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**Dangerous effects and protective measures
against electromagnetic disturbances when an
Internet data centre is co-sited with a high-
voltage substation**

Recommendation ITU-T K.125



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Summary

Recommendation ITU-T K.125 specifies calculation methods for dangerous effects, tolerance limits of dangerous effects, tolerance limits of electromagnetic effects from a high-voltage substation, distance requirement and protection methods, protective measures, as well as requirements for the power frequency magnetic field immunity of servers when an Internet data centre is co-sited with a high-voltage substation.

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Recommendation ITU-T K.125

Dangerous effects and protective measures against electromagnetic disturbances when an Internet data centre is co-sited with a high-voltage substation

1 Scope

This Recommendation specifies calculation methods for dangerous effects, tolerance limits of dangerous effects, tolerance limits of electromagnetic effects from a high-voltage substation, distance requirement and protection methods, protective measures, as well as requirements for power frequency magnetic field immunity of servers when an Internet data centre (IDC) is co-sited with a high-voltage substation.

This Recommendation discusses co-sites for an IDC and a high-voltage substation while taking into account proximity, the co-earthing network, and shared accommodation.

This Recommendation is applicable to IDCs and large communication centres co-sited with high-voltage substations. It is possible that this Recommendation may not apply to small Internet data sites.

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.104] Recommendation ITU-T K.104 (2015), *Method for identifying the transfer potential of the earth potential rise from high or medium voltage networks to the earthing system or neutral of low voltage networks.*
- [ITU-T K.107] Recommendation ITU-T K.107 (2015), *Method for determining the impedance to earth of earthing systems.*
- [IEC 61000-4-8] IEC 61000-4-8:2009, *Electromagnetic compatibility (EMC) – Part 4-8: Testing and measurement techniques – Power frequency magnetic field immunity test.*

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 common bonding network (CBN) [b-ITU-T K.27]: The CBN is the principal means for effecting bonding and earthing inside a telecommunication building. It is the set of metallic components that are intentionally or incidentally interconnected to form the principal bonding network (BN) in a building. These components include: structural steel or reinforcing rods, metallic plumbing, AC power conduit, protective conductors (PEs), cable racks and bonding conductors. The CBN always has a mesh topology and is connected to the earthing network.

3.1.2 earthing network [b-ITU-T K.27]: The part of an earthing installation that is restricted to the earth electrodes and their interconnections.

3.1.3 (effective) touch voltage (195-05-11 of [b-IEV]): Voltage between conductive parts when touched simultaneously by a person or an animal.

NOTE – The value of the effective touch voltage may be appreciably influenced by the impedance of the person or the animal in electric contact with these conductive parts.

3.1.4 grounded system [b-IEEE Std. 142]: A system in which at least one conductor or point (usually the middle wire or neutral point of transformer or generator windings) is intentionally grounded, either solidly or through an impedance.

3.1.5 high-resistance grounded [b-IEEE Std. 142]: A resistance-grounded system designed to limit ground-fault current to a value that can be allowed to flow for an extended period of time, while still meeting the criteria of $R_0 < X_{co}$, so that transient voltages from arcing ground faults are reduced. The ground-fault current is usually limited to less than 10 A, resulting in limited damage even during prolonged faults.

NOTE – R_0 is the per-phase zero-sequence resistance of the system; X_{co} is the distributed per-phase capacitive reactance to ground of the system.

3.1.6 inductive coupling (131-12-33 of [b-IEV]): Coupling between electric circuit elements, by which an electric current in one of them gives rise to a linked flux between the terminals of another element.

3.1.7 low-resistance grounded [b-IEEE Std. 142]: A resistance-grounded system that permits a higher ground-fault current to flow to obtain sufficient current for selective relay operation. Usually meets the criteria of R_0/X_0 less than or equal to 2. Ground-fault current is typically between 100 A and 1 000 A.

NOTE – R_0 is the per-phase zero-sequence resistance of the system; X_0 is the zero-sequence reactance of the system.

3.1.8 resonant grounded [b-IEEE Std. 142]: A system in which the capacitive charging current is neutralized by an inductive current produced from a reactor connected between the system neutral and ground. By properly “tuning” the reactor (selecting the right tap), a low magnitude of fault current can be achieved. In general, when this occurs the arc will not maintain itself and the ground fault is extinguished or “quenched.” In a parallel circuit, consisting of L and C , this happens when,

$$\omega L = \frac{1}{\omega C} \quad \text{or} \quad f = \frac{1}{2\pi\sqrt{LC}}$$

NOTE – C is capacitance; f is frequency; L is inductance; ω is angular frequency.

3.1.9 solidly grounded [b-IEEE Std. 142]: Connected directly through an adequate ground connection in which no impedance has been intentionally inserted.

NOTE – *Grounded* is a synonym of *earthed*. The term *earthed* is used instead of *grounded* hereafter in this Recommendation for the sake of consistency.

3.1.10 step voltage (195-05-12 of [b-IEV]): Voltage between two points on the Earth's surface that are 1 m distant from each other, which is considered to be the stride length of a person.

3.1.11 ungrounded system [b-IEEE Std. 142]: A system without an intentional connection to ground except through potential indicating or measuring devices or other very high-impedance devices.

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 dangerous effect: Effect on telecommunication line maintenance personnel and telecommunication equipment when power lines under normal operation or accident conditions induce nearby telecommunication lines and facilities to generate current and voltage due to the influences of inductive, capacitive and resistive couplings.

3.2.2 synthesized tolerance limits of dangerous effects from high-voltage: Vector sum of inductive coupling effect and resistive coupling effect on an Internet data centre from a high-voltage substation.

3.2.3 current-earthing coefficient: A ratio of the magnitude of current going back to earthed neutral point of the substation through earth return path from faulty short circuit point to the magnitude of total short circuit current going back to earthed neutral point of the substation transformer through earthing system and earth return path.

3.2.4 current-sharing coefficient: The value obtained by subtracting the current-earthing coefficient from 1.

3.2.5 transient co-earthed: The working earthing and shield earthing of an Internet data centre, as well as other earthing for lightning arrestors and surge protective devices, are divided into two independent earthing systems that are connected together using a transient earthing protector; the two systems are unified if subject to lightning strike and work separately during normal operation.

3.2.6 high trustworthy power transmission lines: Power transmission lines of the neutral point directly earthed system, having low failure rate, with short single phase earthing shorted fault current duration, typically less than 0.2 s, but not more than 0.5 s in most cases.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

CRT	Cathode Ray Tube
EMF	Electromotive Force
EPR	Earth Potential Rise
ICT	Information and Communication Technology
IDC	Internet Data Centre
RMS	Root Mean Square

5 Conventions

None.

6 Reference configuration

Where an IDC is co-sited with a high-voltage substation, basically two factors should be taken into consideration: the longitudinal electromotive force (EMF) on the communication wires and cables that is induced from the transmission power system, and earth potential rise (EPR) of the earthing system in an IDC that is coupled through the earthing network. The vector sum of the two factors forms the dangerous effects on IDC, as shown in Figure 1.

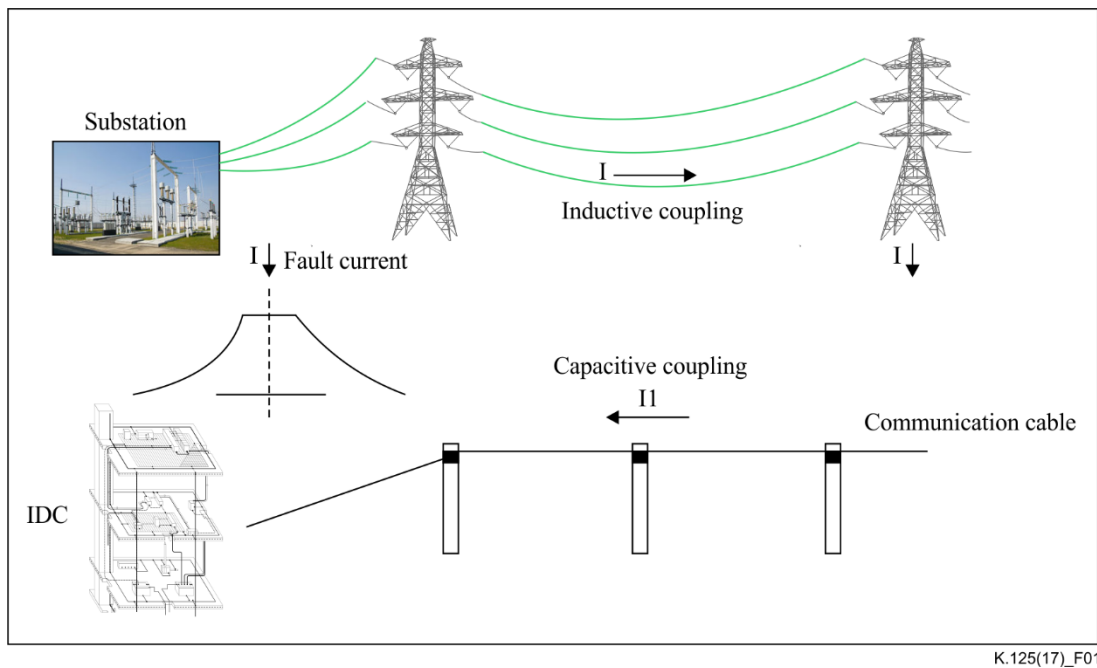


Figure 1 - Reference structure of approach to synthesized dangerous effects on an Internet data centre from a high-voltage substation

7 Analysis on dangerous effect

7.1 Earthed type of high-voltage power system

Power systems are classified into several types according to the earthing methods of their neutral point. The earthing method influences the rating and duration of fault current, thus influencing the magnitude of the EPR.

For a power system having a solidly earthed or low-impedance earthed neutral point, the earth fault current is relatively high and the fault will be cleared by the relaying protection system in a short time.

For a power system with a resonant earthed or high impedance earthed neutral point, the earth fault current is relatively low, typically not more than 100 A, and the earth fault time is relatively short. This kind of system can be provided with a delayed trip to clear a persistent earth fault.

For a power system with an unearthed neutral point, the earth fault current is generally low, but the fault duration can be long. A large scale power system can cause a very high capacitive fault current. If this kind of system is equipped with automatic fault clearance devices, the fault duration is shortened to some extent.

The earth current generated by an earth fault of the power system results in an EPR at the points where the fault current is conducted into and out of the earth. The EPR is measured in relation to earth potential in the distant neutral earth. The values of earth potential and extended range depend on:

- the rating of the fault current;
- the earthing resistance of the high-voltage substation;
- the current-earthing coefficient of the fault point;
- the soil resistivity;
- the layout of the earthing device;
- the earthed type of power system;

- the environmental conditions of the IDC;
- the transmission mode of transmission lines (overhead transmission line, buried power cable, cable metal sheath, power supply circuit, etc.).

7.2 Calculation of dangerous effects

The calculated value of synthesized dangerous effects on IDC from high-voltage transmission system is determined by the root mean square (RMS) value of the magnetic induced longitudinal EMF of high-voltage transmission system to communication line and the EPR of high-voltage transmission system earth electrode in the proximity of IDC as follows:

$$U = \sqrt{E^2 + V^2} \quad (1)$$

where

E : inductive coupling of the longitudinal EMF

V : resistive coupling of the EPR.

Typically, a common bonding network is used inside an IDC, therefore the EPR cannot damage the communication equipment without wires and cables into and out of the site. However, all kinds of equipment with wires and cables into and out of the site can be affected by an EPR from an earth fault of a high-voltage power system.

The tolerance limits need to take into consideration not only personal safety, but also the insulation tolerance levels of wires and cables into or out of the site.

In a solidly earthed neutral point system, tolerance should be calculated according to the single phase earth fault.

[b-ITU-T Dir. Vol.II] and [b-ITU-T Dir. Vol.III] give details of the calculation method for values of induced voltages and currents.

[ITU-T K.104] and [ITU-T K.107] give details of the calculation method and relevant information about EPR.

8 Synthesized tolerance limits of dangerous effects from high-voltage

8.1 General requirements

The synthesized tolerance limits of dangerous effects of a high-voltage on an IDC are established on the basis that:

- a common bonding network is recommended – for those sites where common earthing is difficult, transient co-earthed method should be applied;
- the earth fault clearing time is short through a highly reliable and fast clearance system of the high-voltage substation; and
- there are rationally planned wires, cables and metallic pipes into and out of the site.

8.2 Synthesized tolerance limits

For an IDC adjacent to a high-voltage substation or transmission system, but not a co-earthing network, the synthesized tolerance limit of dangerous effects is 1 000 V, and the clearing time for an earth fault in the high-voltage substation is limited to 350 ms.

For an IDC co-sited, but transiently co-earthed with a high-voltage substation, the synthesized tolerance limit of dangerous effects is 1 500 V, and the clearing time for an earth fault in the high-voltage substation is limited to 200 ms.

For an IDC co-sited and in a co-earthing network with a high-voltage substation, the synthesized tolerance limit of dangerous effects is 2 000 V, and the clearing time for an earth fault in the high-voltage substation is limited to 100 ms.

For an IDC co-sited with a high-voltage substation, the power frequency magnetic field limit for an information and communication technology (ICT) equipment room is 30 A/m.

NOTE – See Table II.1 for the value of synthesized tolerance limits, extracted from [b-ITU-T K.68].

9 Protective measures

Concerns about co-sites for an IDC and a high-voltage substation include proximity, co-earthing network and shared accommodation. Proximity mainly involves the dangerous effects on an IDC of a resistive-coupling EPR when an earthing short circuit accident happens in the high-voltage substation. For an IDC that has a common earthing network or a common building room with the high-voltage substation, concern mainly involves the dangerous effects on the IDC from the resistive coupling EPR when an earthing short circuit accident happens to the high-voltage substation and the dangerous effects on servers of the magnetic field distribution generated by the high-voltage substation.

In order to decide whether protection measures should be taken when an IDC is co-sited with a high-voltage substation, the dangerous effect value is calculated according to clause 6. If the dangerous effect value is greater than the synthesized tolerance limits, the protective measures listed in clause 9.1 should be implemented, according to the specific circumstances.

9.1 IDC that is in close proximity, but not co-earthed with a high-voltage substation

The following are the protective measures to be taken into account when an IDC is in close proximity, but not co-earthed with a high-voltage substation:

- 1) In the course of planning and design, adequate separation between a high-voltage substation and an IDC should be ensured.
- 2) Measures should be taken to maximize the distance of the earthing networks of the IDC and the high-voltage substation.
- 3) The clearing time during an earth fault for the high-voltage substation should be less than 0.35 s.
- 4) The resistances of the earthing networks for the substation and the IDC should be as low as possible, typically not more than 1 Ω .
- 5) To decrease the magnitude of current flowing into the earthing network when an earth fault occurs in a high-voltage substation, the high-voltage power cable should be buried with its shield or metallic sheath earthed at both ends. The electrical continuity of the shield or metallic sheath should be ensured.
- 6) Insulation segments should be inserted at the endpoints of pipes connecting various metallic pipes into and out of the station.
- 7) For power cables from a high-voltage substation to an IDC outside the earthing network, it is recommended that non-armoured cables be used to prevent fault current flowing into the IDC earthing network.
- 8) Optical cables should be used as the communication and control cables between a high-voltage substation and an IDC. It is recommended that fibre without metallic trace wires be used.
- 9) Optical cables should be used between the decentralized server room communication systems. It is recommended that fibre without metallic trace wires be used.

9.2 IDC is co-earthed with high-voltage substation

In the case where an IDC is co-earthed with high-voltage substation, the following measures should be taken:

- 1) The natural earthing electrodes of all buildings on the site should be mutually connected to form a single earthing network. The earthing resistance of the earthing network should be maintained to within 0.1 Ω .
- 2) The clearing time during an earth fault for the high-voltage substation should be less than 0.1 s.
- 3) To decrease the magnitude of current flowing into the earthing network when an earth fault occurs in a high-voltage substation, the high-voltage power cable should be buried with its shield or metallic sheath earthed at both ends. The electrical continuity of the shield or metallic sheath should be ensured.
- 4) Insulation segments should be inserted at the endpoints of pipes connecting various metallic pipes in and out of the station.
- 5) Optical cables should be used as the communication and control cables between a high-voltage substation and an IDC. It is recommended that fibre without metallic trace wires be used.
- 6) Optical cables should be used between the decentralized server room communication systems. It is recommended that fibre without metallic trace wires be used.

9.3 Methods for shortening the clearing time for earth fault

The fault clearing time is the duration between a fault occurrence and its complete clearance from the power system. It includes the full operating time to relay protection and the trip time of the circuit breaker.

Typical values of fault clearing time are in the range of 0.08-0.5 s. The following measures can be considered in order to clear the fault within 0.1 s:

- use a high-speed circuit breaker to ensure the excellent mechanical driving performance of the breakers and reduce the inherent operating time limit;
- select breakers with a high arc suppression performance to improve the arc breaking capacity;
- use a fast contactless lockout in the intermediate relay of the protective device;
- use a high-precision time limit monitoring instrument to measure the operating time of protective devices and switchgear, thus shortening the fault clearance time.

9.4 Step voltage and touch voltage

When an IDC is co-sited with a high-voltage substation, issues, such as soil resistivity, the layout of buildings and the layout of cables, should be taken comprehensively into account.

Special measures should be taken in order to maintain the step voltage and touch voltage in a safe range. For example, by increasing surface soil resistivity, the contact resistance between the feet and the earth can be increased, which can decrease the current passing through the human body, leading to reductions in step voltage and touch voltage.

10 Power frequency magnetic field and its mitigation measures

10.1 Characteristics of a power frequency magnetic field in a high-voltage substation

A continuous power frequency electric field and magnetic field are generated in the normal operation of a high-voltage substation. When a power frequency short circuit happens at the

substation, the short circuit current also generates a strong short-time power frequency electric field and magnetic field. Generally, the power frequency electric field does not cause hazards to personnel and equipment in a co-sited IDC due to the existence of reinforcing bars inside the building. However, the reinforcing bar structure has almost no shielding effect on the power frequency magnetic field, so hazards to ICT equipment in the co-sited IDC can occur.

Within a high-voltage substation, a power frequency magnetic field is mainly generated by conductors and equipment including a current-carrying conductor, transformer, reactor and capacitor banks, which carry a large load current. The power frequency magnetic field rapidly declines with increase in distance.

10.2 Power frequency magnetic field immunity requirements of servers in a cloud data centre

In [IEC 61000-4-8], the power frequency magnetic field immunity test is classified into two categories: continuous and short duration, simulating the magnetic fields during normal operation and short circuit fault, respectively. The test levels are classified into five classes based on the application environment, as shown in Table 1.

Table 1 – The level classification for power frequency magnetic field immunity test

Class	Magnetic field strength/(A/m)	Magnetic field strength for short durations of 1–3 s/(A/m)
1	1	—
2	3	—
3	10	—
4	30	300
5	100	1 000

At present, for all kinds of communication equipment (excluding display and magnetism-sensitive devices using electron beams), the power frequency magnetic immunity test level is class 2, i.e., the permissible power frequency magnetic field strength of communication equipment is 3 A/m, but there is no requirement for short-duration power frequency magnetic field immunity.

It is suggested that class 4 in Table 1 be used for the immunity test of ICT equipment in an IDC co-sited with a high-voltage substation.

10.3 Mitigation measures for the effect of power frequency magnetic field

When an IDC is co-sited with a high-voltage substation, mitigation measures should be considered, on the one hand, to control the continuous and short time magnetic field strength where IDC equipment, especially data servers, is installed; and on the other, to increase the immunity of ICT equipment.

The following mitigation measures should be considered:

- 1) When an IDC is co-sited with a high-voltage substation, data server rooms and cables of both systems should be planned and arranged reasonably, and the natural shielding of special shafts should be performed along the path of 10 kV cables.
- 2) Active shielding should be applied locally at key positions and on the high-voltage side. Open bus-bars can be replaced with enclosed ones, and local magnetic shielding measures can also be used, if necessary.
- 3) To decrease the effect of the power frequency magnetic field generated by a reactor on ICT equipment, the distance between data servers and the reactor should not be less than 10 m.

- 4) To decrease the effect of the power frequency magnetic field generated by capacitor bank on ICT equipment, the distance between the data servers and capacitor bank should not be less than 5 m.
- 5) To control the short duration power frequency magnetic field strength generated by the substation bus, the distance between the data servers and the substation bus should not be less than 10 m.
- 6) Tests confirm that cathode ray tube (CRT) displays are extremely sensitive to power frequency magnetic fields. Therefore, liquid crystal displays instead of CRTs should be used in an IDC co-sited with a substation.

Appendix I

Basic data for determining the tolerance limits of dangerous effects on an IDC from a high-voltage system

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

I.1 High-voltage transmission lines

In order to determine the tolerance limits of dangerous effects on an IDC from a high-voltage system for high-voltage transmission lines, the following should be considered:

- a) the structure of buried power cable and the type of metal used for the outer sheath;
- b) the section radius of overhead power cable and the type of metal;
- c) the earthing type at the neutral point of a high-voltage substation;
- d) the position of an earth fault in high-voltage transmission lines and the pole location;
- e) the earthing type of overhead lightning conductors;
- f) the voltage class of high-voltage transmission lines;
- g) the clearance time of earth faults of high-voltage transmission lines;
- h) the curve of one-phase short circuit current in 10 to 15 years for neutral point earthed high-voltage transmission lines;
- i) the method of arrangement of the overhead transmission line conductors;
- j) the dimensions of the overhead lightning conductor hanger, conductor mass, cross-section and resistance per length.

I.2 Earthed types of high-voltage transmission system

For earthed types of high-voltage transmission the following should be considered:

- a) the geometry of the high-voltage substation earthing network and the value of earthing resistance;
- b) the earthing resistance of the overhead power line tower;
- c) whether measures for resistance reduction have been taken for the high-voltage substation and tower earthing system;
- d) the soil resistivity.

I.3 Geographic environment between the high-voltage transmission lines and telecommunication network

With regard to the geographic environment between the high-voltage transmission lines and telecommunication network the following should be considered:

- a) the spacing between high-voltage transmission lines and communication lines and their wiring ducts;
- b) whether communication lines use shielding measures and the form of pipeline;
- c) the spacing between the high-voltage transmission system earth electrode and communication bureau (station) earthing network;
- d) the pipelines accessing the high-voltage substation;
- e) the pipelines accessing the communication bureau (station);
- f) other pipelines between the communication network and high-voltage transmission lines and their wiring ducts.

I.4 Parameters of the communication network

For the parameters of the communication network, the following should be considered:

- a) the earthing type and earthing resistance of the communication bureau (station);
- b) the voltage withstand level of the communication equipment;
- c) the type of communication cable, number of cores and shielding factor of cable sheath;
- d) the layout plan of the communication bureau (station).

Appendix II

Limits related to danger in case of electromagnetic interference produced by AC power plants in fault conditions

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

Table II.1 – Limits related to danger in case of electromagnetic interference produced by AC power plants in fault conditions (from [b-ITU-T K.68])

Reference fault duration, t/s	Induced voltage r.m.s./V
$t \leq 0.10$	2 000
$0.10 < t \leq 0.20$	1 500
$0.20 < t \leq 0.35$	1 000
$0.35 < t \leq 0.50$	650
$0.50 < t \leq 1.00$	430
$1.00 < t \leq 3.00$	150
$3.00 < t$	60

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