Electromagnetic Pollution of the Environment and its Effects on the Materials from the Built up Media

IOSIF LINGVAY1, ADRIANA MARIANA BORS2*, DANIEL LINGVAY4/5, LADISLAIU RADERMACHER1, VLAD NEAGU6
1National Institute for Research and Development in Electrical Engineering INCIDIE ICPE-CA, 313, Splaiul Unirii, 030138, Bucharest, Romania
2ICPE SA, 313, Splaiul Unirii, 030138, Bucharest, Romania
3Technical University of Cluj, Faculty of Electronics, Telecommunications and Information Technology, 26-28 George Baritiu Str., 400027, Cluj Napoca, Romania
4University of Petrosani, Petrosani, Bucharest, Romania
5Technical University of Cluj, Faculty of Electrical Engineering, 26-28 George Baritiu Str., 400027, Cluj Napoca, Romania
6Sapientia Hungarian University of Transylvania, Faculty of Sciences and Arts, 4 Calea Turzii, 400193, Cluj Napoca, Romania

In built up media (complex built environment), the materials are simultaneously exposed to a series of physical, chemical and microbiological stress factors that act synergistically with disturbing electromagnetic fields and cause material degradation - with consequences on the durability and safety in exploitation of buildings and installations. The main generative sources of disturbing fields (stray current generators) on built up media are railroads with DC or AC traction with various operating voltage and frequency, medium and high voltage overhead power lines and unbalanced currents from a three-phase power system. The generated stray currents cause destruction both in metallic elements of built structures (railroads, power installations) and in neighbouring constructions and installations (belonging to other administrations) with negative environmental implications.

Keywords: corrosion, stray currents, electromagnetic pollution, built structures

With a view to sustainable development, the durability and safety of built structures (buildings and installations - especially high-risk in exploitation ones such as gas and oil pipelines, power installations etc.) is a priority issue. The durability and safe operation of buildings and installations (built up media) is determined by their degradation, ageing due to the simultaneous and synergistic action of several stress factors specific to the environment (usually complex polluted) exploitation such as chemical and microbiological soil aggressiveness, aggressive pollutants from the atmosphere (SO₂, H₂S, CO₂ etc.), mechanical stresses, ionizing and non-ionizing radiation and, last but not least, electrical stresses [1].

By their specificity, electrical disturbances can be either, functional electromagnetic pollution of environment [1,2] (e.g. of an anthropogenic origin operating voltage of power cables) or of a natural origin (telluric currents, atmospheric discharge - lightning). Intelligent and predictive diagnosis studies can evaluate the degradation state of targets, the appointment and timing of repairs and the safe exploitation lifetime of built-up media objectives. These studies achievement presupposes the stressors factors knowledge (intensity, mechanism and kinetics of the degradation processes caused, synergy effects, etc.) acting on the investigated objectives [3-7].

The paper aim is to analyze the degradation induced by the environmental electromagnetic pollution effects on the built media.

Electromagnetic pollution sources - stray current generating voltage

Soil, natural environment, electro-conducting medium, of 2nd order electrolytic [1] conductors, where there are numerous metallic structures exposed to corrosion, is a heterogeneous environment, being a relatively weak electric conductor and having an electrical resistivity of between 1 and 1000 Ωm. On the other hand, concrete - a material often used in construction - is also a heterogeneous environment, which, depending on the actual operating conditions, can become a 2nd order electrolytic conductor with an electrical resistivity below 1000 Ωm [8]. The voltage difference applied to these electrolytic environments generate current lines focused on preferential high conductivity paths, the shortest current path - respectively on the metallic structures in these environments (underground metallic pipes, steel reinforcements of structures reinforced concrete etc.), which have a resistivity below 10-6 Ωm. Under these conditions the currents cross at least twice the metal / electrolyte interface - with all the related consequences on the corrosion reactions kinetics.

The source of all disturbing electrical signals of the natural electrochemical processes is the chain of generation / transmission / distribution and electric energy use [1, 2].

The perturbing voltage is primarily the AC alternating current with a power frequency overlapping both the harmonics and the transients generated by the power system and the reactive consumers and / or those operating in switching mode [9-12] as well as the DC components from industrial consumers such as electric traction in DC (tram, subway, etc.) and / or industrial installations in DC (such as electrolyzers) [1].

Under these conditions, stray currents generated are complexes and contain both DC components and AC components in a wide spectrum of frequencies. The following are some representative situations where metallic structures are disturbed by DC and / or AC stray currents.

In figure 1 is a simplified circuit diagram of AC disturbances due to three phase power system imbalance currents.

By analyzing the diagram of figure 1 it's found that AC stray current by pipeline IAC is component of unbalanced current IU [13], respective (1):

\[ I_U = I_{AC} + I_{US} \] (1)
In (1) the \( I_{AC} / I_{US} \) ratio is determined by the insulation level between the pipeline and the ground, the ground resistivity, the distance between the grounding plugs and the pipeline geometric position to the grounding plugs. It’s noted that the \( I_u \) is given by the system’s operating regime and does not depend on how to execution (overhead or underground) power lines.

In the overhead power lines case, the pipeline is disturbed in addition to \( I_{AC} \) (1) by a induced current computable by long conductor and / or long conductor methods (based on Maxwell’s equations where resolutions are made using different methods of numerical analysis - more often the finite elements method) [14-17].

Similarly, AC stray currents are generated in steel rebar from underground reinforced concrete structures.

In figure 2 the complex AC disturbances coming from overhead power lines and electrified railroads are presented.

Analyzing the depiction from figure 1 it is noted that the \( I_{VD} \) component decrease may be achieved by increasing the insulation level between the railroad and soil as well as between the perturbed metallic structure and soil (electro-insulating layers applied on the pipes [19-21]).

Figure 1 and figure 2 show that in practice the ELF extremely low frequency (power frequency and harmonics) AC stray currents which disturbs the metallic structures operating in electro-conductive environments of 1 order (soil and / or reinforced concrete) come primarily from tree phase power system by both induction and voltage drop (due to imbalances between phases and / or major consumers specifics such as electrified railroads).

In crowded urban centers, metallic structures operating in electro-conductive environments are interfering with AC stray currents (fig. 1 and fig. 2) overlapping with DC stray currents that originate primarily from urban electric transport railroad.

In figure 3 depicts the DC stray currents under the conditions of crowded urban area with the urban surface electric transport (tram) and underground (metro).

Analyzing figure 3 one may observe that in crowded urban centers the disturbances in DC stray currents are complex with random circulation and affect the urban utilities networks metallic components (underground gas and water pipelines, sewagerage, underground power cables etc.), railroad and steel rebar from reinforced concrete structures [1, 22-24].

![Fig. 3. The sketch of DC stray currents under the conditions of crowded urban centers](image)

In crowded urban centers, metallic structures operating in electro-conductive environments are interferring with AC stray currents (fig. 1 and fig. 2) overlapping with DC stray currents that originate primarily from urban electric transport railroad.

At the metal Me / electrolytic interface, in the absence at external polarization an equilibrium is established (2):

\[
Me \leftrightarrow Me^{+} + 2e^{-}
\]

characterized by the mixed corrosion potential \( E_p \). The behavior of the metal/electrolyte system is described by the polarization curve (fig. 4) [1].

![Fig. 4. Polarization curves which characterize the electrode/electrolyte systems: 1-polarization curve specific to partial anodic process; 2-polarization curve specific to partial cathodic process; 3-global polarization curve; i_a -partial anodic current; i_k -partial cathodic current; i_b-the change current specific to the system; I_A -global anodic current; I_k -global cathodic current; E -potential of the electrode / electrolyte system; E_eq-equilibrium potential](image)
According to the polarization curve (fig. 4) [1], the metal / electrolyte system equilibrium is disrupted when the polarization phenomenon occurs.

From the analysis Fig. 4 it’s observed that at equilibrium, cathodic partially current is equal to the partially anodic one (3):

\[ i_0 = |i_k| = |i_a| \tag{3} \]

where the metal corrosion is determined by the value \( i_0 \) (the functional and morpho-structural metal characteristics theoretical redeposited by \( i_k \) is completely different from that dissolved by \( i_a \)).

At cathodic polarization of the metal to the electrolyte the metal dissolution is impossible thermodynamically (cathodic protection by \( i_k \)).

At metal anodic polarization \( i_a \) increase and produces metallic corrosion - the metal amount dissolved \( \Delta m \) during the anodic polarization being (4):

\[ \Delta m = \frac{M}{z} \int_i^0 i_a(t) \, dt \tag{4} \]

where \( F \) represents the Faraday number (= 96500 Coulomb / equivalent grams), \( i_a \) the anode current, \( M \) the atomic mass and \( z \) the metal valence.

In figure 5 it is presented the metal / electrolyte system response at AC polarization (a disturbing signal AC overlapped to the polarization curve in fig. 4).

Figure 5 it’s show that the metal / electrolyte system response to the AC disturbing signal is an anodically predominantly deformed current \( i(t) \) and moves the equilibrium (2) to the right (accelerated corrosion).

In the metallic conductors case protected by the cathodic current at the \( E_k \) potential, the system response to overlapping an AC disturbing signal is illustrated in figure 6.

From figure 6 it’s noticed that the cathode-protected \( (E_k) \) metal / electrolyte system response at AC disturbing signal is an anodically predominantly deformed current \( i(t) \) - so even at \( E_k \) the metal corrosion occurs because the equilibrium (2) moves to the right (accelerated corrosion) the metal mass dissolved being given by (3) the anode component \( i(t) \) - confirmed and experimental finding [27].

In practice, metallic structures that operate in electrolytic environments (soil, concrete, etc.) are often exposed to DC stray currents (for e.g. fig. 3) which anodically polarizes \( E_k \) localized to the metal surface. In these situations overlapping an AC component (fig. 7) creates a corrosion major risk.

In figure 7 it is observed that, in the case of the anodic polarized \( (E_a) \) case metal / electrolyte interface overlapping of an AC disturbing signal, the metal surface is traversed by a deformed alternating current to which even the negative semiperiod is in the anodic field with consequences (often baneful) on corrosion speed.

Stress factors of degradations in built up media - synergy effects

Construction and installation related materials are exposed simultaneous to several stress factors specific to the operating environment. Stress factors may be natural (e.g. salinity, humidity and soil microbiological load, oxygen and atmospheric CO\(_2\), visible spectrum radiation - especially UV and IR, telluric currents [28] etc.) or anthropogenic origin (aggressive pollutants from the atmosphere, electric stress, etc.). The stress factors action mechanisms influence each other and thus the degradations produced in the built up media are greater in the simultaneous action case than the sum of the individual degradations produced individually by each factor (effects of synergism [29]).

Thus, the higher salinity and humidity of the soil reduces the metal / soil resistance (fig. 1 and fig. 2), which has as effect increasing the stray currents, the metabolism products of the microorganisms (organic acids) increase the chemical aggressiveness and the electrical conductivity of the environment - depolarizes anodic processes and thus accelerates electrochemical and microbiological corrosion [30-37], 50 Hz (power frequency) electric field produces major changes in behavior - accelerates growth and multiplication of moulds - therefore materials biodegradation enhances [21, 30, 33, 37-47].

AC and DC stray currents effects on some representative constructions

From the point of view of the degradation mechanisms under the AC and DC stray currents action and the representative stress factors action, there are:

- underground constructions and installations where the stressing factors are humidity, salinity, microbiological flora and morpho-structural soil structure;
overground reinforced concrete structures exposed to AC induced AC stray currents, climatic factors and aggressive agents in the atmosphere.

In practice, at the complex targets with overground and underground portions and / or in contact with ground, develop representative destructions due to AC, but especially DC stray currents.

a. Accelerated corrosion of metal structures in contact with soil

Figure 8 shows the tram rails (DC traction) representative destructions that can be seen along the entire railroad (fig. 3). Similar destructions have also been found in the metallic elements fastening of the rails on embankment in cases when they were not provided with adequate insulation systems (fig. 9).

Figure 8 and figure 9 shows that the anodic polarization of the railroad metallic elements of the urban transport systems with DC traction can lead to massive degradation and endanger the safety in operation. The DC lines coming out of the railroad and entering the ground are taken over by the underground metallic structures (especially pipelines and reinforced concrete structures) from which it exiting in the vicinity of the “−” cable connection point where the dissolution localized by polarization anode of pipelines and reinforced concrete structures disturbed (fig. 3).

It is noted that underground metallic structures disrupted in DC stray currents are simultaneously exposed to AC disturbances according to figure 1 and / or figure 2- situation where the overlapping of the anodic polarization in DC and of the AC polarization, the destructions (according to figure 7) worsen substantially as illustrated in figure 10.

On the route of the energy grand highway, the high voltage overhead power line generally has a common route with underground gas and oil pipelines, where the disturbances caused by induced AC signals at power frequency are significant, which required the evaluation and study of the AC polarization effects of pipelines [1, 27, 48-54], elaboration of the method for calculating disturbances [13-17, 55-59] and for the corrosion damage prevention [60-65]. Figure11. shows the destructions by corrosion of the earthing sockets (made from galvanized steel profiles) polarized in AC through unbalanced currents of tree phase power system [66-68].

b. Reinforced concrete structures degradation

In the reinforced concrete structures case, AC and DC stray currents cause both steel bars corrosion and concrete degradation [24, 72-79]. At the concrete anodic polarization, the cement oxidation components dissolve and the concrete is leached (pH decreases [77]) which leads to the concrete degradation and to the steel bars accelerated corrosion [72]. In the concrete excessive cathodic polarization, the oxidation degree of oxide components in the cement is reduced, which leads to the contraction and the concrete cracking [72].

Corrosion products of steel bars, generate mechanical stress (up to 500 kg/cm²) [82] leading to major physical degradation of the concrete. In these conditions, due to stress factors and AC and DC stray current and multiple
Synergic effects, the underground reinforced concrete structures degradation [24, 78, 79, 81, 83-85] and / or overhead [76, 86] are significant. Figure 12 presents degradation representative images of a metro tunnel under the DC stray currents synergic action, of microbiological factors and hydrostatic water pressure.

To increase the exploitation time of the structures in figure 12, the corrosion rate may be decrease (3) by a voltage reduction and providing an adequate and reliable isolation system between the rails and the embankment / soil.

Figure 1 and figure 3 show that AC and DC stray currents act on the output and inlet areas (in the AC case) from the metal to the electrolytic medium of the current lines.

In order to reduce the disturbed surfaces areas, to reinforced concrete structures exposed to AC and / or DC ditsy currents disruptions it is necessary to ensure the electrical continuity between steel rebar that involves fastening stirrup by welding (not by binding as seen in fig. 13 and fig. 14 - fully corroded stirrups).

c. Underground power cables degradation

Underground power cables degradation is the result of some successive complex processes, due to the synergic action of several stress factors (electrical, thermal, chemical and microbiological soil aggression etc.) [29, 43, 45-47, 87, 88].

The first stage (determinant of the global process) consists in the degradation of the protective polymer coating (fig. 15) under influence of the chemical and microbiological soil stress. The protective layer polymer becomes porous, permeable to soil aggressive agents (humidity, salinity, oxygen, etc.) that penetrate the metal screen and thus makes possible the metal corrosion. Corrosion products formed and the moisture, penetrate to the insulation surface (usually cross-linked polyethylene) form water treeing which, under electric stress act (operating voltage), initiates and develops electrical treeing that penetrate into the insulation volume and form conductive channels.

Thus, the cable insulation resistance decreases significantly (ageing) and in extreme situations, under the operating voltage, the cable breaks down through puncture (fig. 16).
From figure 17 it’s found that the resistance at molds action of the polymer used in the medium voltage cables manufacture is relatively limited [89].

In Fig 15 it is observed that during the operation between the metallic shielding of power cables and soil, on the polymeric jacket an AC disturbance occurs at the industrial frequency, both by induction and by the operating voltage division on the capacitive divisor consisting of conductor capacity / metallic shielding and metallic shielding / soil.

Under these conditions, the surface in contact with the polymeric jacket soil is exposed to an AC electric field. The 50 Hz electric field modifies the microorganisms metabolism [37-39] and accelerates their growth and multiplication [41], which leads to the bio-corrosion processes integration [44] and polymers biodegradation [18, 42].

A protective process [90, 91] with efficiency demonstrated by field monitoring [45-47] has been developed to prevent aging processes of underground power cables from corrosion products of metallic shielding formed by the polymeric jacket degradation.

Conclusions

As technological developments are continuously growing, the electricity production and consumption are constantly increasing, so the electromagnetic pollution sources of the environment are becoming more and more diversified and intensified.

In built up media (complex built environment) the materials are exposed simultaneously to a physical, chemical and microbiological stress factors series that act synergistically with disruptive electromagnetic fields and cause material degradation - with consequences on the durability and safety in operation of buildings and installations. The most common disruptions fields generators sources (stray currents generators) on built of media are transport systems on rails with traction in DC or AC transmissions with various operating voltage and frequency [92], medium and high voltage overhead power lines and the unbalanced currents from three-phase system [1]. Generated stray currents cause damage to both metallic structures / elements and reinforced concrete of the generators sources (railroads, power installations) and neighboring constructions and installations (with other administrations) with negative environmental implications.

With a view to sustainable development, in order to increase the buildings and installations durability and safety, to prevent the destruction caused by AC and DC stray currents, it is considered appropriate to develop and implement effective preventive and protective methods. This is only possible through inter- and transdisciplinary knowledge and sustained environmental education [93-95] and to develop and implement appropriate technical regulations [96] environment / health issues, not economic interests).

Acknowledgment: This work was financially supported by the UEFISCDI of Romania, under the scientific Program NUCLEU 2016 - 2017, contract PN 16 11 02 11 /2016 and the H2020 program, Project ID: 766180/2017-2021, acronym INTERACT H2020-MSCA-ITN - 2017, https://cordis.europa.eu/project/rcn/212860_en.html

References

1. LINGVÁY, I., VOINA, A., LINGVÁY, C., MATEESCU, C., Revue Roumaine des Sciences Techniques série Électrotechnique et Énergétique, vol. 53 (2bis), 2008, pp. 95-112.
2. ZAKOWSKI, K., DAROWICKI, K., Polish Journal of Environmental Studies, vol. 8 (4), 1999, pp. 209-212.
3. ISOC, D., IGNAT-COMAN, A., JOLDÍ, A., AIP Conference Proceedings, 2008, p. 1019, pp. 383-388.
4. IGNAT-COMAN, A., ISOC, D., JOLDIS, A., GAZIUC, I., IEEE International Conference on Automation, Quality and Testing, Robotics, AQTR 2008 - THETA 16th Edition – Proceedings 1.4588730, 2008, pp. 178-183.
5. ISOC, G., ISOC, T., ISOC, D., Studies in Computational Intelligence, vol. 486, 2014, pp. 53-64.
6. ISOC, D., Advances in Intelligent Systems and Computing, vol. 633, 2018, pp. 18-33.
7. ISOC, D., Advances in Intelligent Systems and Computing, vol. 633, 2018, pp. 34-46.
8. NEVILLE, A., Pitman Publishing Ltd 1975, pp. 370-374.
9. MATEI, G., LINGVÁY, D., SPAFIU, P.C., TUDOSIE, L.M., Electrotechnica, Electronica, Automatica (EEA), vol. 64 (4), 2016, pp. 52-58.
10. CHICCO, G., POSTOLACHE, P., TOADER, C., Electric Power Systems Research, vol. 81 (7), 2011, pp.1541-1549.
11. SPAFIU, P.C., LINGVÁY, D., MATEI, G., Electrotechnica, Electronica, Automatica (EEA), vol. 65 (3), 2017, pp. 24-30.
12. MARIN, D., MITULEP, A., LINGVÁY, M., Electrotechnica, Electronica, Automatica (EEA), vol. 61 (2), 2013, pp. 58-64.
13. NASSEREDDINE, M., RIZK, J., NAGRIAL, M., HELLANY, A., MUCI, D.D., Proceedings of the Universities Power Engineering Conference, 2015, p. 7339854.
14. CZUMBIL, L., MUCI, D.D., STET, D., CECLAN, A., International Symposium on Fundamentals of Electrical Engineering, ISFEE 2016, p. 7803231.
15. STET, D., MUCI, D.D., CZUMBIL, L., MANEA, B., EPE 2014 - Proceedings of the 2014 International Conference and Exposition on Electrical and Power Engineering, p. 669903, 2014, pp. 231-236.
16. MUCI, D.D., CHRISTOFORIDIS, G.C., CZUMBIL, L., Electric Power Systems Research, vol. 103, 2013, pp. 1-8.
17. STET, D., MUCI, D.D., AVRAM, C., DARABANT, L., 7th International Symposium on Advanced Topics in Electrical Engineering, ATEE 2011, p. 5952251.
18. BORS, A.M., BUTOI, N., CARAMITIU, A.R., MARINESCU, V., LINGVÁY, I., Mat. Plast., vol. 54, no. 3, 2017, p. 447-452.
19. OPRINA, G., RADERMACHER, L., LINGVÁY, D., MARIN, D., VOINA, A., MITREA, S., Rev. Chim. (Bucharest), 68, no. 3, 2017, p. 581-585.
20. NITA, P., LINGVÁY, M., SZATMÁRI, L., LINGVÁY, I., Electrotechnica, Electronica, Automatica (EEA), vol. 61 (3), 2013, pp. 40-45.
21. VOINA, A., NITA, P., LUCHIAN, A.-M., LINGVÁY, D., BUTOI, N., BORS, A.M., LINGVÁY, I., Electrotechnica, Electronica, Automatica (EEA), vol. 65 (2), 2017, p. 60-65.
22. LINGVÁY, J., Korróziós figyelő, 44 (6), 2004, pp. 187-194.
23. PUKLUS, Z., LINGVÁY, J., HODOSSY L., Korróziós figyelő, 45 (2), 2005, p. 43.
24. LINGVÁY, I., GABOR, M., LINGVÁY, C., Rev. Chim. (Bucharest), 57, no. 2, 2006, p. 180-183.
25. *** CIGRE Working Group 36.02. - Guide Concerning Influence of High Voltage AC Power Systems on Metallic Pipelines. Canada, 1995
26. CZUMBIL, L., MUCI, D.D., MUNTEANU, C., STET, D., TOMIOJANO, B., Proceedings of the Universities Power Engineering Conference, 2015, p. 7339841.
27. DING, Q., FAN, Y., International Journal of Corrosion, vol. 2016, 2016. doi.org/10.1155/2016/5615392, Article ID 5615392 (8 pages).
28. VILJÀNEN, A., Geophysical, vol. 25 (1-2), 1989, pp. 135-159.
