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Dangerous touch voltages in buildings: The impact of extraneous conductive parts in risk mitigation

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ABSTRACT

International (IEC) European (CENELEC) and American (NEC) Standards require, in each building, the connection of extraneous conductive parts (i.e. metal water or gas pipes) to the main grounding terminal. There are two good reasons for this: the voltage between extraneous conductive parts and exposed conductive parts is zeroed and extraneous conductive parts can contribute to the leakage of fault current into the ground. There is however a third advantage in the bonding connection: the entire structure (floors and walls of the building), together with the exposed and the extraneous metallic parts, forms a quasi-equipotential system, with the consequent strong reduction of touch voltages. Metallic pipes and reinforcement of reinforced concrete have a particular relevance thanks to their large widespread through buildings. However, in some practical cases, it is not possible to connect all extraneous conductive parts to the protective equipotential bonding because they are not accessible. In the paper, the reduction of touch voltages in buildings, when these extraneous conductive parts are present but not connected to the protective equipotential bonding is quantified. Different building models are created and solved by the finite element method in order to calculate touch voltages in different scenarios. The results show that the mere presence of widespread metallic parts in buildings helps to reduce touch voltages, but not enough to ensure safety against indirect contacts. The electrical installation safety performance is greatly improved in reinforced concrete buildings if at least some easily accessible parts, like water or central heating pipes, are connected to the main grounding terminal. Also in brick buildings, they provide a certain reduction of GPR, maximum and mean touch voltages.

1. Introduction

An electric shock can be caused by a direct or by an indirect contact with energized parts [1]. In this paper the focus is on indirect contacts inside buildings. An indirect contact is defined in the International Standard IEC 60364-1 [2] as “contact with conductive parts normally not energized, but likely to become live upon faults (e.g., enclosures of equipment).” The effects of electric current on persons depend mainly on the magnitude and duration of the current itself. Based on this, protection methods against indirect contacts are mainly founded on equipotentialization techniques (to reduce the current magnitude) and on the adoption of protective devices such as circuit breakers or fuses (to limit the persistence time) [3].

The automatic disconnection of supply in case of fault is one of these methods and it is based on both the principles described above. In fact, on one hand IEC 60364-4 [4] defines the maximum disconnection time of protective devices and, on the other hand, it states that the grounding conductor, the main grounding terminal (MGT) and the extraneous conductive parts (EXCPs) shall be connected to the protective equipotential bonding.

According to the definition of the International Electrotechnical Vocabulary IEC 60050-826, EXCPs are “conductive parts not forming part of the electrical installation and liable to introduce an electric potential, generally the electric potential of a local earth” [5]. EXCPs are characterized by a resistance to ground, R_{EXCP}, lower than 1000 Ω [2].

The EXCPs to be connected to the protective equipotential bonding are:

- metallic pipes supplying services into the building;
- structural metalwork if accessible in normal use;

Abbreviations: AQE, average quality element of a mesh; CPE, control parameter error; ECP, exposed conductive part; EXCP, extraneous conductive part; FEM, finite element method; GEC, grounding electrode conductor; GPR, ground potential rise; MGT, main grounding terminal; NEC, national electric code; PE, protective conductor (IEC) or equipment grounding conductor (NEC); SLGF, single line to ground fault.

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- metallic central heating and air-conditioning systems;
- metallic reinforcement of constructional reinforced concrete, if reasonably practicable.

The North American National Electric Code (NEC) [6] has similar requirements for grounding and bonding. Although the approach is quite different [7], the goals are the same [8]. NEC requests that metal underground water pipes, metal frames of the building, concrete-encased electrodes, and all the "intentional" grounding electrodes (ground ring; rod and pipe electrodes; plate electrodes, etc.) shall be bonded together to form the grounding electrode system [6].

In case of Single Line to Ground Fault (SLGF), the connections required by both IEC 60364-4 [4] and NEC [6] bring two main advantages [9–11]:

- all the interconnected metallic parts contribute to the leakage of the fault current, thus reducing the equivalent ground resistance of the earthing system;
- the electric potential differences among all the metallic parts are reduced, producing a nearly equipotential condition [8].

Both these effects can be appreciated in Fig. 1, which refers to a TT system. The resistance to earth of the EXCP, R_{EXCP}, is in parallel with the resistance to earth of the LV User ES, R_{ES}, contributing to the leakage of the fault current. Moreover, the Exposed Conductive Part (ECP) and the EXCP are interconnected to the MGT through the Protective Conductors (PEs), holding the voltage between metallic parts down.

In addition to this, the connections increase the electrical potential of floors and walls too, in a way that depends on the building properties (e.g. the building materials employed or the number of encased metal parts). The more this effect is noticeable, the more a quasi-equipotential condition can be achieved, with a reduction of touch voltages. In this paper, this latter effect is investigated. Even if the benefits of the wired equipotential bonding are well known by the international standard institutions since a long time [4,12], some aspects have not been clarified yet. In literature, many researchers emphasize the reduction of touch voltages between an ECP and an EXCP due to electrical bonding (hand to hand contact); vice-versa, according to the Author's knowledge, the equipotentialization effect in case of contact with only an ECP (hand to feet contact) has not been discussed yet. In particular, it is not clear if a wired connection among the metallic reinforcement of constructional reinforced concrete, other EXCPs, and the main grounding terminal (MGT) is strictly needed to obtain a consistent reduction of the touch voltage or, instead, just the presence of these metallic parts could be sufficient to improve electrical safety.

A quantitative investigation of the equipotentialization effect introduced by metal parts encased in buildings, to the authors' knowledge, is not available in the scientific literature yet.

In this paper, different scenarios are simulated in order to understand the contribution of non-connected metallic parts to the reduction of touch voltages in buildings. The models refer to a TT system, in which a SLGF has occurred. For each scenario, the floor and walls potential profile is computed, taking into account different situations defined by different building construction typologies (reinforced concrete or masonry), different wired connection configurations, different kinds of foundations and different grounding systems.

For each scenario, a model is implemented and solved by the finite element method (FEM), that allows to simulate systems with complex geometry and electrical discontinuities [13–16].

Table 1
Geometric characterization of the models.

Part	Geometrical dimensions (m)
Building	
Floor surface area	10 × 7
Room height	3
Floor and wall thickness	0.4
Spread footing foundation length	0.25
Reinforced concrete	
Rod radius	0.02
Center to center distance along x-axis	1.7
Center to center distance along y-axis	1.2
EXCPs	
Pipe radius	0.02
x length (external wall y = –3.5 m)	9.7
x length (internal wall y = 0 m)	5.0
x length (external wall y = 3.5 m)	2.5
y length (external wall x = –4.9 m)	6.1
Radiator type 1 area	0.8 × 0.68
Radiator type 2 area	0.4 × 0.68
Earthing system	
Earth rod radius	0.02
Earth rod length	1
Ground ring radius	4

Table 2
Resistivity for building materials (kΩ m) in different environment conditions, measured at different voltages (V).

Voltage	Bricks			Concrete	
	Dry	Moistened	Wet	Dry	Wet
100	11.4	6.5	0.060	3100.0	0.4
200	7.5	4.4	0.054	1700.0	0.4
300	5.5	3.6	0.050	1200.0	0.4
400	4.3	2.0	0.049	800.0	0.4

Table 3
Materials properties of the models.

Material	Electrical conductivity (S/m)
Iron	1.12×10^{7}
Building material 1	10^{-2}
Building material 2	10^{-3}
Soil 1	10^{-2}
Soil 2	10^{-3}

Different resistivity values of building materials are also used, according to field measurements carried out by the authors in a previous work [17].

2. Methodology

The building models are built and solved by using the FEM software COMSOL Multiphysics [18]. The verification and validation of the software was carried out in previous works [19,20].

In the paragraphs below, the implemented building models and the method settings are discussed. Details about the touch voltage computation are also given.

2.1. Building structure: geometry and materials

For the models definition, the foundation type, the presence of embedded metal pipes, the grounding system geometry, the choice of the soil and building materials electrical properties and, of course, the connection configuration among metallic parts are the points taken into account. The main geometrical details and material properties about the models implemented are presented in Tables 1 and 3 respectively.