On the Hazardous Situations Due to the Presence of HV/MV Substations in Urban Areas

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Abstract— **The paper focuses on the hazardous situations that can rise in urban areas in case of earth fault inside a High Voltage/Medium Voltage station. IEEE and IEC/EN Standards and technical documents are examined and discussed, in order to propose some practical guidelines for a safe integration of such installations in contexts characterized by the presence of low voltage systems and not trained persons.**

Keywords— Substations; Safety; Earth fault; Global Earthing Systems

I. Introduction

High Voltage/Medium Voltage (HV/MV) stations are integrated in the urban context and, therefore, built very close to residential, commercial and tertiary buildings supplied by the low voltage (LV) utility grid (Fig. 1).

Fig. 1. Example of HV/MV station integrated in an urban area with residential building in the neighborhood.

In the event of a single-line-to-earth (1LtE) fault occurring on the HV side inside such a station, high voltages can be transferred to the closest buildings, creating dangerous situations for persons or damage to equipment insulation.

by the Research on the Electric System Programme. Consequently, a proper design of the earthing system of a HV/MV station in an urban areas must take into account not only the protection against electric shock of the station personnel but also the protection of persons outside its boundaries.

In particular, it is mandatory to protect against dangerous touch and step voltages the public immediately outside the station fences or outer walls, that are mainly exposed in the case of 1LtE.

Also the presence of water or gas pipelines, external continuous metal fences or railways must be considered in the design of the earth electrode of the station [1]. In fact, the above-mentioned metal elements can be responsible of the transfer of the earth potential rise (or part of it) to great distances from the fault, in places where an adequate protection against dangerous touch and step voltage can not be easily put into effect [2].

Starting from these considerations, the present paper analyses various elements that influence the transfer of the hazard from the station towards neighboring installations, when a 1LtE fault occurs within a HV/MV station. Moreover, based on IEEE and IEC/EN standards, the paper proposes an operative protocol for assessing the risk and some measures to be applied for reducing the hazard due to the fault. Finally, an application example of the risk assessment methodology is proposed.

The novelty of the paper is in the merging of both IEEE and IEC/EN main recommendations in order to propose an unique and practical guide for protecting against the risks due to the proximity of HV/MV substations to LV installations.

II. Hazardous Situations

The presence of a HV/MV station inside an urban areas gives place to hazardous situations for persons due to the following issues:

- voltages transferred from the faulted HV/MV station to MV/LV cabins, trough the metal shields of the cables of the MV lines supplied by the station;
- accessible metal fences;

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- metal pipelines connecting the earthing system of the faulted substations to the earth electrodes of the surrounding buildings;
- metal railways outgoing from the station;
- stress voltages rising in presence of LV network neutral point earthed at the same earthing system of the faulted station.

A. *Transferred voltages*

This issue has been deeply discussed in some previous papers of the same authors [3]-[4]. The studies carried out show that in case of a 1LtE fault occurring at the HV/MV substation, the substations closest to the supply experiment very high values of the earth potential rise. These values are less influenced by the number of secondary substations of the MV line, the number of MV lines, the distance between the substations and the values of the substation's earth resistance. The increase of the number of line outgoing the HV/MV station gives place to a reduction of the earth potential rise at the substations. On the other side, the connection of the earth electrodes of the secondary substations to the earthing system of the HV/MV substation does not give significant advantages to the HV/MV substations itself.

B. *Metal fences*

A correct earthing of metal fences around HV/MV substations is of vital importance because they are accessible to the public. The safety concerns related to these elements are deeply discussed in the IEEE Standard 80/2013 [5], in the National Electric Code [6] and in the IEC Standard 61936-1 [7]. Metal fences' earthing can be accomplished in two different ways: electrically connecting the fence to the substation earthing grid (in this case the metal fence can be inside or outside the grid area), using a separated earthing systems (in this case the metal fence MUST be outside the grid area). IEC Standard 61936-1 suggests, as a measure for reducing touch voltage outdoor the substation, to install a supplementary horizontal earth electrode connected to the fence at about 1 m from the fence and at a maximum depth of 0.5 m, as depicted in Fig. 2 (recognized specified measure M2.2).

A situation that must be addressed in presence of metal fences is the case in which metal fences do not follow the normal equipotential lines on the earth surface resulting from a fault in the HV/MV station. In such a case, a voltage distribution as that reported in Fig. 3 can occur, due to the electrical continuity of the fence. For avoiding the rise of dangerous voltages in correspondence of the fence poles, it is necessary to introduce insolating joints in the fence.

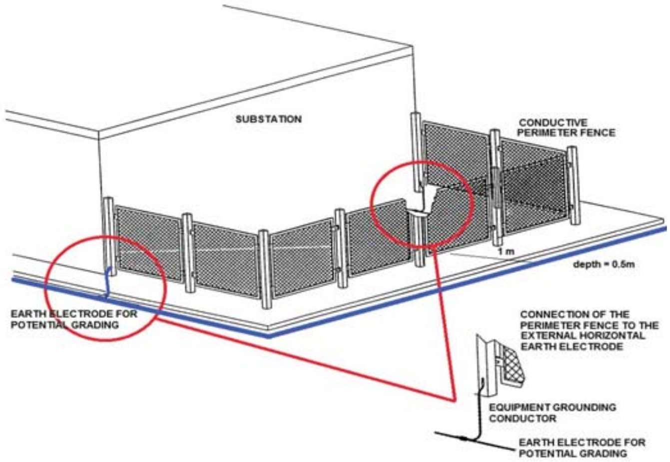

Fig. 2. Potential grading for substations' metal fences [17].

C. *Metal pipelines*

When metal pipes electrically connect the HV/MV station to surrounding buildings, the latter should be treated as part of the station with regards to the protection against dangerous voltages. This is not always possible in an urban area where the buildings are supplied by the LV utility grid and are equipped with simple rods as earth electrodes. LV installations' earth electrodes are, indeed, able to contain the Earth Potential Rise (EPR) due to a fault at the LV side below the tolerable limits imposed [6], [8], [9], whereas the protection against electric shock assured by the earth electrode of a HV/MV station is, generally, done containing touch and step voltages. For this reason, the connection between LV and HV installations' earthing systems can be accepted without further investigation only if the earthing system of the station is declared intrinsically safe, as defined in [10].

Consequently, insulating joints should be installed on the metal pipes outgoing the station, as represented in Fig. 4.

Electrical separations of parts of pipelines on the two sides of the substations border is suggested both by IEEE Standards [5], [11], [12], and by IEC/EN standards [7], [13], [14], [15], [16], [17].

D. *Metal railways*

Railways entering a substation must be connected to it earthing systems. The connection can create a hazard situation at an external location by transferring all or a portion of the earth potential rise due to a 1LtE fault.

IEEE Standard 80/2013 suggest removing the track sections from the substation or, as indicated also by EN Standard 50522, using insulating joints (Fig. 5). Instead of insulating joints, an alternative solution is that of substituting a metal track section with an insulating one. This solution reduces the probability of short circuit of the tracks towards remote earth.

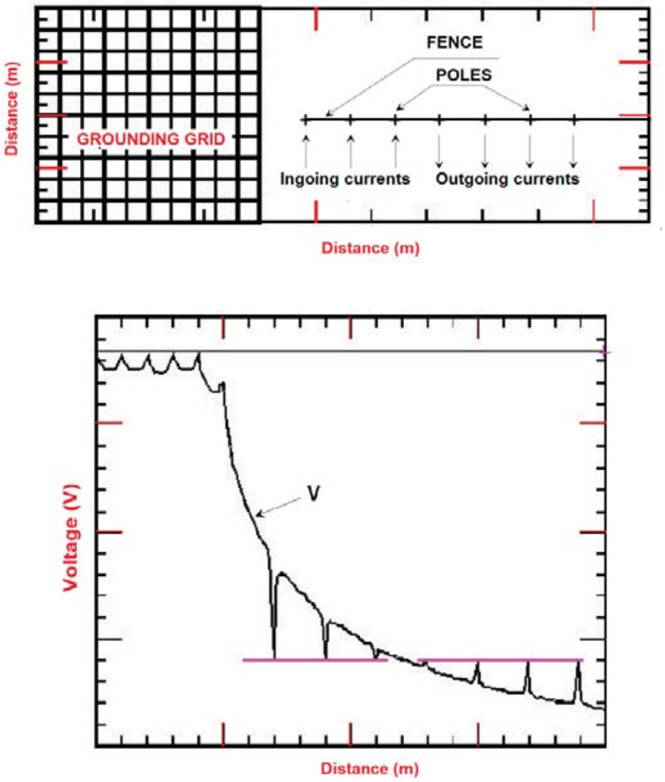

Fig. 3. Voltage profile on the soil surface due to a 1LtE fault in the substation, in presence of a long continuous metal fence [17].

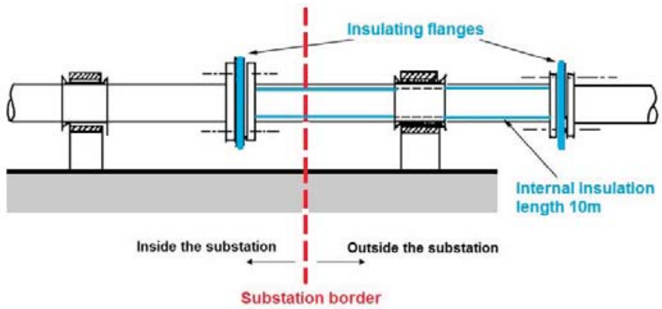

Fig. 4. Metal water pipeline crossing the substation border [17].

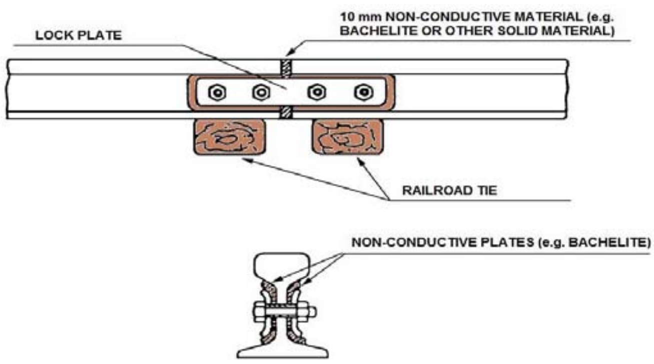

Fig. 5. Insulating flanges for railways [17].

E. Stress voltages

In the case the neutral point of MV/LV transformers is connected to the grounding system of a close HV/MV station, the hazard due to stress voltages on the insulation of the components connected to the LV network must be checked. According to EN Standard 50522. Being 1LtE faults eliminated in less then 5 seconds, LV neutral point can be connected to the station earth electrodes is the maximum earth potential rise due to the fault does not exceed 1200 V.

III. Guidelines for Risk Assessment

Table I reports a checklist for assessing the risk due to a 1LtE fault occurring in a HV/MV station located in an urban areas. The list is based on the above-reported considerations and on the application of the recognized specified measures M defined by IEC Standard 61936-1 and EN Standard 50522.

The table reports:

- measures I, assuring safety with reference to all the aspects reported in Section II (pipelines, fences, etc.);
- measures M, assuring protection against the transfer of dangerous voltage to the MV/LV substations through the metal shields of the MV cables;
- measures F, assuring protection of persons in contact with the outer walls or fences of the HV/MV station;
- measures P, assuring protection against the transfer of dangerous voltages through metal pipes;
- measure R, assuring protection against the transfer of dangerous voltages through railways;
- measure S, assuring protection of the insulation of the LV installations.
- The risk assessment is done as described below.
- It is evaluated if the earthing system is intrinsically safe. If so, no other measures are necessary. If not, it must be investigated if metal fences, cable metal shields, pipelines and railways are present and, if so, measures C, F, P, R and S must be taken. In the following an application example is reported.

IV. Application Example

Let's consider a HV/MV station in an urban areas, with the following characteristics:

- five MV cable lines with ARG7H1RX cables, outgoing from the station;
- perimeter reinforced concrete walls on three sides and a metal fence on one side;

- earthing grid of the station within the boundaries of the station (outer wall and fence);
- no railways ingoing in the station;
- one metal pipe from the local aqueduct entering the station boundaries.

The EPR at the station due to a 1LtE fault on the HV side is 6000V. Therefore, the earthing system is not intrinsically safe and, in addition, measure S.1 must be carried out for preventing damage of LV insulation due to stress voltages (EPR is above 1200V).

The MV cables have copper screens that must be disconnected from the earthing system of the station (measure C.1), connected together and isolated for becoming not accessible to the personnel (measure C.2).

For protecting the public close to the perimeter walls and fence, the floor outside the station must be done with high resistivity material (measure F.7). Potential grading is carried out by installing a horizontal earth electrode connected to the earthing grid of the station at a distance of 1 m outside the fences and buried at a depth not over 0.5 m (measure F.5). Moreover, the fences must be interrupted by insulating joints (measure F.6). Finally, the metal pipe arriving at the station must be connected to not metal pipes for the water distribution within the station and must be isolated from the soil (measure P.2).

TABLE I
CHECKLIST FOR ASSESSING THE RISK IN CASE OF 1LTE FAULT IN A HV/MV STATION

I.1	The earthing system of the station is intrinsically safe and is able to contain the EPR within the value of 50V.
C.1	Disconnection of the metal shields of the MV cables from the earthing system of the HV/MV station. The connection point must be made not accessible to the workers inside the station.
C.2	Connection of all the metal shields of all the MV lines outgoing the station. The connection point must be made not accessible to the workers inside the station.
F.1	Use of non conductive fences.
F.2	Use of non-conductive outer walls.
F.3	No grounded metal parts accessible from outside the HV/MV station.
F.4	Earthing of the metal fence by the station earthing system or by a separated earthing system if the fence is outside the station's earth electrode area.
F.5	In case of conductive perimeter fences, potential grading by installing a horizontal ground electrode connected to the grounding grid at a distance of 1 m outside the fences and buried at a depth not over 0.5 m.
F.6	Installation of insulating joints in the metal fences.
F.7	Use of high resistivity material for covering the soil outside the station
P.1	Use of insulating flanges on metal pipes outgoing the station.
P.2	Use of insulating pipes inside the station.
R.1	Remove unused track sections.
R.2	Installation of insulating joints between tracks.
R.3	Substitution of a metal track section with an insulating one.
S.1	If the maximum earth potential rise in the HV/MV station is over 1200 V, disconnect the neutral point of the MV/LV transformers from the earth electrode of the station.

V. CONCLUSION

An analysis of the hazard due to a 1ltE fault inside a HV/MV station located in an urban area has been presented. The main international standards have been examined in order to define a procedure for assessing the risk for the LV installations due to the fault. Finally, an application example of the risk assessment methodology has been provided.

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