Electromagnetic Compatibility System for the Lightning protection of EDF hydro-electric power plants in Corsica

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Abstract: This document describes the unclassified part of the Lightning protection studies for a power plant.
The studies were conducted with a new EMC (Electromagnetic Compatibility) System concept: "Zero Method". This concept uses an accessible and easy process to control the industrial electromagnetic interference from various electromagnetic effects. In particular, the protection against the lightning current intrusion is treated.
The adopted solutions improve personnel and facility safety and provide light costs and effective works.

Keywords: Lightning protection, EMC system, Zero Method.

1. Introduction

The Corsica hydro-electric Power stations and their outer structures are particularly subjected to the effects of the lightning, because of the climate, of the geology and of the metal good conducting networks which make easy the circulation of the lightning currents. These structures are organized in 2 groupings: Castirla and Ocana. Studies of protection were carried out from 1994 to 1998 by the mean of an original methodology having already shows reliable results in other activities (Central of Hospitalet and pipeline networks), first on Castirla, and on Ocana. This paper presents the sources of the problems and their solution. If the configurations are extremely diversified over fifty studied sites, the spirit in which they were treated is common, it's a technique at the experimental stage called since the years 1995: "Zero Method", exposed and detailed in this paper.

2 French Standard, Regulation and Guide.

2, 1 Standards about the protection of the people and the goods

- NF C 15-100 is applicant to the construction of installations BT with in particular concerning the electromagnetic compatibility, the equipotentiality of the of the masse and earth networks
- Practical realization [2] ground network (Standards NFC 13--100, NFC 15-100 NFC 17-100) and equipotential ground network

This equipotential network must make it possible to ensure simultaneously

- The safety of the people .
- The protection of the power installations .
- The protection of the sensitive equipments .

2, 2 *Lightning protection*

It relates to the whole of the buildings [3]. The possible implementation of lightning rod, of down conductors , of the Faraday rooms and the earth electrodes is treated in France according to NFC17-100 and 17-102 French standards.

2, 3 *Overvoltage protections*

In order to obtain a good level of protection it is necessary to install several stages of coordinated surge protection device :

- Principal protection at the head of installation must evacuate a maximum of energy towards the earth
- The secondary protections placed as close as possible to the sensitive equipment must be compatible with the equipment susceptibility

2, 4 *Protection of the sensitive equipments*

It is essentially reached by maintaining a good «ground potential ». The aim of the studies carried out was to apply the various techniques indicated here before, by preserving especially the quality of this ground reference.

3. Compatibility ElectroMagnetic « system »

3, 1 State of the art

3, 1, 1 *State of the art on EMC system*

The field of the Electromagnetic Compatibility of systems is still at the stage of the studies and the project standards, even at the international level. This research is based on tests, metrology and complex coupling calculations. Among the studied systems, aeronautics, the nuclear power and the weapon systems are the first supports, in particular concerning the lightning protection.

3, 1, 2 *Zero Method*

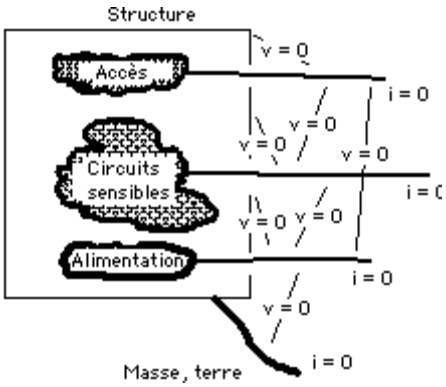
The Zero Method is a research orientation connected to the other common research, supported by a specific metrology on the field and a simpler access, reserved to the industrial facilities, practical and economic, matched to non-specialists on theoretical electromagnetism who use sometimes heavy means of measurement and calculations. The Zero Method does not need stimulation of circuits, it uses the existing electromagnetic environment.

It is the subject of many papers [5] and international communications.

3, 2 Zero Method

3, 2, 1- *Concept*

This new concept is based on an obvious fact that a reference potential (Ground, 0, Battery, Neutral and other potentials) remain a reference only if no HF current (usually from 10 kHz to 10 MHz) circulates in its conductors, and that there are not HF voltage between different reference potentials, whenever it occurs.



This concept can be extended to greater frequencies for other applications.

The reference potentials are usually the following: ground, earth, 0 electronics, and power with D.C. current, power with AC current, communications.

3, 2, 2 *Feedback experience on the significant sites*

In practice, it is recognized that the "Zero" are ideal and non-essential in the sensitive installations for former technologies concerning informatics and communication (tolerance to the signal-to-noise ratio).

When 1 Vc is measured between references, it's very correct.

The graph hereafter shows the experimental situations most frequently met.

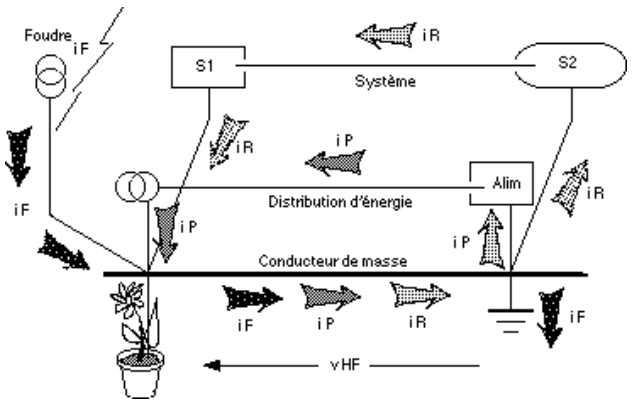
The current limit is calculated easily considering approximately an inductance 1 µH per meter of reference conductors. It results a few hundreds of mAc for a few tens of meters length of conductor, concerning the frequencies usually concerned.

Let us recall that for the very low levels (towards 0), frequencies and wave forms are not significant parameters. Whereas at the high levels, these parameters become important and require particular analyses.

3, 2, 3 *Application of Zero Method*

The schematic figure which follows summarizes the various situations usually met. We can see:

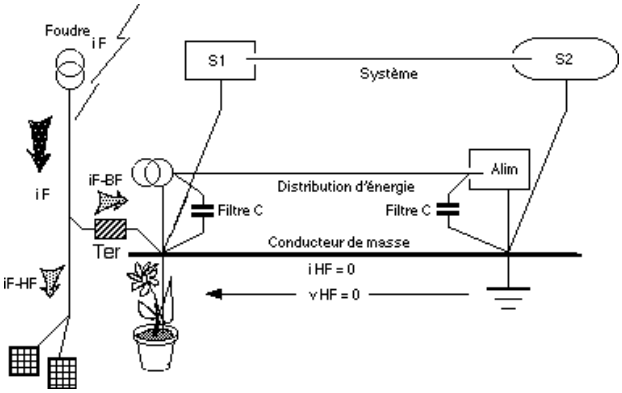
- A « equipotentiality »conductor between 2 zones more or less distant.
- A relatively resistive earth electrode or with high impedance (flower pot).
- An earth electrode of good quality with low resistance or impedance.
- A power source (DC or usually AC) possibly delivering electric noises (power electronics)
- A power user generating electric parasitances (power electronics).
- A sensitive system (informatics, low levels measurements, etc...) made of 2 equipments in different zones (different references).
- A great and rapid current injection whose origin is the lightning (coupling by antenna effect, with lightning conductor, surge protection of air lines, earth conductors, etc...).



Thus, we note the circulation of 3 types of currents on the equipotentiality conductor. The Zero Method immediately indicates if the safety of the system is guaranteed. The equipotentiality characteristic V = 0 will be reached only if I = 0.

3, 2, 4 *Realization of the solutions*

The Zero Method proposes 2 principal solutions making it possible to cancel or reduce considerably I:



1- The filtering of the source and its ground reference (TNS or IT mode with an additional filter for IT, specific Filters FAO). This filtering is never alone, because power is distributed and its quality must be ensured by a technique similar to the networks hardening (aptitude not to collect or not to drive disturbances). The distribution hardening of power is carried out with a new reduced filtering and a new referencing with the local ground by a specific Filter FAO (TNS or IT configuration).

2- The derivation of the lightning current out of equipotentiality conductors.

We can note that the disturbance collected by the system is not exempted of precaution, it must too be weak because it could disturb other operating systems.

These 2 points are the this document object.

3, 3 Principle of the filtering of the power sources and the distribution hardening

3, 3, 1 *Filtering of the power sources*

The filtering of the power sources fulfills 2 functions:

- To eliminate the interferences coming from the power source itself.
- To constitute a very low HF impedance, that is a common element of a whole distribution in the aim do not be sensitive to the interferences of the power users and not to contribute to the proliferation of HF disturbances.

3, 3, 2 *Power distributions hardening*

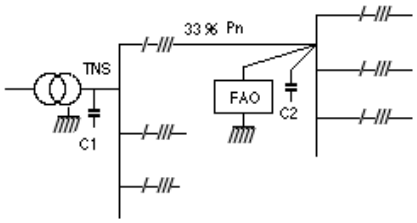
The electric distributions hardening results in ensuring a null HF voltage between Neutral and ground/earth, also between Phases and Neutral.
It 's carried out by a original cell for which one can say that it function like the last element of a filtering cell (use in derivation), making a HF short circuit between Neutral and ground/earth.

3, 4 Theoric study of the power distributions filtering and hardening – Corsica sites

3, 4, 1 *Example of an analyzed configuration*

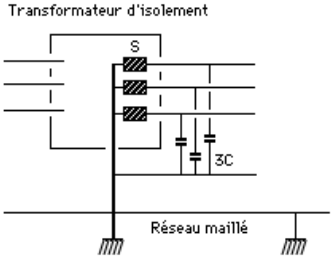
One considers a configuration that is made of:

- TGBT Room equipped with a HTA-BT transformer (250 KVA three-phases) .
- All the distribution is in TNS Neutral mode.
- A divisional departure of 80 KVA three-phases .
- A distant divisional board distributing the 80 KVA three-phase power.



3, 4, 2 *Configuration Modelling*

Let us consider two sources of disturbances and a filtering element :



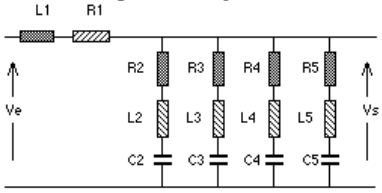
- Disturbances in differential mode related to the transmission of power.
- Disturbances in common mode related to the insulation from the ground of the user circuits.
- Devices which are placed in parallel manner.

The added components to the installation are follows:

- A set of capacitor laid out between each phases and the Neutral, in "star" configuration (commercial name «permanent correction of cosine Ø »).
- A set of filters (X and Y class) laid out between Neutral and ground (commercial name « FAO » [6]).

3, 4, 3 *Modelling*

The modelled and simplified diagram is as follows.



It will be enough in the Vs equations = f(Ve, F) to give matched values for L, R or C parameters according to the required performance.

One meets two typical situations in the studied site which will be the subject of this analysis :

- Filtering of the power source sector in differential mode .
- Attenuation in common mode, TNS Neutral mode distribution.

This common diagram leads to 2 theoretical studies making it possible to treat sometimes contradictory technical interests, and finally defining technological choices offering performance compromises.

- Evolution of the cos Ø installation.
- Attenuations effectiveness in differential and common mode.

3, 4, 4 *Physical Relations related to the cos Ø correction*

$$\mathrm{Pap(Origin)} = \sqrt{\mathrm{Pac}^2 + \mathrm{Pr}_L^2} \text{ and } \mathrm{Pap(End)} = \sqrt{\mathrm{Pac}^2 + \mathrm{X}^2}$$

$$\text{with } X = X_L - X_C \text{ and } \mathrm{Xc(\%)} = 100\frac{\mathrm{X(c)}}{\mathrm{Pap(Origin)}}$$

The following graph (Figure 1) shows the evolution of the final apparent power according to the quantity of reactive power installed for the filtering of the sources and the hardening of the distributions.

It is seen that insertion up to 20 % of power reactivates in an installation does not raise difficulties, even when the cos Ø of origin is already 0,95. Practically, 5% per zone are necessary in the majority of the case (approaching formulation : C (µF) = P (KVA) in three-phase current).

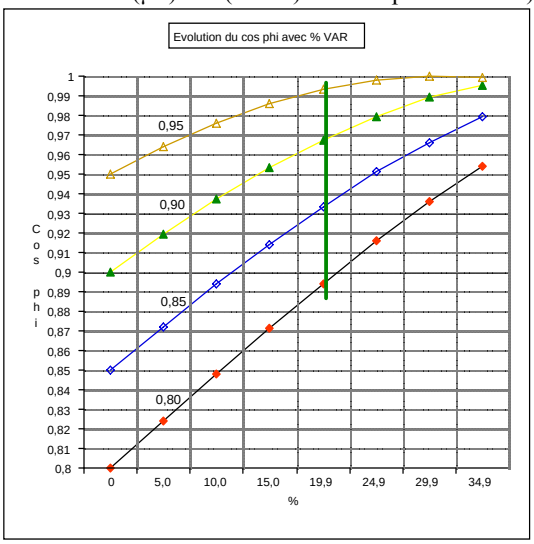


Figure 1

We can note that the voltage evolution is forced to overvoltage when the user impedance is low or great.

3, 4, 5 *Physical Relations related to the attenuations in differential mode and common mode*

$$\frac{Ve}{Vs} = \frac{1}{1 + z_1 y_2}, \text{ with :}$$

$$z = R + jX \text{ et } X = Lw - \frac{1}{Cw} \text{ and } y = \frac{1}{R + jX} \text{ or } y = \frac{R - jX}{R^2 + X^2}$$

$$\frac{Ve}{Vs} = 1 + (R_1 + jX_1) + \left(\frac{R_2 - jX_2}{R_2^2 + X_2^2} + (indice3) + (indice4) + (indice5)\right)$$

Considering $\frac{R_2 - jX_2}{R_2^2 + X_2^2} = \frac{R_2 - jX_2}{Q_2}$, idem for indice 3 … 5.

$$\frac{Ve}{Vs} = 1 + \frac{R_1R_2}{Q_2} + \frac{R_1R_3}{Q_3} + \frac{R_1R_4}{Q_4} + \frac{R_1R_5}{Q_5} + \frac{jX_1R_2}{Q_2} + \frac{jX_1R_3}{Q_3} + \frac{jX_1R_4}{Q_4} + \frac{jX_1R_5}{Q_5} - \frac{jR_1X_2}{Q_2} - \frac{jR_1X_3}{Q_3} - \frac{jR_1X_4}{Q_4} - \frac{jR_1X_5}{Q_5} + \frac{X_1X_2}{Q_2} + \frac{X_1X_3}{Q_3} + \frac{R_1X_4}{Q_4} + \frac{R_1S_5}{Q_5}$$

We get now

$$\frac{Ve}{Vs} = 1 + \left(\frac{R_1R_2 + X_1X_2}{Q_2}\right) + (--_3) + (--_4)(--_5) + j\left(\frac{X_1R_2 - R_1X_2}{Q_2}\right) + (--_3) + (--_4) + (--_5)$$

and finally $Att = \frac{1}{\sqrt{r^2 + i^2}}$

The solution of these equations gives the whole of the useful solutions, in particular coefficient the attenuation Ve/Vs vs frequency and according to selected options.

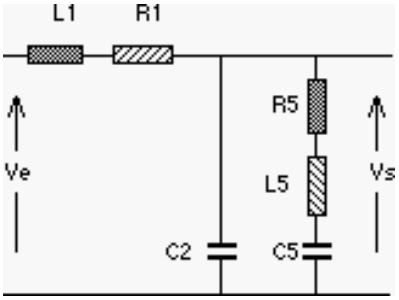
3, 5 Numerical applications

3, 5, 1 *Filtering of the power source in TGBT stage*

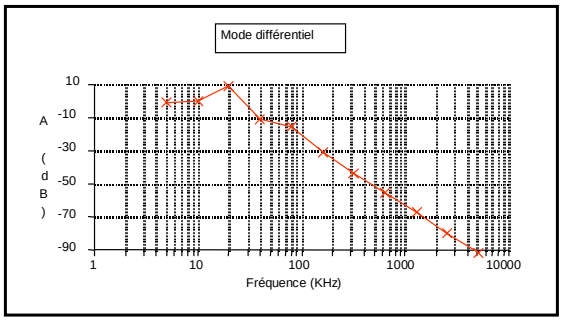
Among the assumptions chosen, we retain the following values for the power distribution studied:

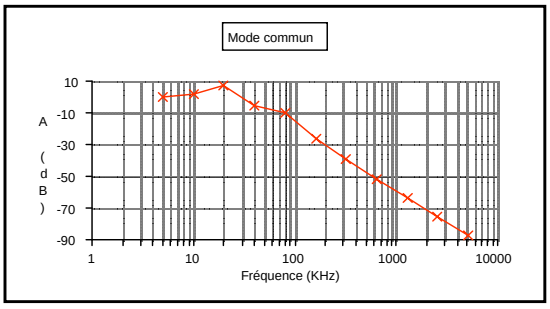
Type	**Filter « 1 »**	**Filter « 2 »**	**Filter « 5 » Differential source**
L (µH)	80	0	400
R (Ω)	0,019	0	0,170
C (µF)	∞	250	∞

- The Filter « 1 » corresponds to the transformer characteristics.
- The Filter « 2 » corresponds to the capacitor for cos Ø correction.
- The Filter « 5 » corresponds to the user impedance characteristics in differential mode ; single-phases current.



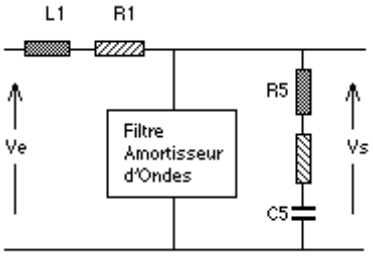
- Power of transformer HTA-BT: 250 KVA Three-phases
- 97% yield effectiveness which conditions R1 series resistance.
- Short-circuit voltage: 5 % which condition the leaky inductance L1 with R1.
- Considering 100 KVA with cos Ø = 0,8.





3, 5, 2 *Distribution hardening (Attenuation in common mode)*

We consider that the distribution board works with 80 KVA supply. The retained values considering the conditions similar to the source, with 1 % of line voltage drop are as follows:



Type	**Filter « 1 »**	**Filter « 2 »**	**Filter « 3 »**	**Filter « 4 »**	**Filter « 5 » Distrib common mode**
L (µH)	50	40	0	0	250
R (Ω)	0,015	4,7	47	0	1000
C (nF)	∞	220	1000	470	50

- The Filter « 1 » corresponds to the characteristics of the 80 KVA distribution board.
- The Filters « 3 and 4 » are contained in a component called Filtre Shock absorber of Waves (FAO) whose role is to carry out a HF short-circuit between Neutral and Earth. The indicated values are study ones, appreciably representative of the commercial product subjected to the confidentiality. By feedback experience and for economic reasons (without harming the performances), this component is used in a very wide range of powers and configurations. This is possible because of the presence of the cos Ø correction capacitor, whose power reactive is proportional to the total power.
- The Filter « 5 » corresponds to the characteristics of the impedance user in mode common – Insulation of the circuit user from the ground/earth, evaluated in part with insulation of a 80 KVA three-phase transformer.

3, 5, 3 *Exploitation of the attenuation curves*

We note :

- That there is no disturbance voltage in common mode on the source stage with the TNS neutral mode.
- That the significant rate of attenuation is obtained towards 30 KHz.
- That this 40 dB attenuation (ratio of 100) is obtained from 200 to 300 KHz, which represents a good effectiveness against the effects of the lightning [7], as well in differential mode on the source as in common mode in distribution.

3, 5, 4 *Experimental Results*

In the field, it is noted that initial voltages from 5 to 9 Volts peak on the source and on the distribution are reduced towards 0,1 Volts peak, in accordance with the required objectives.

In addition, it should be noticed that the effectiveness of these corrections is largely conditioned by the care in installing them and connect them, in particular with the great reduction of connection lengths.

3, 6 Derivation of the lightning current from the ground network

The following analysis reuses the Zero Method concept and relates to a component especially developed in experiments since ten years « TER 5 to 80 Amps – Ets Sare ». Its aim is to fictitiously separate the ground networks in HF while ensuring the human safety, according to the French Decree from November 14, 1988, and related standards.

Its physical component is similar to that a low length ground conductor wound on a non-linear magnetic core (§3,2,4).

3, 6, 1 *Numerical analyzes of TER*

In a general way, the connection between the system of lightning conductor and the ground network of a sensitive site to protect are subjected to the following constraints:

- Electric safety aspect
  - Equipotentiality at the power frequency to be in conformity with the human safety requirements.
- Direct Lightning protection aspect
  - Equipotentiality at low frequency to limit the increase of potential and voltage breakdowns

between the system of lightning protection system and the ground network.

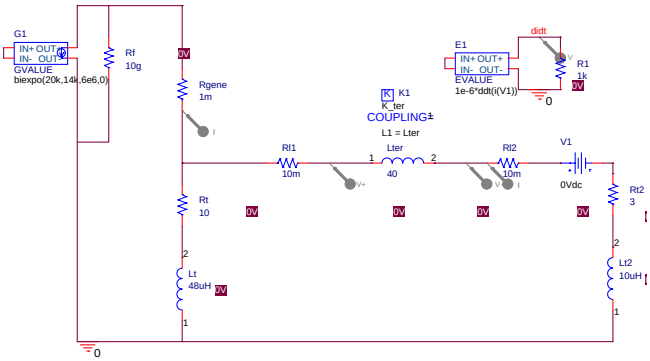
- Attenuation of the impulse and the high frequencies to limit the intrusion of these strong levels frequencies in a sensitive ground network.
- Resistance of the high frequency filtering component from the Lightning overvoltage.

- EMC protection aspects
  - The lightning protection system is an important collector of high frequency external parasitance. These parasitances are introduced into the ground network of the site, which is often the cause of problem in sensitive sites.

These constraints impose compromises which are not reachable by the traditional means and methods, which systematically can't cover all these constraints.

3, 6, 2 *An approach of modelling*

The insertion of a component TER (prototype) in a connection between the lightning down conductor and the ground network was modelled with PSPICE software.



This approximate modeling makes it possible to evaluate in a qualitative way the performances of TER with respect to the constraints indicated above.
These performances are synthesized in the following table.

Electric safety	At 50 Hz frequency, calculation shows an impedance of **50 mΩ** for a rated current of **50 A**, which is coherent with measurements and which is in conformity with the safety requirements by developing only 2,5 V eff.
Direct Lightning Protection	• In low frequency, calculations show that the impedance does not exceed **1 Ω**. • Considering a lightning impulse on the lightning down conductor, the penetrating current in the ground network reach a light attenuation from approximately **15%** in peak amplitude, compared with the current du to the short-circuit connection. • The most significant effect is the reduction in the speed of the current. For the first derivative di/dt, one has a reduction of approximately **20%** and for the second derivative di^2/dt^2 (sources of high frequencies) one has a reduction of approximately **30 dB**. • Compared with a traditional coil linear having the same performances in EMC (coil of some mH), TER develops a voltage approximately **6 times** less important (considering a 20kA lightning current), which makes it possible to be supported.
EMC Protection	For the high frequencies (F > 10 kHz) TER bring an attenuation from approximately **20 dB**.

3, 6, 3 *Conclusions*

This table shows that the TER prototype is a powerful specific means which makes it possible to cover all the essential constraints imposed on a significant site. The theoretical profits obtained with these prototypes are found in reality case looking at the significant reduction of the incidents related to the lightning.

Studies exist in this approach to control the whole of constraints EMC and protections by using numerical analyses associated with technological analyses of the TER component and the lightning earth electrodes type (rod, plates, earth network...).

4 GENERAL CONCLUSIONS

4, 1 *Quasi-perfect equipotentiality*

Measured in Volts peak, it implies the absence of current in a conductor, the impedance do not need to be reduce while it's in accordance to standard indications.

4,2 *Experimental regulation of electromagnetic disturbances*

The regulation of the conducted disturbances is ensure by the quality of the power sources which receive cos Ø correction capacitor not in triangle but in star configuration, and whose required function is not any more the rectification of the cos Ø, but a quasi-null HF impedance.

In addition, the distributions of these sources « are hardened »in the electromagnetic way, conferring an quasi-insensitivity to them to collect the electromagnetic waves and to drive the voltages and currents which they drive in a traditional way.

Finally, if it's possible, it is imperative to send the lightning current impulses out of the sensitive ground networks which must hold good references, whatever it occurs.

4, 3 *Responsibilities*

The theoretical and practical aspects of the concept «Zero Method » shock in the practices, they do not need standardization because they are physically obvious. It is possible that in the future this concept becomes a tool of legal assistance making it possible to better define responsibilities which can be opposed sometimes.

4, 4 *Point of view of the customer and the user*

The positive financial assessment of exploitation relating to the effectiveness protection from the

lightning of the equipment and systems is clearly noted since the protection are been carried out.

It should be noticed however that if the concept is quite understood, its implementation need attentive care by the intervenant, because practices change from electric behaviours of the installations to an electromagnetic one.

4, 5 *Approaches « System » of Electromagnetic Compatibility by the Zero Method.*

This method based on the strict respect of the system potential references is worth to be explored, with an aim of checking its capacity to lead to a methodology of coherent and universal analysis in the field of the EMC system.

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