minimum depth of 0.5 m.

2) Three radial horizontal electrodes shall be installed, extending from the ring electrode. These radial electrodes shall have from 15 m to 20 m and be buried at least at 0.5 m in the soil. The end of each radial electrode shall be connected to a vertical rod, as shown in Figure 4.

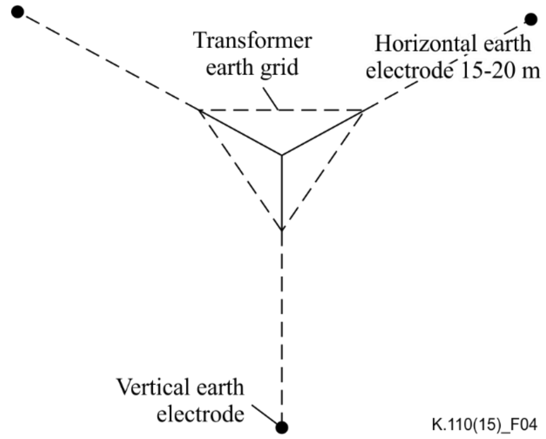

Figure 4 – Transformer earthing network

8 Direct lightning protection

If the transformer is mounted close to the RBS tower, the tower will provide lightning protection as detailed in [IEC 62305-3]. If this is not the case, then appropriate protection measures shall be taken. A protection example would be to have a lightning protection system (lightning rod and down conductor) added to the pole that supports the transformer.

9 Transformer insulation level

The transformer insulation level shall comply with [IEC 60076-3] and [IEC 60076-4]. The most relevant data for the transformer insulation level is summarized in Table 2.

Table 2 – Transformer insulation level

Winding voltage level kV (RMS)	Rated frequency withstand voltage kV (RMS)	Rated impulse withstand voltage kV (Peak)	
		Full-wave	Chopped wave
20	55	125	140
10	35	75	85
0.4 (<1.1 kV)	5	10	–

NOTE – A dedicated transformer located in the suburbs, rural or mountainous areas may be exposed to high overvoltage levels and may require higher insulation levels. These higher levels should be negotiated between the telecommunication operator and the transformer manufacturer.

10 MV/LV arresters requirements

MV/LV arresters should be waterproofed for outdoor mounting and the overall characteristics should comply with [IEC 60099-4]. The nominal current rating (I_N) of the arresters used for protecting the dedicated transformer should be selected while taking into account the field experience at a particular location. In general, a common earthing network configuration (see Figure 1) presents a higher stress to the MV arrester, whereas a separated earthing network (see Figure 2) presents a higher stress to the LV arrester.

If field experience is not available, the data in Table 3 should be used to determine the minimum nominal current rating (I_N) of the arresters used for protecting the dedicated transformer. The required protection level is determined according to clause 6.

Table 3 – Minimum nominal current rating (I_N) of the arresters (8/20 µs waveshape)

Protection level	Common earthing network		Separated earthing network	
	MV arrester	LV arrester	MV arrester	LV arrester
Basic	10 kA	5 kA	5 kA	10 kA
Reinforced	20 kA	10 kA	10 kA	20 kA
Special	under study	20 kA	under study	under study

11 MV/LV arresters installation

Arresters should be used for the protection of the dedicated transformer MV and LV sides. In order to reduce the arrester residual voltage between phase and ground terminals caused by lightning impulses, the impedance of conductors between the arrester and the transformer should be as small as possible. To this aim, the arresters should preferably be fixed on the transformer enclosure directly. The arrester earthing terminal shall be connected to the transformer enclosure and then to the earthing system. This bonding procedure shall be applied to both MV and LV sides and it allows to achieve the lowest residual voltage (see Figure 5).

11.1 Protection schemes

For the Basic protection level, the power distribution box shall have a LV surge protective device (SPD) for the three-phase (3 PH) load of the RBS, indicated as SPD1 in Figure 5. Moreover, another LV SPD shall be installed nearby the transformer LV side, indicated as SPD2 in Figure 5. The protection level of SPD1 shall be selected according to the resistibility level of the RBS equipment, whereas the protection level of SPD2 shall be lower than the insulation level of the transformer LV side for a full-wave impulse (see Table 2).

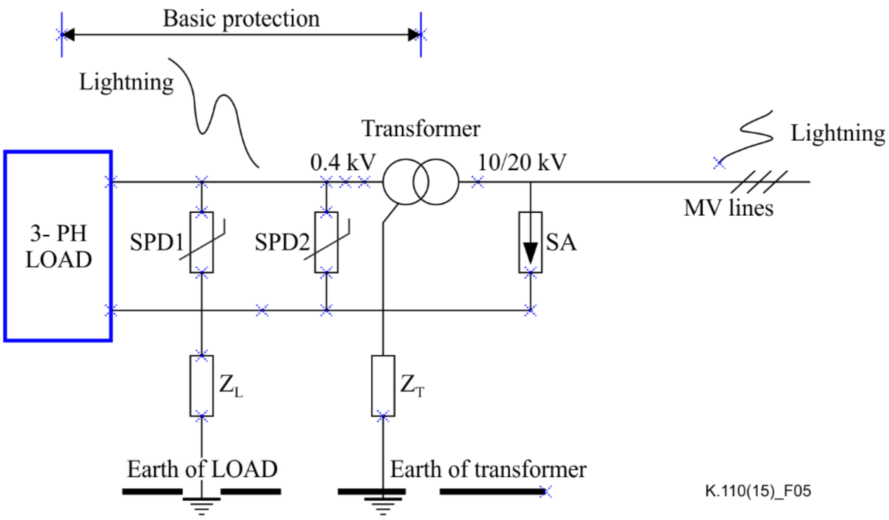

Figure 5 – Protection scheme for Basic protection level

When the protection level is Reinforced or Special, besides the protection procedures for Basic protection level, additional protection shall be applied to the MV line, as shown in Figure 6. This additional protection can be line surge arresters or lightning protection insulators.

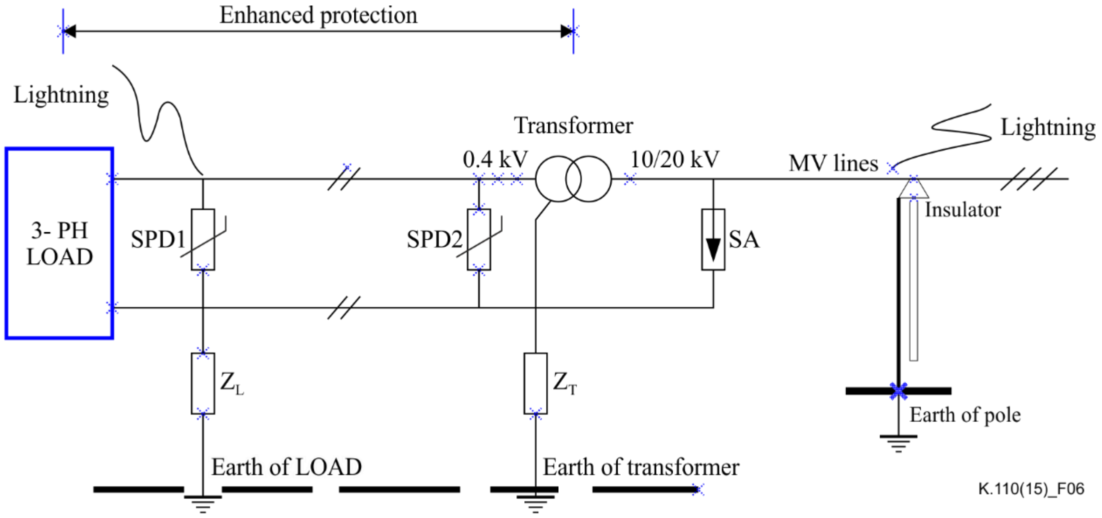

Figure 6 – Protection scheme for Reinforced or Special protection level

11.2 Bonding of the transformer

If the arrester earthing conductor is long, the equivalent overvoltage U_{eq} applied to the transformer is given by:

$$U_{eq} = U_r + U_{line}$$

where U_r is the residual voltage of SPD and U_{line} is the voltage drop along earthing conductor (see Figure 7). As the inductive voltage drop U_{line} may reach high values, the transformer insulation may be damaged even if the arrester is properly specified.

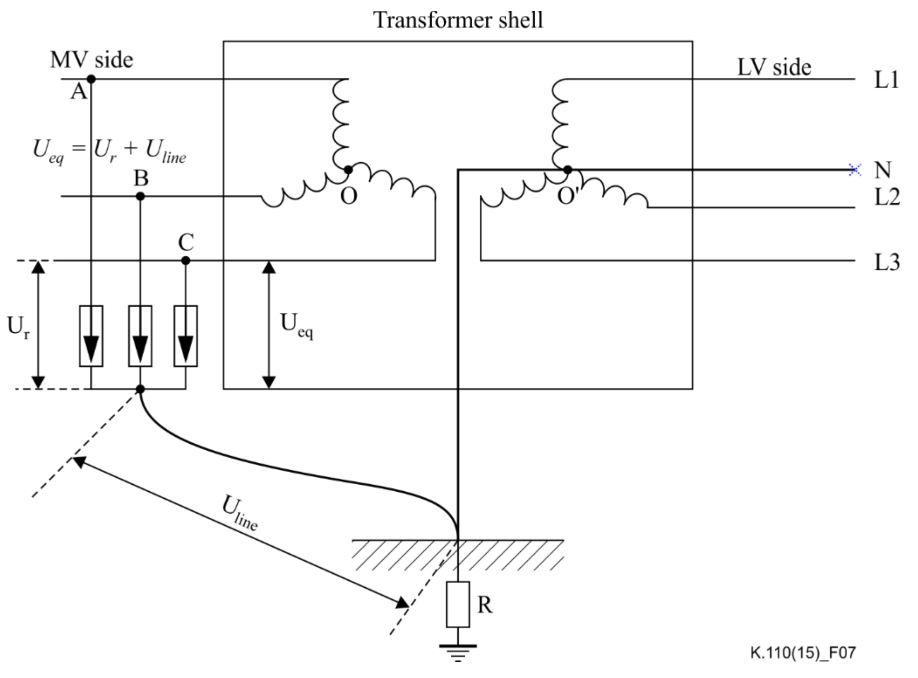

Figure 7 – Incorrect bonding of MV arresters

Transformers are generally installed at a significant height above the ground, leading to a relatively long earthing conductor and, consequently, a high inductive voltage drop. For example, considering that each meter of down-conductor has approximately 1.6 μH, assuming that the surge current may reach 10 kA/μs, then each meter of down-conductor would add about 16 kV to the voltage applied to the transformer winding.

If the arrester ground terminal is directly connected to the transformer enclosure, the value of the voltage applied to the transformer is given basically by the arrester residual voltage, as the inductive voltage drop on the bonding conductor is strongly reduced. This situation is shown in Figure 8.

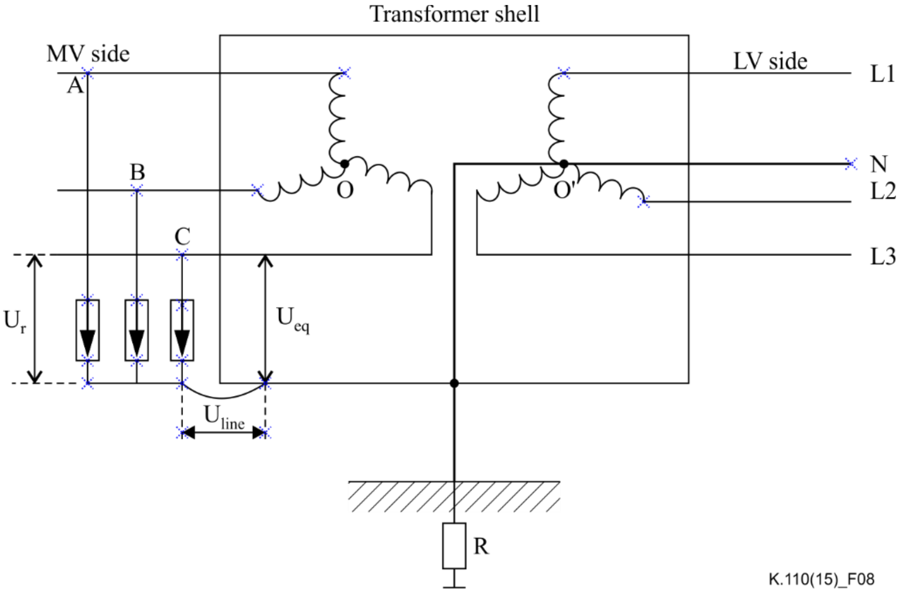

Figure 8 – Correct bonding procedure of MV arresters

When the MV/LV arresters are installed close to the transformer, the residual voltage between phase and earth of the arrester can be further reduced, as illustrated in Figure 9. In this case, the transformer down-conductor shall be connected to the common bonding point of the arresters and transformer enclosure, as shown in Figure 9.

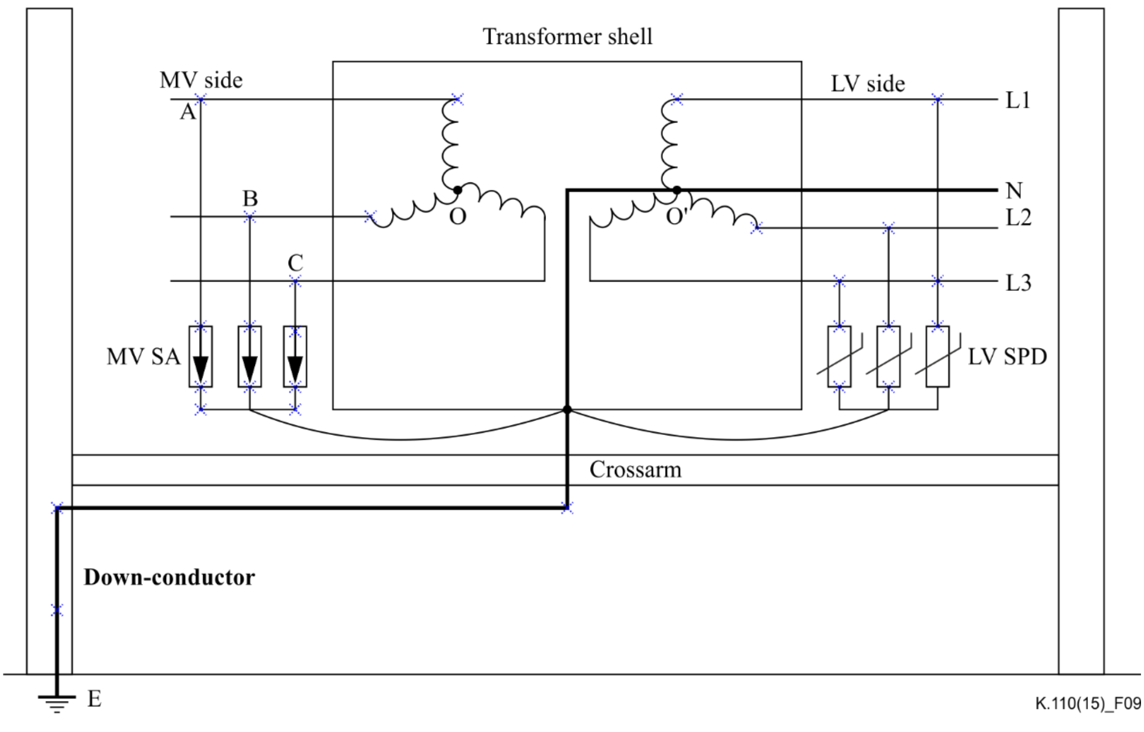

Figure 9 – Earthing and bonding configuration

12 Protection of ancillary facilities

12.1 Power meters

The power meter installed at the RBS shall be protected against lightning. In addition to the earthing procedures that may be required by the power, the earthing bar of the power meter station shall be bonded to the RBS's earthing network. The bonding conductor shall extend from the power meter station up to the closest point of the RBS earthing system and, when applicable, it shall be in contact with the soil.

This conductor shall be treated as part of the RBS earthing system and shall have a minimum cross section equal to 50 mm^2.

SPDs shall be installed at the RBS side of the power meter station (i.e., downstream of the circuit breakers), and these SPDs shall comply with [IEC 61643-11].

The continuous operating voltage (service voltage) of the SPDs shall be sufficiently high so that it will not operate under normal operation or fault conditions of the power line. [IEC 61643-11] provides guidelines for the selection of the SPD continuous operating voltage.

Figure 10 shows a possible configuration for the protection of the power meter.

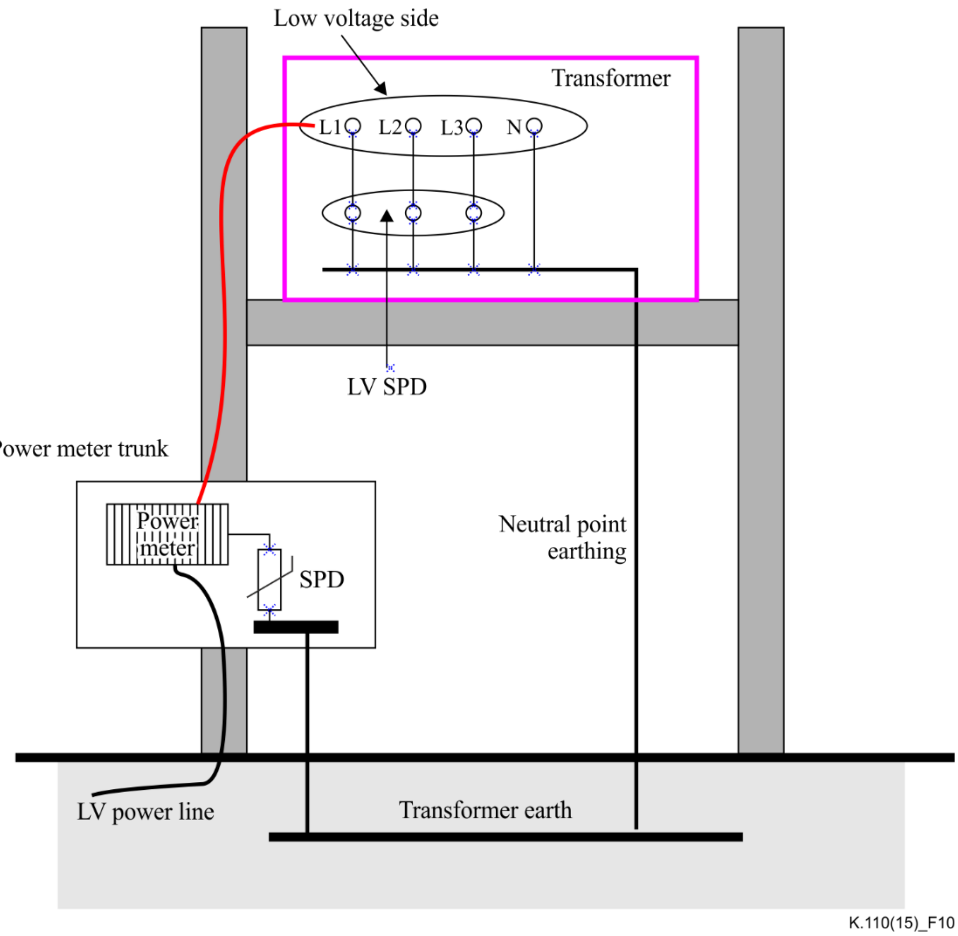

Figure 10 – Protection of power meter

12.2 Power conductors

Power conductors enter the RBS from the transformer LV side, and the following aspects shall be considered:

– if the power line is shielded, its shield shall be bonded to the electric board earthing bar;

– preferably, the power conductors shall exit the electric board inside metallic ducts or trays that shall be bonded to the board frame. The use of plastic duct to carry the power conductors may require the installation of another set of SPDs close to the alternating current (AC) powered equipment (e.g., the power supply).

Annex A

Calculation for lightning risk factors

(This annex forms an integral part of this Recommendation.)

A.1 Lightning risk analysis

The protection need shall be evaluated by the risk assessment of loss of services (R_2) according to [IEC 62305-2]. When the risk is greater than the tolerable risk R_T, defined by the network operator, protection measures are necessary. The comparison between the risk and the tolerable risk allows determining the lightning protection level (LPL) that the protection measure at each equipment interface has to withstand to reduce the risk below the tolerable risk.

The purpose of risk management is to determine the protection level of MV side and LV side of the dedicated transformer. For this particular application, a simplified approach for the evaluation of the protection need, based on [IEC 62305-2], is presented in this Recommendation.

The risk sources include flash to the tower, flash to MV lines, and flash to LV lines. So the protection procedures can be clustered according to the RBS and transformer configurations and to the expected number of direct flashes.

For common earthing network:

$$N = N_D + N_M \quad \text{(A.1)}$$

and for separated earthing network:

$$N = N_D + N_L + N_M \quad \text{(A.2)}$$

where N is the annual total number of flashes to the site, and N_D, N_M, and N_L are the annual number of flashes to the tower, MV line, and LV line, respectively.

According to [ITU-T K.97], the number of direct flashes to the tower (ND) can be calculated by:

$$N_D = 9 \times \pi \times c \times h_t^2 \times N_g \quad \text{(A.3)}$$

where

- c exposition factor (equal to 1 for flat ground and 2 for mountain top)
- h_t tower height (km)
- N_g ground flash density (flashes × km^{-2} × $year^{-1}$).

The number of direct flashes to the MV lines (NM) can be calculated by:

$$N_M = 40 \times N_g \times L \times C_I \times C_E \times C_T \times 10^6 \quad \text{(A.4)}$$

where

- *L* length of the MV lines (m). It is determined by the distance between the upstream protection node and the boundary of protection from tower. Where the length of a line section is unknown, L = 1000 m is to be assumed
- C_I the installation factor of the line (see [IEC 62305-2], Table A.2)
- C_T = 0.2 (see [IEC 62305-2], Table A.3)
- C_E the environmental factor (see [IEC 62305-2], Table A.4).

Similarly, the number of direct flashes to the LV lines (NL) can be calculated by:

$$N_L = 40 \cdot N_g \cdot L \cdot C_I \cdot C_E \, C_T \times 10^{-6} \quad \text{(A.5)}$$

where

L the length of the LV lines (m). It is determined by the distance between the transformer and the boundary of protection from tower.

The annual total number of flashes (N) is considered in order to determine the required protection level (Basic, Reinforced, or Special) for the RBS site, as shown in Table A.1.

Table A.1 – Determination of the protection level

Total annual number of flashes	Protection level
$N \leq 0.5$	Basic
$0.5 < N \leq 1$	Reinforced
$N > 1$	Special

A.2 Calculation examples

1) Flashes to the tower (N_D)

If $N_g = 0.04 \times T_d^{1.25} = 2.1$ per km^2 and year for $T_d = 24$ (thunderstorm days/year)

$$N_D = 9 \times \pi \times 2 \times (0.04)^2 \times 2.1 \approx 0.2 \text{ flashes per year}$$

or if $N_g = 0.04 \times T_d^{1.25} = 12.6$ for $T_d = 100$ (thunderstorm days/year)

$$N_D = 9 \times \pi \times 2 \times (0.04)^2 \times 12.6 \approx 1.2 \text{ flashes per year}$$

2) Flashes to the MV line (N_M)

$C_I = 1$ for aerial line

$C_E = 1$ for line environmental is rural

$C_T = 0.2$ (see [IEC 62305-2], Table A.3)

L = 500 m (MV line is 500 m long)

If $N_g = 0.04 \times T_d^{1.25} = 2.1$ for $T_d = 24$

$N_M = 40 \cdot N_g \cdot L \cdot C_I \cdot C_E \cdot C_T \times 10^{-6} = 40*2.1*500*1*1*0.2*10^{-6} = 0.0084$ flashes per year

or if $N_g = 0.04 \times T_d^{1.25} = 12.6$ for $T_d = 100$

L = 3000 m (MV line is 3000 m long)

$N_M = 40 \cdot N_g \cdot L \cdot C_I \cdot C_E \cdot C_T \times 10^{-6} = 40*12.6*3000*1*1*0.2*10^{-6} = 0.3$ flashes per year

3) Flashes to the LV line (N_L)

$C_I = 1$ for aerial line

$C_E = 1$ for line environmental is rural

$C_T = 1$ (see [IEC 62305-2], Table A.3)

L = 30 metres for low voltage line is 30 metres long

If $N_g = 0.04 \times T_d^{1.25} = 2.1$ for $T_d = 24$

$N_L = 40 \cdot N_g \cdot L \cdot C_I \cdot C_E \cdot C_T \times 10^{-6} = 40*2.1*30*1*1*1*10^{-6} = 0.0025$ flashes per year

or if $N_g = 0.04 \times T_d^{1.25} = 12.6$ for $T_d = 100$

L=500 m (LV line is 500 m)

$N_L = 40 \cdot N_g \cdot L \cdot C_I \cdot C_E \cdot C_T \times 10^{-6} = 40*12.6*500*1*1*1*10^{-6} = 0.25$ flashes per year

The results of these examples are summarized in Table A.2, along with the determination of the protection level required for the RBS and dedicated transformer.

Table A.2 – Examples of protection level determination

Conditions considered	Calculation of N	Protection level
T_d = 24 and common earthing network	N = 0.2 +0.0084 = 0.20084 $N \leq 0.5$	Basic
T_d = 60 and common or separated earthing network	N = 0.64 + 0.3 = 0.94 $0.5 < N \leq 1$	Reinforced
T_d = 100 and separated earthing network:	N = 1.2 + 0.25 + 0.3 = 1.75 $N > 1$	Special

Appendix I

Analysis on the reasons of lightning damage

(This appendix does not form integral part of this Recommendation.)

I.1 Analysis of the processes that may lead to damage

For the MV and LV power distribution system (under 35 kV), the power utility only considers the protection of the conducted and induced overvoltage derived from a distant lightning flash, but not the direct lightning flash on, or near, the power lines and its effects on the transformer. Under this approach, only the MV side of the transformer are usually equipped with arresters. Considering the flashover of the lines to earth (the insulation level of MV lines is low) and the wave impedance of the MV lines, the discharge current capacity of the equipped MV arrester is low. For instance, in China the rated discharge current of MV arrester is only 5 kA (8/20 µs waveshape). But due to the presence of a tall metallic tower of a RBS and the severe environment, the protection of dedicated transformers for RBSs becomes much more complex. The main processes that may lead to damage are described as follows.

I.1.1 Influence from the EPR when lightning strikes a tower

When lightning strikes a tall metallic tower, the lightning current flows into the earth and the EPR can reach a level of hundreds of kV or more. The operation of SPDs in RBS or MV arresters would deliver the high potential to the connected lines and the high potential would be transmitted along the lines. Two distinct situations need to be considered:

– when the transformer and the RBS share the same earthing network, the conducted high voltage may cause the flashover of lines to earth on the nearest pole, and the current flowing through MV arresters would be very high, leading to damage of the MV arresters. Moreover, the safety of the power supply and the power lines are also affected;

– when the transformer and the RBS have a separated earthing network, the EPR will be applied to the LV side of the transformer and may lead to the breakdown of its insulation.

I.1.2 Induced voltages due to a lightning stroke current

Due to the short distance between the transformer lines and the metallic tower, when the latter is struck by lightning, the induced voltages will be very high. Figure I.1 shows the diagram of the induced voltage when a lightning flash hits a tower.

Because of the existence of a tall tower, the probability of a lightning flash stroke increases greatly, which can shorten the life of arresters and other protective devices. Therefore, these protective components shall be specified with a reasonable safety margin.

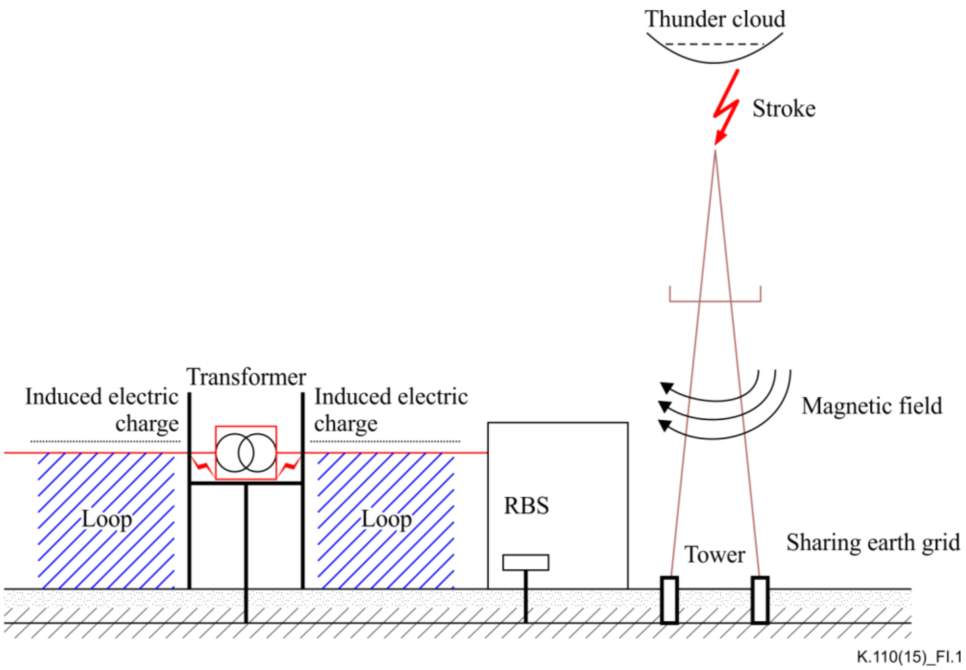

Figure I.1 – Common-mode induced voltage due to a lightning strike to a tower

I.1.3 Direct flashes to the lines

Depending on the degree of exposure, the LV and MV aerial lines nearby the transformer (within 1~2 km) may be struck by a lightning flash. Due to the close distance between the point of stroke and the transformer, the MV arrester would operate first and thus the breakdown of the line insulation is unlikely. The overvoltage and overcurrent along the conductor will be very large, which may be beyond the capability of the MV arrester. Therefore, a dedicated transformer for the RBS needs a specific approach from a lightning protection point of view.

I.2 Reasons for transformer damage

The main reasons for transformer damage include the following:

1) When damaged MV arresters are not replaced in time, then the next lightning flash may destroy the transformer.

2) Overvoltage from LV lines may breakdown the insulation of transformers directly.

3) The earthing conductor of the arrester is too long so that the residual voltage drop on the arrester and earthing conductor would be higher than the insulation capacity of transformers. Figure I.2 shows an analysis of the residual voltage for an incorrect connection of transformer and arrester.

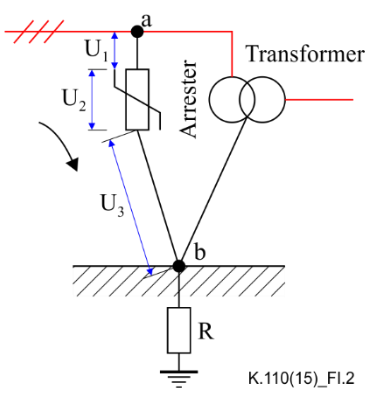

Figure I.2 – Incorrect connection of transformer and arrester

I.3 Forward transformation overvoltage (FTO)

The overvoltage from LV lines introduces a surge in LV winding, which produces a high voltage on the neutral point of MV side according to the ratio of the number of windings between MV and LV. If the MV neutral point is ungrounded and the MV winding is protected by surge arresters, a high voltage will appear on the MV neutral point, which may breakdown the MV neutral insulation and destroy the transformer. Figure I.3 illustrates this process.

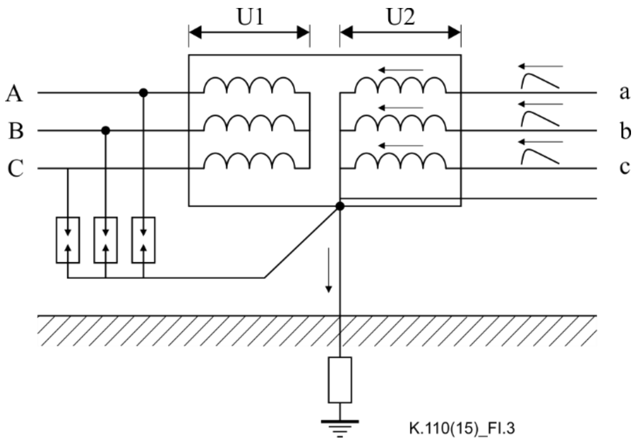

Figure I.3 – Illustration of FTO

I.4 Inverse transformation overvoltage (ITO)

When the MV arresters operate, the lightning current flows into the earth grid and the potential would rise. Because the neutral point of LV side is connected to earth directly, the EPR is applied to the neutral of the LV windings. Then this high voltage will be applied on LV the winding mostly, because the surge impedance of winding is much higher than the one of the lines. Similar to the FTO, this overvoltage may destroy the insulation of neutral point or winding of MV side. Figure I.4 illustrates this process.

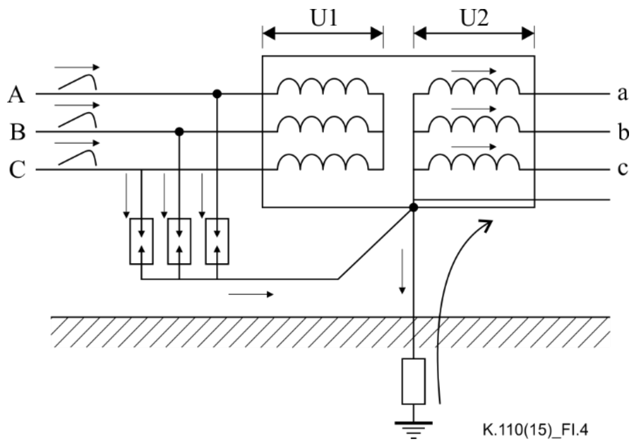

Figure I.4 – Illustration of ITO

Theoretical and experimental investigation have shown that when lightning strikes a tower, surge voltage will be generated on the transformer MV side and LV side.

Based on field experience and simulation results, when there is a lighting event on the tower of a base station or near the facility, the dedicated transformer of the based station will experience very high overvoltages on its low-voltage side terminals even for low peak values of lightning current. In most cases, these overvoltages are above the insulation level of the transformer, which will cause its failure. The installation of an SPD at the low-voltage side of the transformer will reduce the observed overvoltages to values far lower than the insulation level of the transformer and thus retain the reliability of the site.

Appendix II

Selection and installation of MV/LV arresters

(This appendix does not form integral part of this Recommendation.)

II.1 Solidly earthed power distribution systems

Metal-oxide surge arresters without gaps are widely used for solidly earthed power distribution systems. The rated voltage (U_R) of the surge arrester should be greater than the maximum line-voltage that may occur on the power system. Continuous operating voltage (U_c) should be greater than the maximum phase-voltage that maybe occur on the power system. Nominal discharge current (I_N) should be greater than or equal to 10 kA, with residual voltage (U_{res}) not greater than 65% and 52% of the nominal system insulation level of the MV and LV sides, respectively.

Peak current value (I_{peak}, 4/10 μs) is selected by the manufacturer to obtain a particular discharge energy. The energy shall not be higher than the total energy in two line discharges of the classifying class or the energy due to one high current impulse, 100 kA, 4/10 μs. If not applicable, operating duty tests shall be repeated with increased energy to cover the claimed energy.

Heat-melt disconnectors may present a blind zone for the dedicated transformers. If the sample varistor breaks down momentary, it may form a carbonized channel, and the heat-melt disconnector will lose its heat source. In some cases (such as in as outdoor applications), the heat-melt disconnector may fail to operate. As the low-voltage side of the dedicated transformer has no overcurrent protection, lightning damage will cause permanent system failure.

Heat-blast disconnectors shall have low residual voltage, in order to have little effect on the residual voltage accumulated on the arrester. Mounting-bracket materials for disconnectors and arresters should use waterproof materials. The use of plastic materials should be avoided, as its service life is much shorter than that of composite materials.

II.2 Non-solidly earthed power distribution systems

For non-solidly earthed power distribution systems, the power supply does not switch off when one phase short circuits to ground, and the other two phases raise up to the line voltage. As the dedicated transformer is usually connected to a long power line that has a relatively low load, these conditions may give rise to intermittent arcing discharge or ferromagnetic resonance overvoltage. The overvoltage amplitude may exceed the arrester U_R. Once resonance overvoltage happens, they will be sustained until the line resonance conditions remain. This duration may be much greater than the tolerance time of U_R (e.g., it may be much much longer than 10 s).

This kind of overvoltage does not threaten the other power supply equipment, other than metal-oxide surge arresters without gaps. These devices may explode when installed in non-solidly earthed power distribution systems, when the resonant voltage amplitude and duration exceed the arrester capabilities. Therefore, the specification of the arrester rated voltage and protective level (residual voltage) requires a compromising solution.

For non-solidly earthed power distribution systems, the power-frequency withstand voltage should be greater than or equal to 1.4 U_R (1.4*17 = 24 kV). However, the residual voltage of the arrester is likely to exceed the transformer insulation, which will compromise the insulation coordination. In this case, metal-oxide surge arresters without gaps are recommended.

II.3 Installation of MV/LV arresters and drop-out fuse

For maintenance purposes and also to improve the arrester performance, MV arresters are usually mounted on the rear side of a drop-out fuse. In this case, the lightning current goes through the drop-out fuse first, and then flows into the ground via arresters. As transformers have small-size fuses, when a large lightning current passes through the arrester, the fuse will still operate.

During a thunderstorm, a first lightning stroke may operate the drop-out fuse. When a second lightning pulse arrives, it may cause flashover of the support insulator flashover. Moreover, due to the single-phase loss, the other phases will be overloaded and the system may switch off. On the other hand, if the arrester is installed in front of a drop-out fuse, the maintenance becomes difficult.

Because most of the lightning surges come from the MV side of the transformer, additional protection should be installed before the drop-out fuse. By doing this, part of the energy of the incoming lightning surge is prevented from reaching the transformer, avoiding the problems caused by drop-out fuse operation. This additional protection can be arresters or specially-designed lightning insulators, installed on a pole located about 2 to 3 line spans from the transformer. In thunderstorm-prone areas, additional protection should be installed at several points along the entire power line, in order to assure a high reliability. If the LV line connected to a transformer is too long, the installation of additional protection on the LV line should be considered.

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