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Contact current, sensitivity to electricity & 50Hz electric and magnetic fields

TDEE & ACE Team

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Short Summary

Our main objective is to quantify and qualify the contact currents, both by simulations and on-site measurements.

Our team has developed specific numerical tools to compute and understand the influence of High Voltage (HV) power lines around 3D electrical structures in private homes. We can detect critical configurations that produce high or low contact currents in an isolated house or in a network of houses. The type of network scheme (TT, TN) and the geometry of the connections are as important as the intensity and the direction of the magnetic induction field.

On-site measurements (about 100 houses) were performed to understand the level and the origin of these contact currents in the Belgian housing stock. Instead of a random sample, we preferred to measure (in a strict protocol and quite prepared, see Annex) these contact currents for residences located near the lines, in order to obtain a statistical base to assess the potential correlation between the ambient magnetic field and current contact. It should be noted that very often, the contact current level is near the electrical noise that was in the house. The apparatus used has been chosen accordingly. Many investigations have been performed to understand the origin of these contact current and preventive means have been investigated, both by measurement, model and simulations.

Another important aspect of our research is to inform people about our research and to compare the potential biological effects (by an internationally recognized indicator) between contact currents and exposure to electric and magnetic field.

We also performed a comparison of 15 studies about the human body interactions with E-field, B-field and contact currents. They allow us to classify the influence of these sources. Contact current is clearly a dominant factor.

We also made a device for injecting a current (1 mA max) in a forearm of a person. This device allows you to test the sensitivity of the people at different frequencies and shapes obviously including the 50 Hz, with different protocols. Indeed, the literature (Leitgeb, 2008) has shown a correlation between sensitivity to electricity and hypersensitive peoples. This removable device could help test for tests on site.

Résumé

Notre objectif est de qualifier et quantifier les courants de contact, à la fois par de la simulation et des mesures sur le terrain.

Nous avons développé des outils numériques pour étudier et comprendre l'influence des lignes Haute Tension (HT) aux environs de structures électriques 3D. Nous pouvons déceler des configurations critiques qui diminuent ou augmentent le niveau des courants de contact dans une habitation ou dans un réseau d'habitations. Le type de réseau (TT ou TN) et la géométrie de la connexion sont aussi importants que l'intensité et la direction du champ d'induction magnétique.

Concernant la campagne de mesure (environ 100 maisons visitées), les deux aspects essentiels étaient de comprendre l'origine de ces courants de contact et de connaître leurs valeurs statistiques dans le parc résidentiel belge. Plutôt qu'un échantillon aléatoire, nous avons préféré mesurer (dans un protocole strict et assez élaboré, voir annexe) le courant de contact pour des résidences situées à proximité des lignes. Ceci afin d'obtenir une statistique pour évaluer la corrélation potentielle entre le champ magnétique ambiant et le courant de contact. Il faut noter que très souvent, le niveau des courants de contact est proche du bruit électrique que l'on a dans l'habitation. L'appareillage utilisé a été choisi en conséquence. Par ailleurs beaucoup d'investigations ont été faites afin de comprendre l'origine de ces courants de contact. A la fois par l'analyse des mesures, la modélisation et la simulation.

Un autre aspect important de notre recherche est d'informer la population sur nos recherches et, notamment de comparer les conséquences biologiques potentielles (par un indicateur reconnu internationalement) entre des courants de contact et l'exposition au champ magnétique et électrique à proximité des lignes HT.

Pour comprendre l'influence des différentes sources qui induisent un champ électrique dans le corps humain, nous effectuons une comparaison de 15 études. Celles-ci nous permettent de classer l'influence de ces sources (champ externe E et/ou B, courant de contact). Le courant de contact vient largement en tête pour ce qui concerne la quantification de la contrainte interne associée.

Nous avons également réalisé un appareillage pour permettre d'injecter un courant (max 1 mA) dans un avant-bras d'une personne. Cet appareil permet de tester la sensibilité des gens au courant électrique, à différentes fréquences et formes mais également du 50 Hz, avec différents protocoles. En effet, la littérature, et notamment les études de (Leitgeb, 2008) ont montré une corrélation entre la sensibilité à l'électricité et les hypersensibles. Cet appareil amovible pouvait permettre de tester par nous-mêmes des personnes sur site.

Introduction

The first study on magnetic fields and childhood leukaemia was done in the late seventies [Wertheimer N. & Leeper E., 1979]. Since then, some epidemiological studies put in evidence a (weak) correlation (Carcinogenic risk group 2B[1]) between magnetic fields and childhood leukaemia. The threshold for this correlation was set to the value of 0.3 - 0.4 µT.

External magnetic fields induce very weak currents in biological tissues what gives rise to a very low electric field (0.016 mV/m for an induction of 1 µT). Therefore, assuming that biological effects of magnetic fields are solely due to induced currents seems an inconsistent explanation.

Another hypothesis studied in the USA [Kavet R., 2000] considers an intermediate factor between magnetic fields and childhood leukaemia: the contact currents. These contact currents may induce an electric field of tenths of mV/m in the child bone marrow (for a realistic contact current value of a few microamperes) and without any sensitive reaction of the child. Besides, some correlation could also exist between the contact current level and the ambient electromagnetic field.

The first objective of this project was to compare the Belgian and American grounding schemes by means of numerical modelling. These two grounding systems differ significantly and can give rise to quite different levels of contact currents for the same exposure to magnetic field due to the presence of HV power lines.

We have developed and validated a simple numerical model of a grounding system. This model has been extended and adapted to include ground loops, ground stakes and different electrical wiring. Some interesting results have been evidenced concerning the parameters that influence the contact current level in a house.

In an other way, we have realised a campagne on Belgian residences to evaluate the current contact, earthing, ambient field.

The second objective was to inform people about our research and to compare the potential biological effects (by an internationally recognized indicator) between contact currents and exposure to electric and magnetic field. In this section we have study an existing numerical human model to determine the intensities and the densities of the induced currents generated by HV power lines and contact currents.

Further, a simple electric model of a human being is developed to calculate the induced electric field by contact current and compare it with some studies.A comparison of 15 studies found in the literature has allowed us to somehow classify the influence of electric and magnetic field and contact current on the induced electric field in the bone marrow. Further, a simple electric model of a human being is developed to calculate the induced electric field by contact current and compare it with some studies.

[1] IARC (International Agency for Research on Cancer) Monographs have evaluated environmental agents and exposures. Each exposure is classified into one of 5 groups according to the strength of the published scientific evidence for carcinogenicity. Group 2B means possibly carcinogenic to humans. Erreur ! Source du renvoi introuvable.

We also made a device for injecting a current (1 mA max) in a forearm of a person. This device allows you to test the sensitivity of the people at different frequencies and shapes obviously including the 50 Hz, with different protocols.

Indeed, the literature (Leitgeb, 2008) has shown a correlation between sensitivity to electricity and hypersensitive peoples. This removable device could help test for tests on site.

Main tasks

- **Grounding Scheme Modelling**

The starting point was the study of the Belgian and the American grounding systems[Lacroix B. & Calvas R., 1995]. This preliminary study allowed us to develop the residence grounding system model for our research. This model is based on the Partial Element Equivalent Circuit (PEEC) method [Brennan P.A. & al, 1979] and the Kirchhoff laws. We implement and study the following systems:

- TN and TT grounding systems to compare them,
- A HV power line near a building to study its effects on the electric system. This HV power line can be turned around the building with different voltages and currents;
- Electrical appliances, water pipes, etc.

First, we model an elementary house with only a schematic grounding scheme as shown in Figure 1. In this elementary house, we define four different earth connections. These connections show the influence of geometry of the electrical wiring on the contact current level. A human being is modelled by a resistance of 3 kΩ.

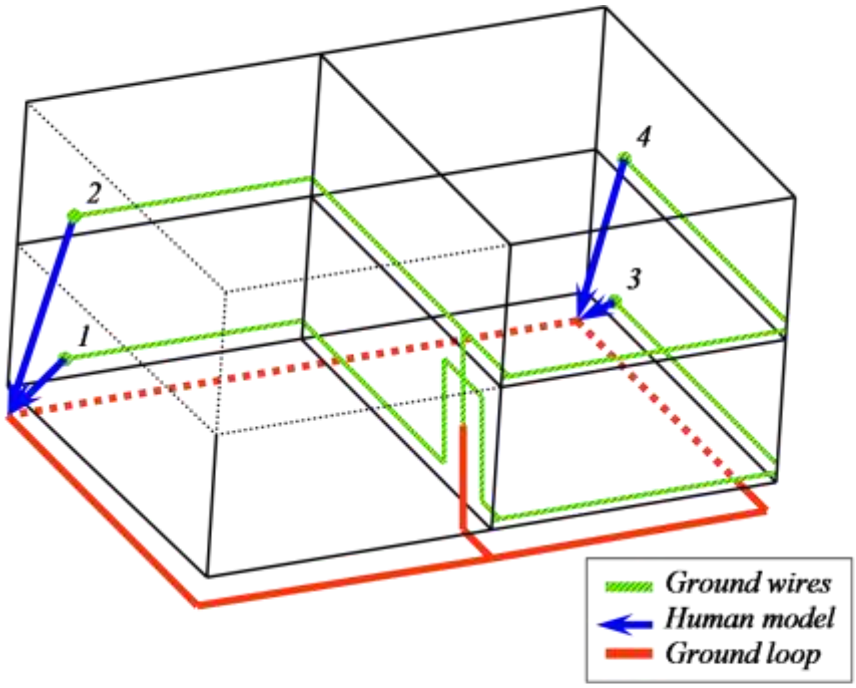


Figure 1: Initial house model.

The following parameters are relevant:

- The distance between the HV power line and the house;
- The orientation of the HV power line;
- The characteristics of the HV power line (currents, geometry);
- The house geometry and the grounding scheme;
- Different networks of houses.

Two different types of houses are considered: with either grounding loop or grounding stakes. Hereafter, it will be shown that the proximity of other houses with the same type of grounding, e.g. a network of houses, does not affect in the same way the contact current level for the two types of groundings tackled.

- **Campaign development**

Two key aspects of our campaign were to understand the origin of these currents in the Belgian housing stock. Instead of a random sample, we preferred to measure (in a strict protocol and quite prepared, see Annex) these contact currents for residences located near the lines, in order to obtain a statistical base to assess the potential correlation between the ambient magnetic field and current contact. It should be noted that very often, the contact current level is near the electrical noise that was in the house. The apparatus used has been chosen accordingly. Many investigations have been performed to understand the origin of these contact current and preventive means have been investigated, both by measurement, model and simulations.

- **Electric interactions between ambient ELF fields and body**

Determining the effects of electromagnetic fields (EMF) and contact currents in a human being is crucial. These fields and currents are responsible of an internal electric field in the biological tissues. In the literature, particular attention is paid to the electric field level in the bone marrow due to the possible correlation with childhood leukaemia.
We have performed a preliminary study on the simple model of a head. The human head comprised only three material discontinuities: bone, eyes and grey substance. The electromagnetic source was equivalent to the one generated by the three coils embedded in the "home-made magnetic helmet" that was developed for the tests performed by the psycho-neuroendocrinology team. Even though the geometry was not realistic, the critical areas are determined: the induced currents are much higher in the eyes (Note the two different scales). The numerical results allow the psycho-neuroendocrinology team to better understand the functioning of the helmet and its effects.

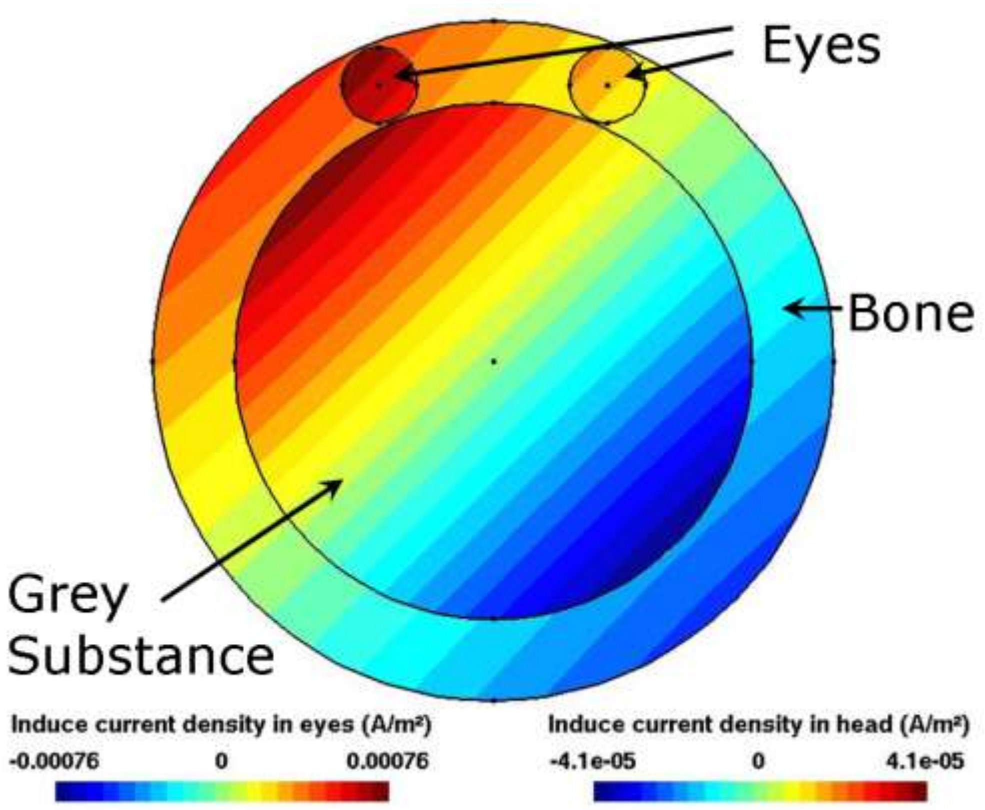


Figure 2 : Induced current density with maximum induction (~20µT).

Next, a comparison of 15 existing studies dealing with the modelling of human beings in an electromagnetic environment was performed. Herein, different types of sources (electric field, magnetic field, combination of both, contact current …) and models (male, female and child) are considered. This analysis allows us to determine which parameters influence the electric field induced in a human body by external sources. Furthermore, a simple electric model of a human being is developed. The level of electric field in the bone marrow calculated by means of this simple model is of the same order of magnitude as the one found in the literature.

- **Support**

Concerning the legal point of view on electromagnetic fields, we follow and read the international, European and Belgian laws and standards (for example, through an email distribution list from C.E.B. of TC 106). We are also following the implementation of the European directive 2004/40/EC.

Concerning the technical and scientific point of view, we analyse the papers available in the literature and particularly those which are distributed by BBEMG members.

Furthermore, we are following the legislation and literature on RF fields, especially on mobile phones and new RF technologies as Wi-Fi, WiMax… (« Ordonnance relative à la protection contre les champs électromagnétiques du Parlement de la Région de Bruxelles-Capitale », new « décret » of the Walloon Region on GSM base stations, Interphone project, SCENIHR, WHO…).

We also participate in the multidisciplinary monthly meetings of the University of Liège groups.

We answer many phone calls and emails (direct email or questions from the Web site) about technical questions on EMF fields.

We participate in the website evolution and answer to FAQs.

We have participated or have done some measurements for particulars and companies like Infrabel.

Contact current : Simulation

1. Grounding Scheme modelling

After developing and validating a first model of grounding scheme, we performed some computations with some specific grounding schemes. The first case is an isolated house with a ground loop (Figure 1). The results obtained for this single house were our reference to study the effects of a network of houses.
We observed the effects of two geometrical parameters on the contact current level, namely, the distance between the HV power line and the house, and the orientation of the HV power line. The HV power line is a 380 kV power line with 2x6 cables that carry a current of 1070 A (worst case, though it does not occur often). The magnetic induction produced by the HV power line as a function of the distance is shown in Figure 3.

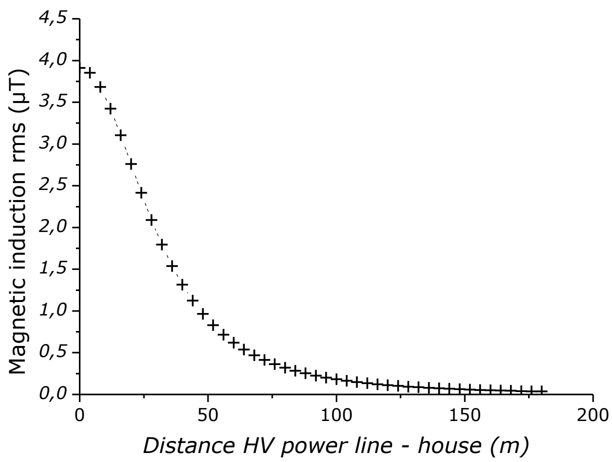


Figure 3 : Magnetic induction of the HV power line in function of the distance.

The first results for a single house concern the induced contact current in the grounding scheme. The Figure 4 and Figure 5 represent the induced contact current level in the four different earth connections as a function of the two geometrical parameters.

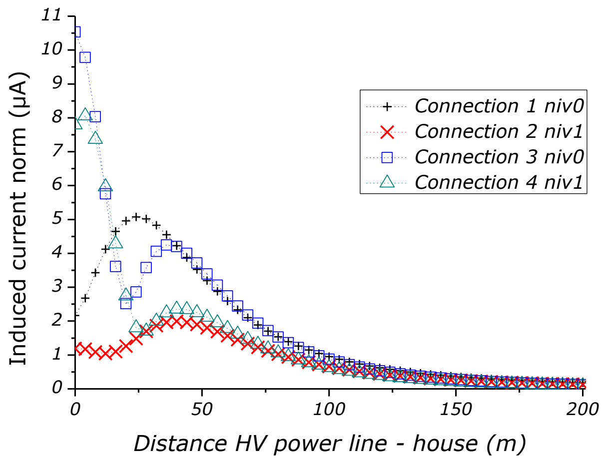


Figure 4 : Induced current level in a single house as a function of the HV power line distance.

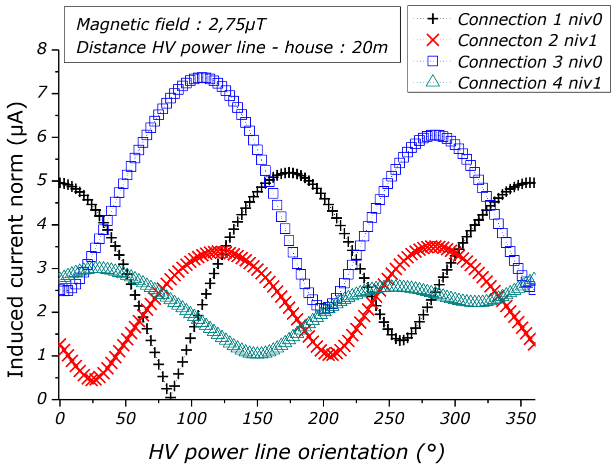


Figure 5 : Induced current level in a single house as a function of the HV power line orientation.

These two figures show a clear influence of the geometry of an earth connection on the contact current level. These differences are especially significant in the vicinity of the HV power line (see Figure 4). When the distance is bigger than 100 m, the induced current level decreases quickly with the magnetic field.

The Figure 5 shows the variation of the induced current in the four considered connections with the orientation of the HV power line. The influence of the HV power line orientation can be observed on Figure 6. We can observe that the imaginary part of the induced current in connection 1 follows the magnetic induction field rotation. The other connections behave analogously.

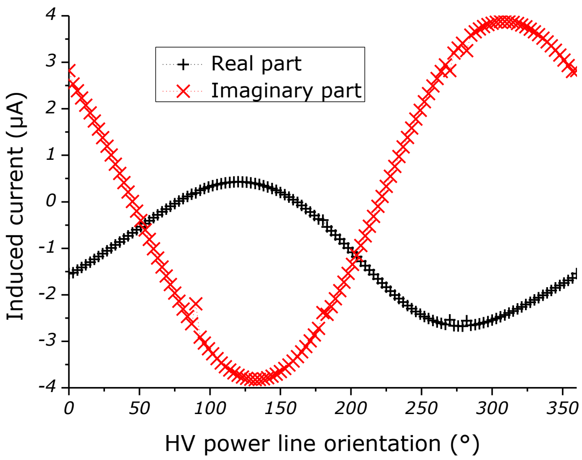


Figure 6: Real and imaginary part of the induced current in connection 1 in Figure 5.

Similar behaviour for the induced contact voltage in the four earth connections is observed in Figure 7 and Figure 8.

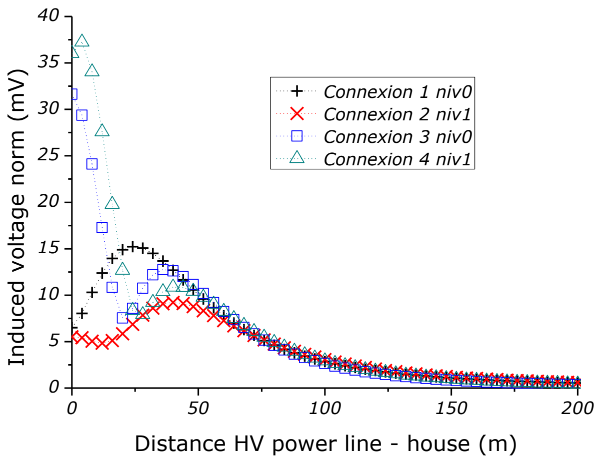


Figure 7 : Induced voltage level in a single house as a function of the HV power line distance.

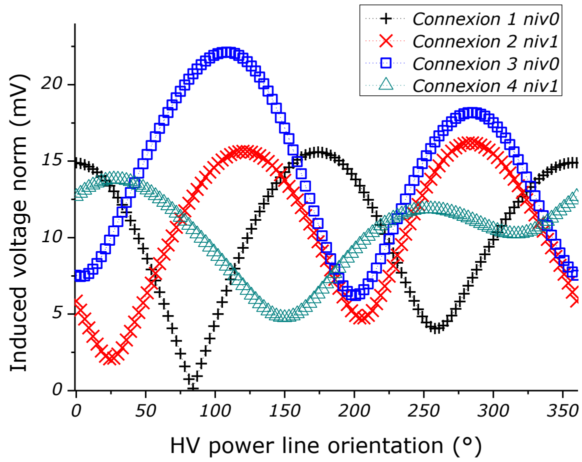


Figure 8 : Induced voltage level in a single house as a function of the HV power line orientation.

The results of this isolated house constitute a reference to study the effects of a network of houses. We define the networks of houses by means of the number of houses in a row and in column (matrix structure), as shown in Figure 9.

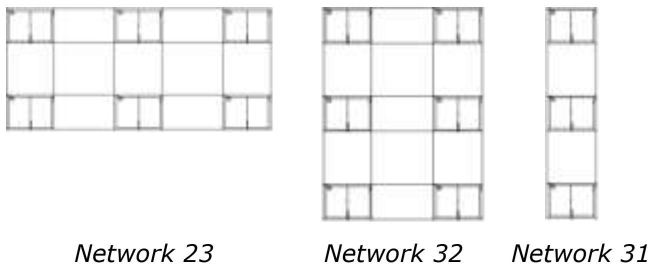


Figure 9 : Networks of houses.

In these different networks, we choose a house at the same relative position, i.e. subject to the same magnetic flux, so we can compare the induced current and voltage level in them. In Figure 10, the induced current in earth connexion 3 in an isolated house is compared to that obtained in a house placed in different networks.

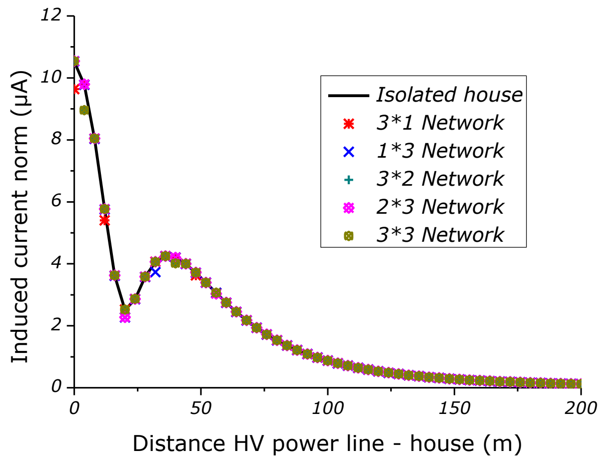


Figure 10 : Comparison of induced current level in houses in different networks.

Other houses at different positions and with other earth connections were considered without observing any effects of the network of houses on contact current and voltage level. Next step is to perform the same study with ground stakes in each house in order to determine a possible different behaviour, i.e. an influence of a network of houses with ground stakes.

The first studies consider only networks of houses with one row or column. So, it is easier to isolate and quantify the possible effects of the network. The first cases comprise 3 and 5 houses. The reference house is in the centre of the network. Figure 11 and Figure 12 represent the induced current level as a function of the HV power line distance for connections 1 and 3, respectively.

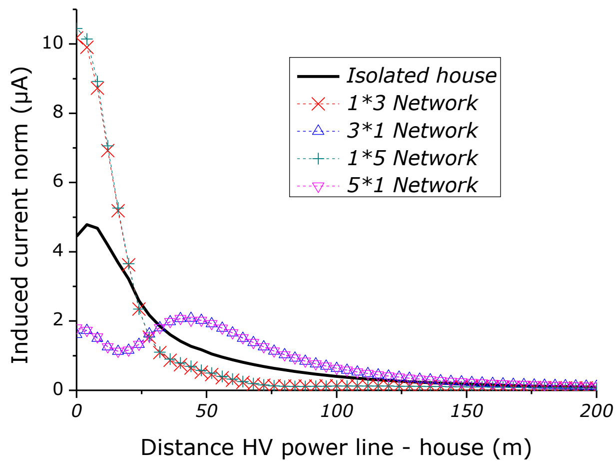


Figure 11 : Induced current in connection 1 for different networks of houses.

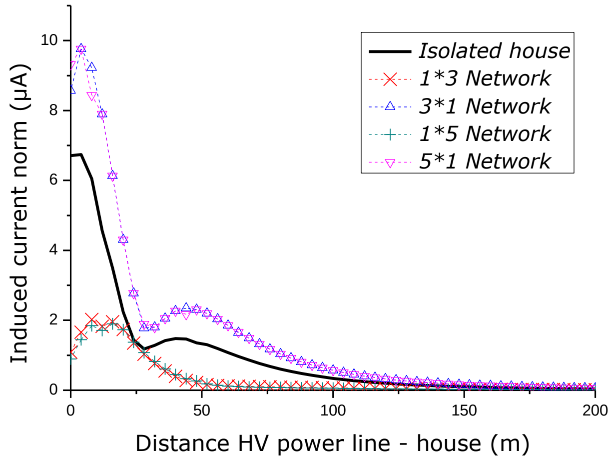


Figure 12 : Induced current in connection 3 for different networks of houses.

Three main conclusions can be drawn from these two figures and for houses in the centre of a network:

- A network of 3 houses has the same influence as a network of 5 or more houses on the contact current level,
- The contact current level in connection 1 increases with an in-row-network configuration,
- The contact current level in connection 3 increases with an in-column-network configuration.

Therefore, there is a correlation between the type of network and the geometry of a connection. We need further results to establish the influence of a network of houses with ground stakes on the contact current level.

The Figure 13 shows that there is no effect of the numbers of houses in a network in row on contact current level. The same result is obtained for networks of houses in column and for the houses on the extremity of the networks. For the next simulations, we consider only networks with a maximum of three houses in either a row or a column.

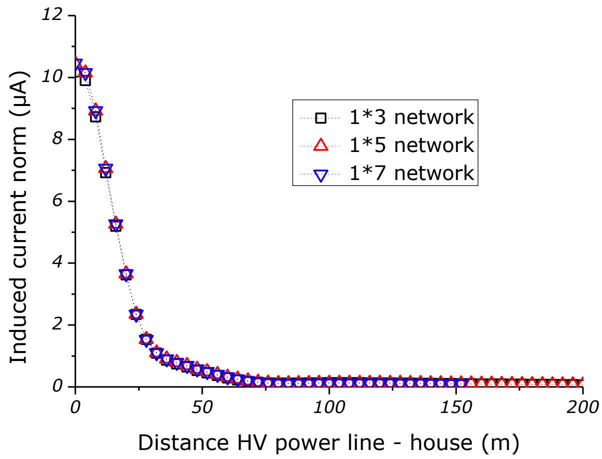


Figure 13 : Comparison between induced currents in connection 1 in different networks of houses.

To understand the influence of a network of houses with ground stakes on induced current level, we study two particular networks in row. We choose the geometries of the connections to compute low contact current (in green in Figure 14) or high contact current (in red in Figure 15). So, it is easy to analyse the influence of a network of houses on contact current level.

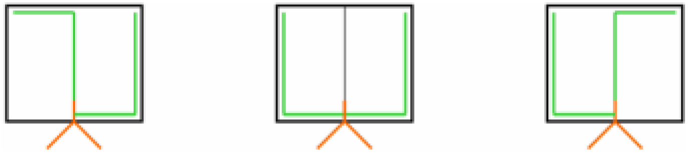


Figure 14 : Network of houses with low induced currents (Top view).

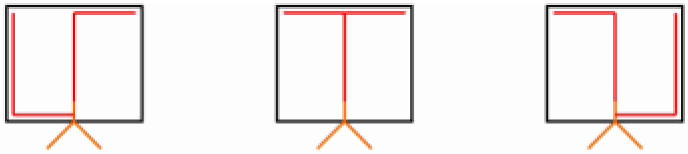


Figure 15 : Network of houses with high induced currents (Top view).

In Figure 16, we observe the induced current level in the connections on the left of each house from the network on Figure 14. The same observation can be done in Figure 17 for the network with high contact currents (Figure 15).

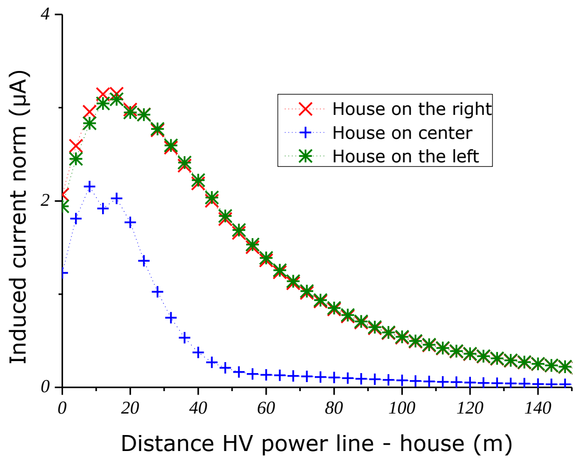


Figure 16 : Induced current in the connections on the left of the houses in the network on Figure 14.

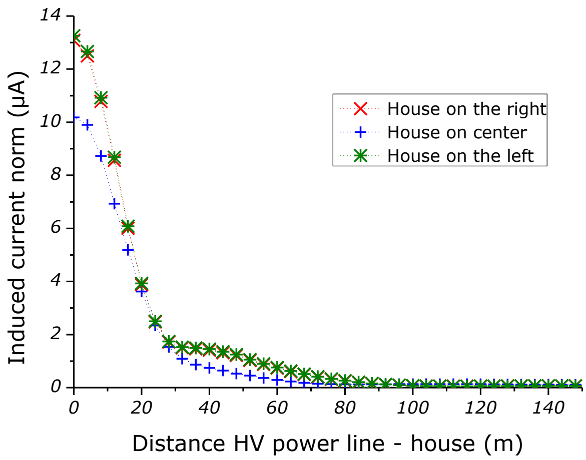


Figure 17 : Induced current in the connections on the left of the house in the network on Figure 15.

We simplify the model to explain the effects of a network of houses with ground stakes. First, we consider a 2-D network of houses as shown in Figure 14 and Figure 15. Then, the magnetic field is taken along the z-axis, i.e. perpendicular to the simplified network (see Figure 18).

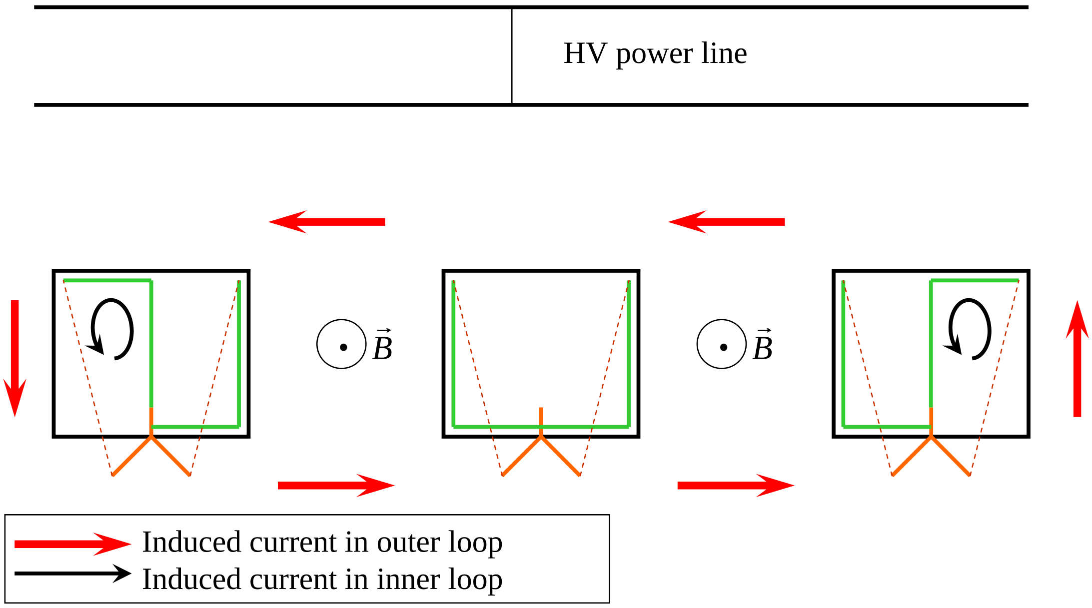


Figure 18 : Scheme to explain the influence of a network of houses on induced currents level.

When a magnetic flux flows through a series of loops, the induced current is maximum in the outer loop and minimum in the inner loops. Indeed, the connections in the centre of the network (Figure 18) give rise to loops with small surfaces so the magnetic flux cannot induce currents bigger than the induced currents in an isolated house. A connection on the extremity generates a loop with an associated bigger surface so there is an induced current which may oppose the current in the outer loop.

The same reasoning holds for Figure 15. In this case, the inner loops are bigger so that a significant induced current can appear. At the extremity, the surface is smaller so that the induced current cannot oppose the current in the outer loop. We also verify the result for a network in column.

The last part of this work deals with computing networks of houses with many rows and columns. Similar remark on the size of a network (maximum three houses in a row or column) can also be made. The results show that in some position the induced current can be multiplied by a factor 4 (up to 20 µA) in comparison with an isolated house.

Contact Voltage Modeler (CVM) program – EPRI software

In order to be able to compare the results obtained with our own software (ACE, ULg) with those obtained with the Contact Voltage Modeler program used by EPRI. The assumptions and simplifications made must be clearly identified.

The approach followed by the CVM program consists in building different types of computer models of large sections of residential areas. Each model accounts for all physical parameters that affect the magnetic field, contact currents and voltages. These parameters characterize the study area: streets, blocks, residences, substation, distributions lines, transmission lines, water pipes, house grounds. For each model, the following local and global quantities are calculated: the magnetic field, the ground current and the contact voltage. Besides calculating the combined effect of all electromagnetic sources (magnetic field and contact voltages), the results are calculated separately by source (distribution line primary loads, secondary loads and transmission lines).

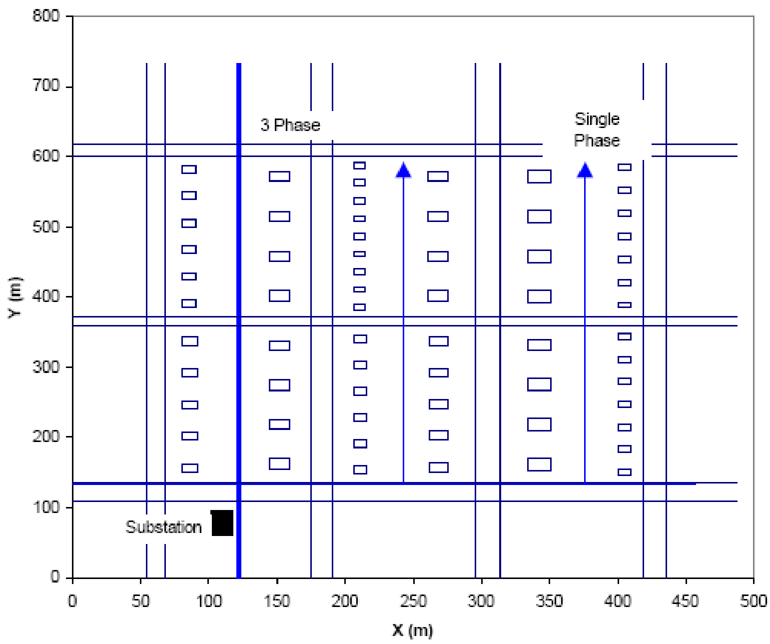


Figure 19: Example of study area.

The three main differences between the CVM program and our own software are shown in Table 1.

Our software (ACE, ULg)	Contact Voltage Modeler (EPRI)
TT grounding scheme: The neutral is not linked to earth in each house	TN grounding scheme: multi-grounded neutral
Contact current & voltage calculated in places where a higher exposure hazard exists (next to a washing machine, in the bathroom…)	Contact voltage calculated only between the water pipes and the neutral at the electrical panel
The transmission line is the only source of contact current and voltage	The transmission line is not the only source of contact voltage

Table 1: The main differences between the Contact Current Software and the Contact Voltage Modeler.

Figure 20 shows that in the CVM the neutral is a connection between each residence. This neutral connection and the water pipes define a conducting loop where a current can flow due to the presence of a power line. To be more realistic, a current flows through the neutral to represent the residence load as shown on Figure 21. With these two differences, we can understand the difference between the contact currents and voltages calculated with our software and the CVM program.

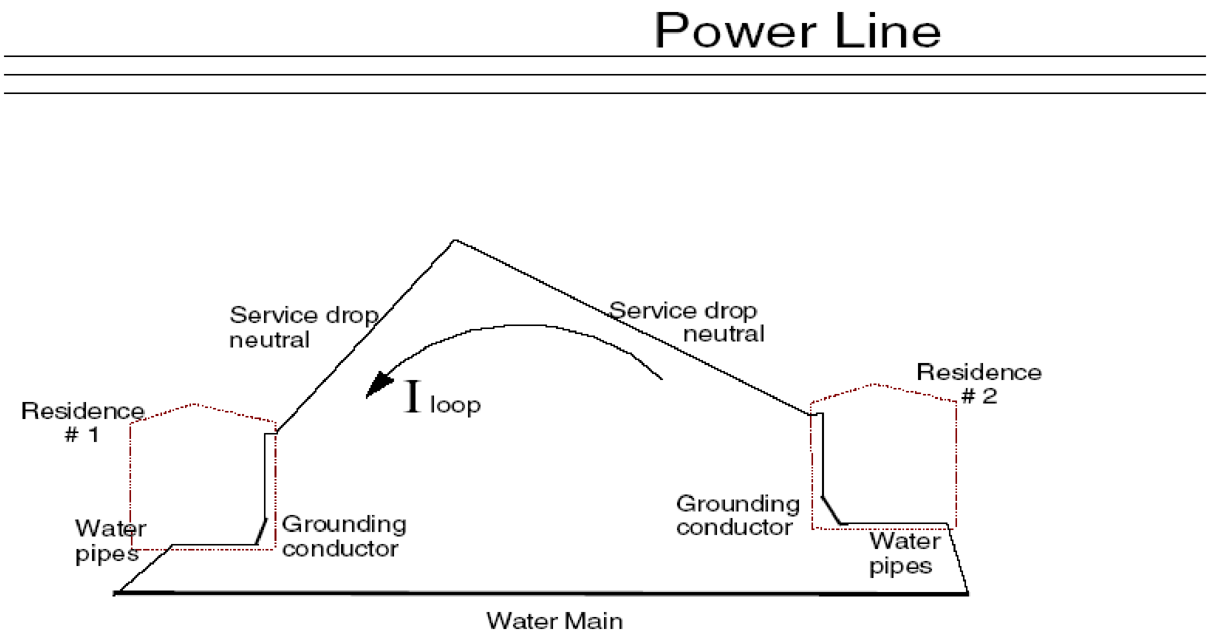


Figure 20: Current induced in a conductive loop by a power line.

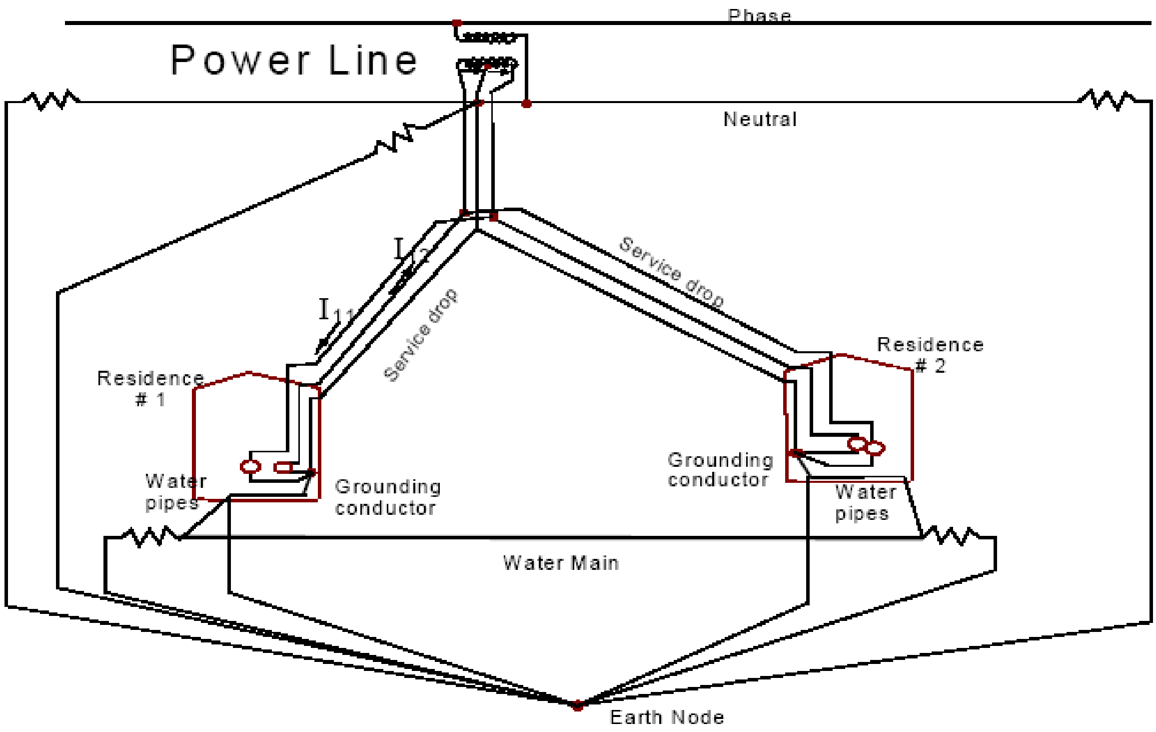


Figure 21: Example of grounded network associated with the secondary wires.

The results depend not only on the model type but also on the values of a number of parameters (house loads, resistance of house groundings…) chosen at random. Another run for the same model but with a different random choice of parameters would give different results. The results given by the CVM program are thus significant statistically, which is not the case of those given by our software.

The main four parameters are:

- Backyard line – Street line;
- One transmission line – No transmission line;
- Low housing density – High housing density;
- Non-conductive water main – Conductive water main.

As shown in Figure 22 and Figure 23, the parameter that, in general, hardly influences the increase of the contact voltage level is the presence of the transmission line.

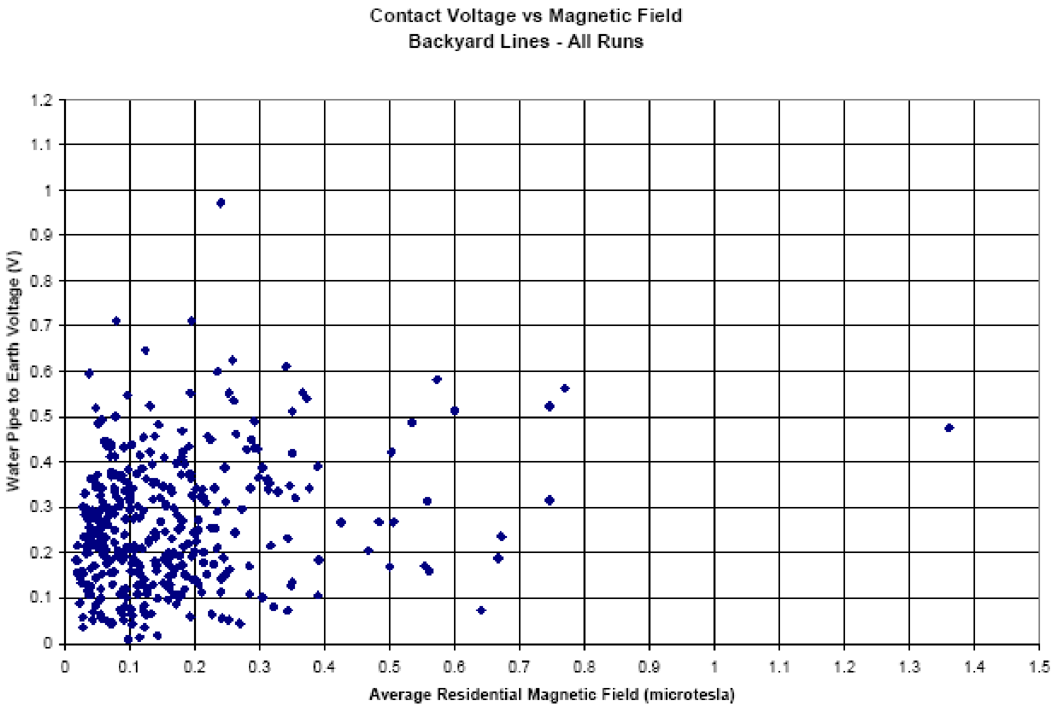


Figure 22: Results with no transmission line, low housing density and conductive water main.

The second parameter that influences the contact voltage level is the position of the distribution line around the house (Backyard line - Street line). When the transmission line power flow is reversed, a change in the behaviour of the contact voltage is observed. This reserve shows the pipe-to-earth voltages depending on the distribution system, the relative phase, and for magnetic field, direction in space.

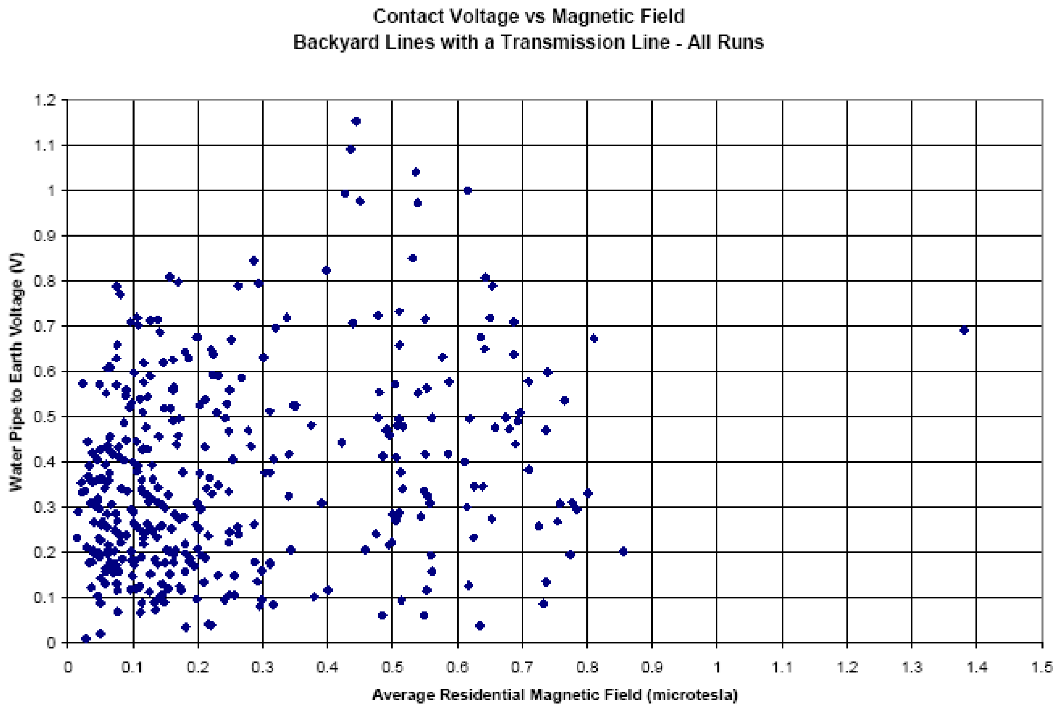


Figure 23: Results with transmission line, low housing density and conductive water main.

To conclude, they used a not-grounded distribution line model to simulate the TN grounding scheme (e.g. Belgian grounding scheme). The neutral is grounded at a single point, at the substation. The performance of these systems was verified by assuming a high impedance for both the distribution line neutral and the service drop neutral. Their results show that this grounding scheme increases/favours the association between contact voltages and average residential magnetic field (Figure 24).

The contact voltage they compute within this multi-grounded neutral scheme is bigger than the one we compute. Indeed, the large impedance added between the neutral and the service drop neutral forces the current to flow through the water pipes and earth to return to the substation. So, the contact voltage calculated for the grounding conductor is bigger. Fortunately, the TN grounding scheme does not work exactly like this.

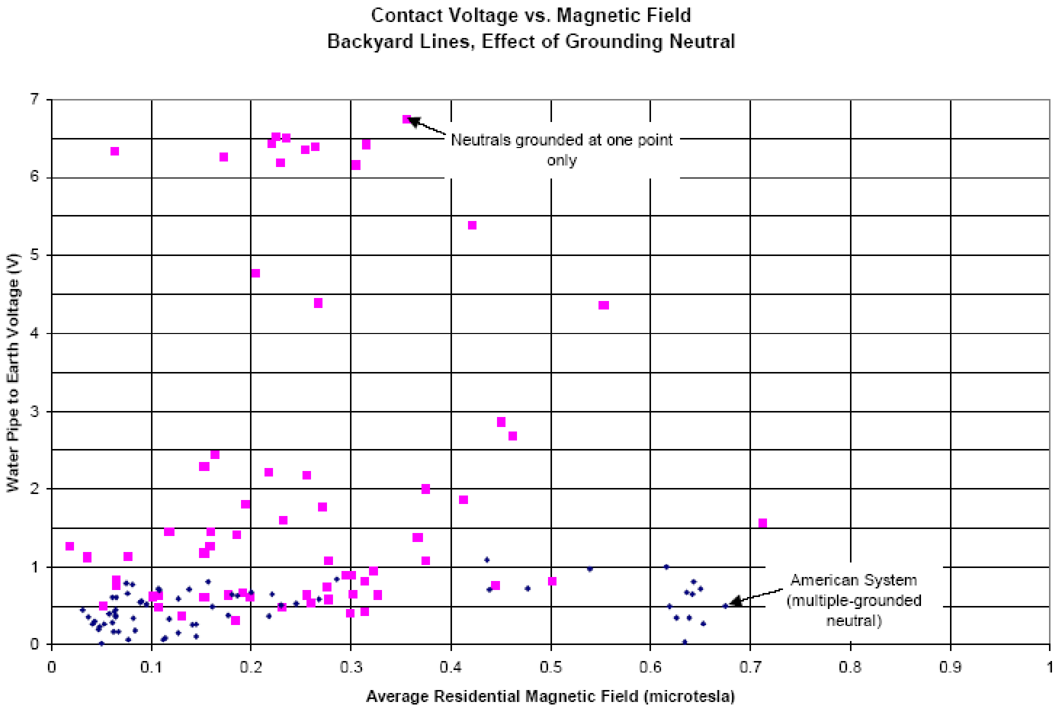


Figure 24: Comparison between the American system and a system with the grounding of neutral at one point (EU).

2. Comparison between Belgian and American grounding schemes with our software

We transform our contact current model to understand the influence of a multi-grounded neutral on the contact current level in a residence. We add the neutral link between each house in a group of houses.

In the CVM program, all ground rods are linked to an earth node. Each ground rod has a resistance of a value chosen randomly in the range [50, 200] Ω, this resistance represents the house ground resistance. In our model, each house is connected to the other with an earth link of about 100 Ω, the value we are using is in the range used by the CVM program.

However, we do not include a distribution line near the residences. Indeed, in our model, we focus on the effect of HV power lines on contact current and voltage levels. We assume that there is no current in the electrical installation of our houses.

In order to compare the two grounding systems with our model, we always calculate the contact current and voltage in the electrical installation (washing machine and bathtub). The CVM program calculates the contact voltage at the grounding conductor between the water pipes and the ground rod near the electrical panel.

We compare a TT grounding scheme (Belgium) and a TN grounding scheme (USA) considering:

- houses either with ground loop or ground stakes,
- contact voltage obtained at a washing machine or in a bathtub.

We calculate the induced contact voltage. Therefore, the resistance of a human being does not influence the results.

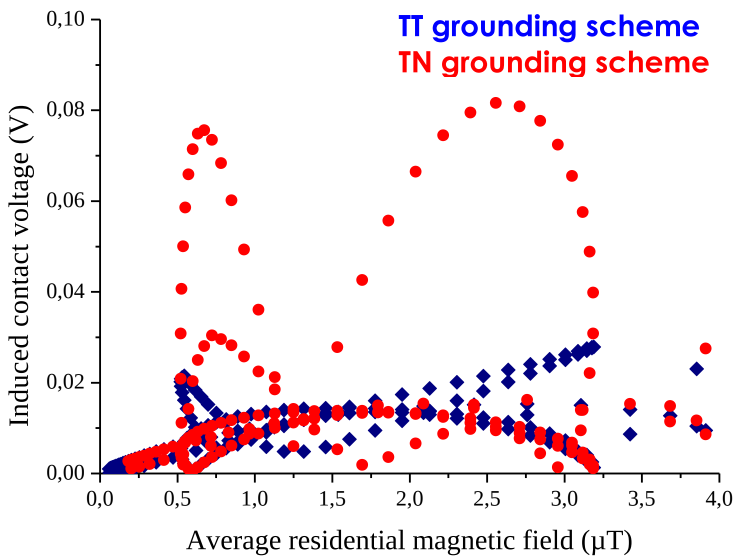


Figure 25: Contact voltage comparison at a washing machine in TN & TT grounding scheme in groups of houses with ground loop.

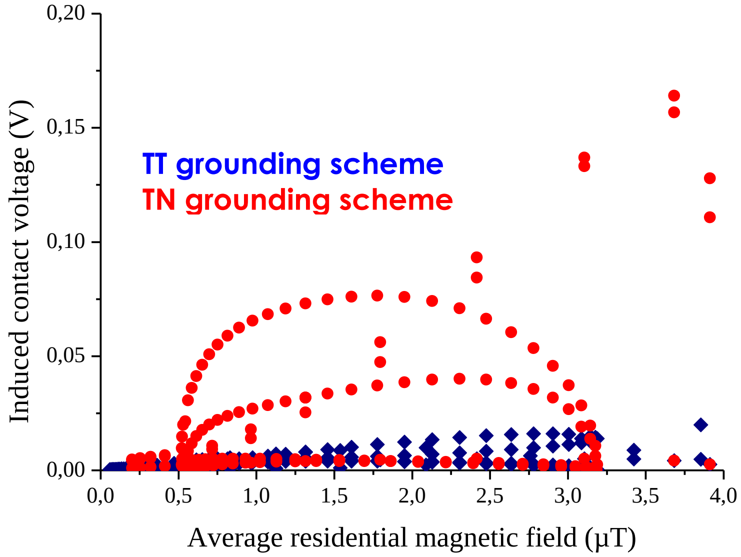


Figure 26: Contact voltage comparison in a bathtub in TN & TT grounding scheme in groups of houses with ground loop.

In Figures 25 and 26, we observe the influence of the grounding scheme on the induced contact voltage. A TN (USA) grounding scheme generates higher induced voltage in a residential electric installation with a ground loop.

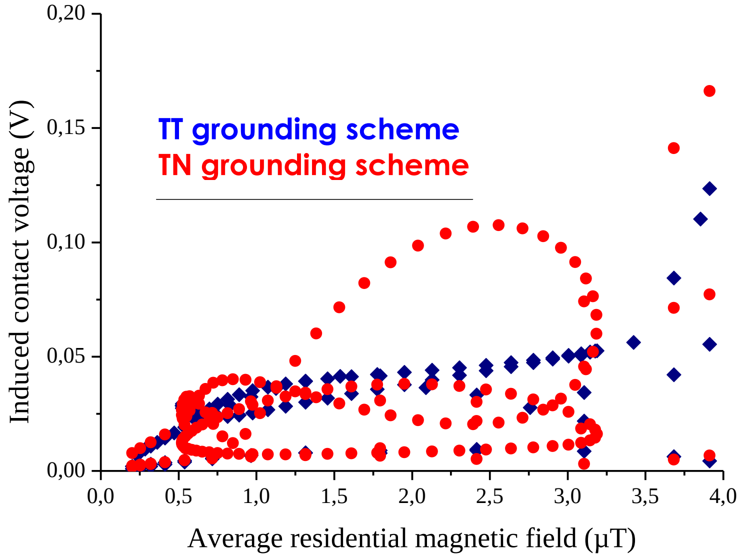


Figure 27 : Contact voltage comparison on a wash machine in TN & TT grounding scheme in groups of houses with ground stakes.

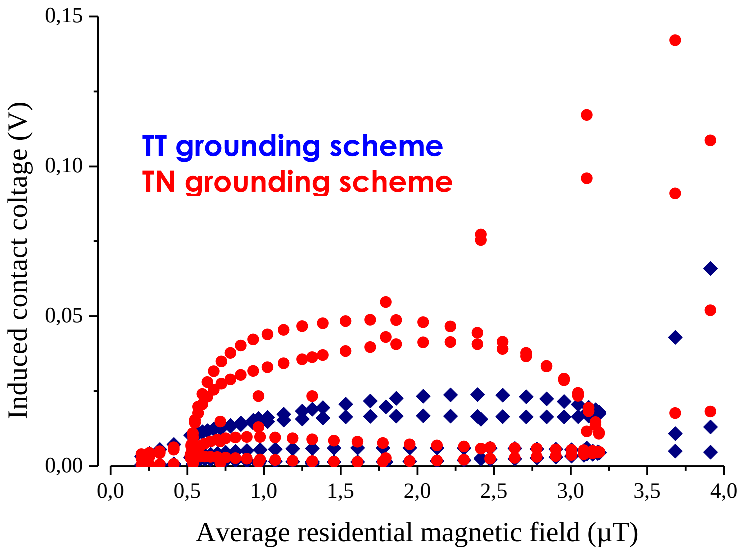


Figure 28: Contact voltage comparison in a bathtub in TN & TT grounding scheme in groups of houses with ground stakes.

These results show that a TT grounding scheme gives rise to lower contact voltage in groups of houses (Figure 25, 26, 27 & 28). In general, a house with ground stakes is more subject to higher contact voltage whatever the grounding scheme. We can conclude that if the only source is a HV power line, the association between contact voltages and average residential magnetic field is greater in a TN grounding scheme.

Equipotential link in a TN grounding scheme

Previously, we observed the influence of the equipotential link on the contact current level in a TT grounding scheme. We can make the same simulation on some critical cases in a group of houses with a TN grounding scheme.

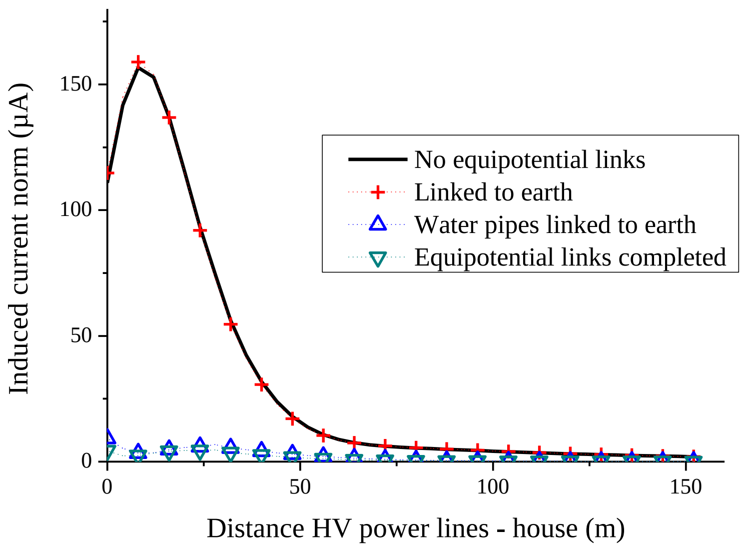


Figure 29: Critical case of contact current level in a bathtub (Ground loop).

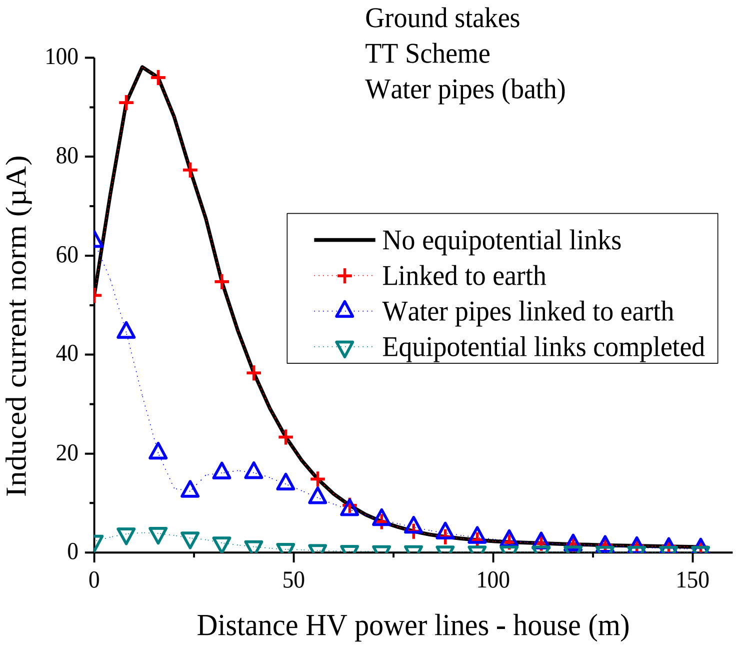


Figure 30: Critical case of contact current level in a bathtub (Ground stakes).

We observe on Figure 29 & 30, the efficiency of a complete equipotential link also on a TN grounding scheme. Like in our previous simulations, we can see the effect of a group of houses on contact current level near water pipes.

Group of houses size

In a group of houses with a TT grounding scheme (Belgian system), we observe that the size of the group of houses does not influence the level of the contact currents and voltages. We simulate different size of groups of houses with a TN grounding scheme to determine if there is an influence of this size on the contact voltage level.

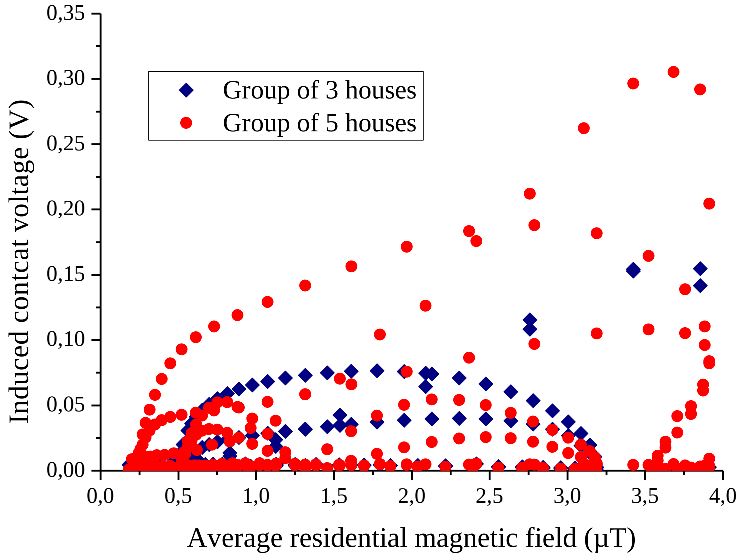


Figure 31: Induced contact voltage level in function of the size of the group of houses with a TN grounding scheme.

As show on Figure 31, we can observe that a group of five houses with a TN grounding scheme have more cases with higher contact voltage level. Thus, in groups of houses with a TN grounding scheme the number of houses influences strongly the contact current and voltage levels.

Contact current : a measurement campaign in Belgium

On-site measurement campaign

Up to now, we have performed measurements in 90 houses (Figure 33). Finding people that agree to participate in this research campaign is not an easy task. Two procedures are used to recruit them: the BBEMG website and posting letters to people living near power lines (to try to find high magnetic field). We take a lot of measurements in the house and a questionnaire is added to have a brief history of the house like the age, the age of the electric network and so on. But for many cases, people doesn't know the plan of the electrical installation. We take a lot of measures to find any relationship. The measures are taken in collaboration with SGS (a certification company), and thanks to the presence of our researchers on the ground, we could improve this protocol (annex 1).

Current may appear at different places in the dwelling. For these reasons, we measure the contact current principally where he could be important for human, like in the bath, shower or near electrical application (washing machine …). Contact current depends on body impedance so that a naked person could be crossed by a larger contact current than a dry people with shoes, for the same potential difference. Contact current only occurs at contact. It is a current at the network frequency (50 Hz) which is going through the body simply because it appears between two parts of the body a voltage difference (the contact voltage).

It must here be pointed out that contact current is obviously not simply the "open circuit" contact voltage divided by the body impedance. In fact the whole electric circuit behind the two points where contact would occur has to be considered (known as "Thevenin equivalent" in electricity). Indeed the voltage source behind the two contact points has internal impedance which may be huge and would therefore not generate any significant current.

That is why appropriate measurement to evaluate such risk absolutely needs two measurements: (i) the open circuit voltage (Figure 32 a) and (ii) the short-circuit-current value. But in practice, to facilitate on site measurement, the second case (short-circuit) is replaced by the measurement of the voltage applied at a 1000 Ω resistance (similar to body impedance) placed between the two potential contact area (as shown on Figure 32b.). In many cases, that second measurement is showing a quasi-nil value, which means that internal global impedance of the circuit is extremely large form some kΩ to several MΩ, which would means consequently a very weak contact current, even if contact voltage is high.

Figure 32 : a: Open circuit measurement b: Measure with 1 kΩ resistance

We try to cover a large part of residential park in Belgium. However, we still need more measurements in Flanders to have a homogeneous distribution in the whole country.

Figure 33 : Actual number of houses treated in each part of Belgium, by our on site measurement

Values of contact currents in different houses are given in Table 1.

	Bath			Shower			Washing machine		
	Rth (Ω)	I (μA)	Fem (V)	Rth (Ω)	I (μA)	Fem (V)	Rth (Ω)	I (μA)	Fem (V)
1	75000	8	0.061	108	416	0.460	37000	25	0.098
2	500	8	0.012	3500	8	0.036	10500	35	0.040
3	71000	14	1.023				48000	2	0.010

Table 2: Different values observed during on-site measurements

- **Magnetic field spot measurement results**

During the protocol, the magnetic field is measured in each piece of the house. To have a good approximation of this field, the median value is chosen as the best estimator to dismiss high value that can be generated near micro wave for example. The measures are taken in the middle of the room at average 1,5 meter from the ground Figure 34 is showing such results.

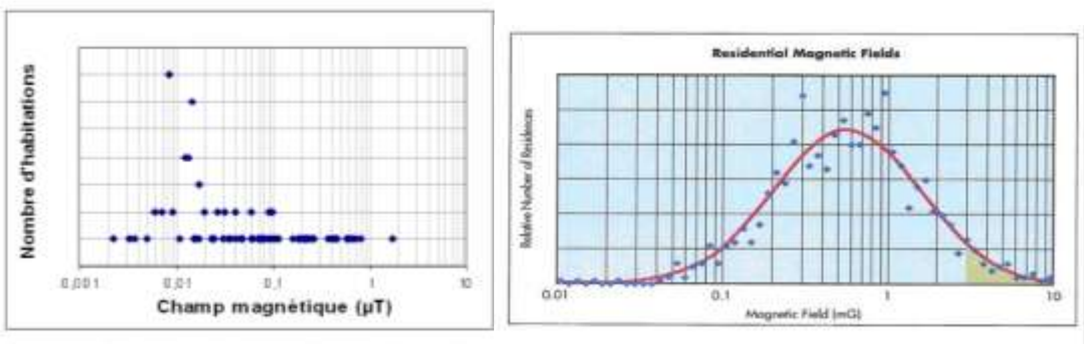


Figure 34 a and b. Belgium case (left in μT) vs USA case (right in mG)

The median value of our own spot measurement is 0, 01 µT. We have 11% of visited houses with a magnetic field higher than the epidemiological threshold of 0,4µT. Our own measurements are close to the result of 24 exposure of children in Belgium (0, 02 µT) [Decat,2009].

If we compare our values with an American study [Syfers. 2006], we have an ambient magnetic field; in average, two times lower. This difference can be explained by the voltage difference between countries. US home voltage is 110V than to deliver the same power they consume twice more current. House magnetic field is close to current consumption this can justified the B field difference.

- **Belgium contact current level**

We have visited about 100 houses, the contact current level varied between 1µA to 1000 µA. Some houses have contact current higher than the threshold of sensitivity (Figure 35).

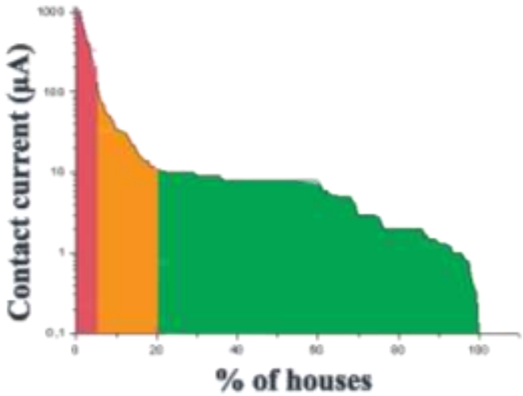


Figure 35: Contact current frequency graph

- The median contact current of the frequency graph is 10 µA
- 80% of houses have contact current lower than 20 µA
- 20 % of houses have a contact current between 20 to 100µA
- 5% of houses have contact current higher than 100 µA

We can consider that 5 % of Belgium houses have a very high contact current.

The contact current vs. relative number of house can be represented by a log – normal law. These kinds of law are generally used in pollution cases [INRS, 2000]. Figure 36 is showing the Belgian case.

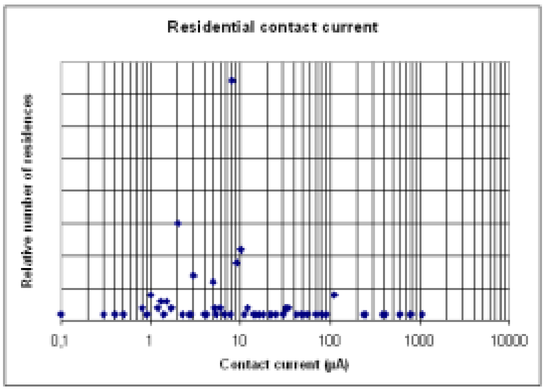


Figure 36: Residential contact current in Belgium

Using this distribution, we can calculate the estimator M of the geometric mean, the standard deviation and confidence interval.

The geometric mean is given by: $\ln(M_G) = \frac{\sum \ln(x_i)}{n}$ and worth 7,4 µA.

The standard deviation is given by: $\ln(s_G) = \sqrt{\frac{\sum\left[\ln\left(x_i\right) - \ln\left(M_G\right)\right]^2}{n-1}}$

The standard deviation value is 13,75 µA

The confidence interval is given by: $\ln(IC) = \ln M \pm \left[\frac{\ln\left(s_G\right)}{\sqrt{n}}\right]$ is between 5,42 and 9,46 µA.

Is there a correlation between contact current and residential magnetic field?

No relation is observed between contact current and magnetic field (Figure 37)

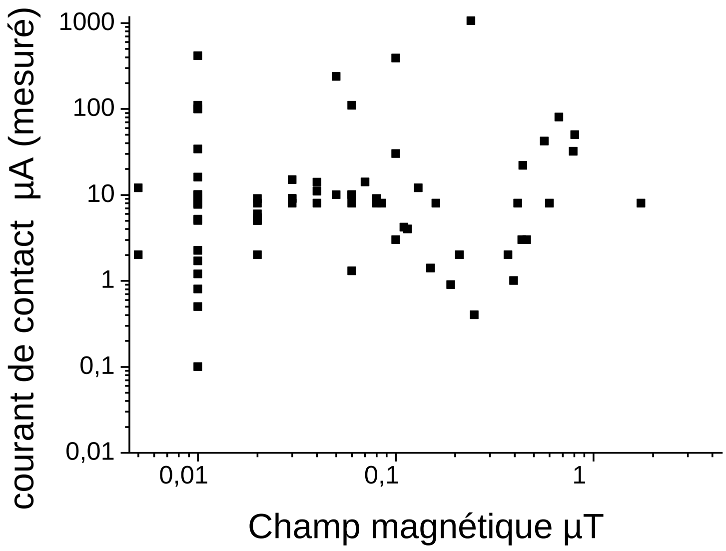


Figure 37 : Contact current versus magnetic field

Actually, no relation is observed between contact current and magnetic field.

The other engineer team has computed the contact current in similar situation.
The limit curve is given in Figure 38 (blue curve).
Contact current obtained by simulation is lower than values measured and couldn't justify the level of measured contact current.

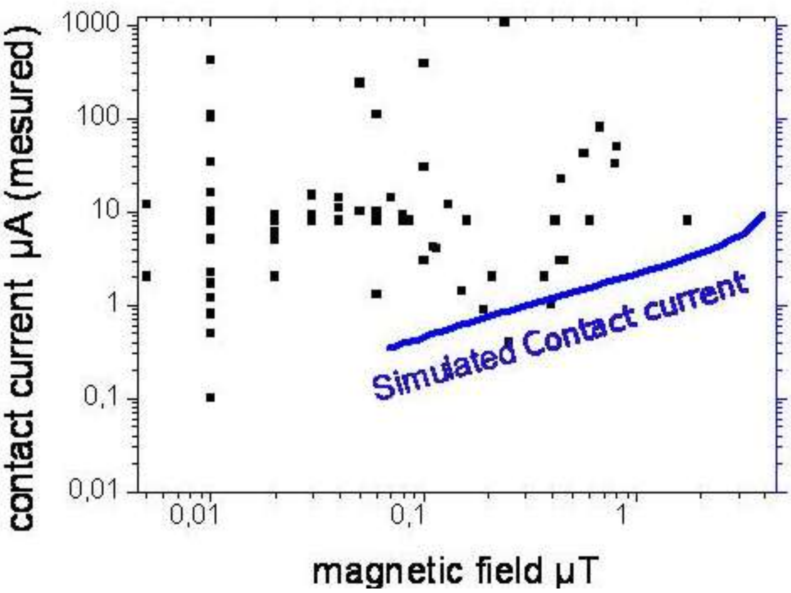


Figure 38 : Simulated contact current for magnetic field compared to measured cases in Belgium

As the contact current could not be explained by the magnetic field. In this case other ways have been investigated like the equipotential bonding.

- **Equipotential bonding.**

One of them is the equipotential bondings, all houses must have equipotential bondings. Such bonding is a link between all metallic structures (water pipe, gas pipe, beam, metallic bath, heating …) and earth to avoid potential differences between different structures. Normally all metallic structures (water, gas) must be connected to these equipotential links (RGIE regulation).

Belgium Legislation from RGIE:

In Belgium, the RGIE describes the ground scheme and the equipotent liaison to realise in a weak tension installation (precisely the article 69-73, and the article 86 for the domestic installation).

Article 72. Principal equipotential connections in low voltage
01. General information
When a principal equipotential connection is imposed, one or more principal drivers of equipotentiality are connected on the principal ground terminal; there are connected:
- Principal internal gas and water drains to the building;
- Principal columns of the central heating and air-conditioning;
- The fixed and accessible metal elements which belong to the structure of the building

Article 73. The additional equipotential connection in low voltage
01. General information
When an additional equipotential connection is locally imposed, it connects all the available metallic parts.
The additional equipotential connection can be realised either by conducting elements such as metal frames, or by drivers, or by a combination of both.

The leakage current going to the ground puts normally all the electrical installation to a given voltage, normally equal to leakage current times the ground resistance. This potential is called ground potential (GP) (with reference to far earth). If all structures are well connected to each others no voltage difference can appear between them.

During the campaign we calculate the electromotive force using Thevenin's theorem. The electromotive force (EF) is given in Volt.

We have compared the EF and GP in the bathroom (Figure 39). Normally the voltage of metallic structure in the house must be the at GP.

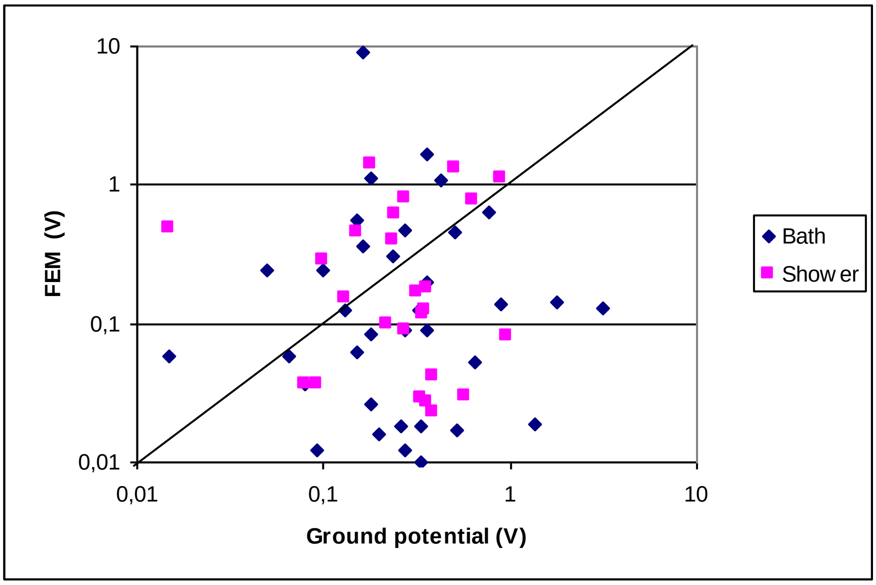


Figure 39: Belgium campaign. Comparison between the ground potential and the Thevenin equivalent voltages as deduced from measurements.

In a standard situation, all the dots must be such that FEM/Ground potential should be equal or lower than 1; but a lot of points are not following such relation.

The first idea was to look after a correlation with the extra-potential and the ambient magnetic field. (Figure 40).

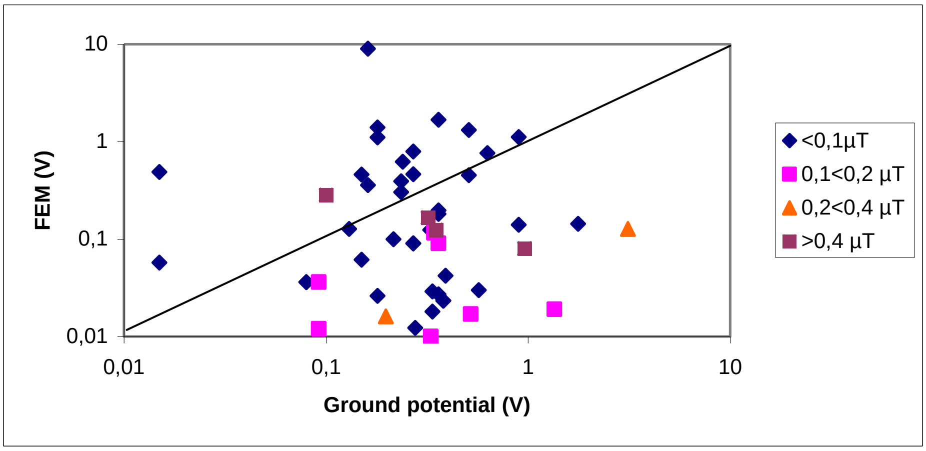


Figure 40: Belgium campaign. The effect of ambiant magnetic field on observed voltages

Currently, no relations are observed between the magnetic field and an increase of electromotive force. Taking into account such observation, we can say that there is **no correlation between the contact current, electromotive force and magnetic field.**

Thus, they are other reasons playing a role in the apparition of contact current.

Houses with a FEM higher or smaller than the ground potential may be explained by bad or non existing equipotential connexion. But we have in some place potential difference generated by an external source and we have shown that it is not the magnetic field.

Site measurements have proved that complete equipotential connexion especially between the water pipe and the drain reduces the contact current value.

The connexion reduces the contact current but didn't delete it.
For these reason we get a look at another possible explanation: the leakage current (mainly capacitive) of electrical cable.
Houses contained generally some hundred of meters of electrical cable put at 230 V. If cable radial divergent current (capacitive) could be of only a few µA/m, some metallic ducts in the vicinity could reach a certain voltage.
We tried to estimate such leakage current of electrical cable using two kinds of calculations. First we use laboratory measurements and second, we realised some numerical model. Theoretically, the leakage current of an electrical cable can be resistive and capacitive, but the resistive part will obviously be negligible for a cable of good quality.

Some other correlations have also been investigated with the following conclusions :

- No relation is observed between contact current and the age of the electrical installation.
- No correlation is observed between contact current value and hypersensitive people's home. There is no higher contact current in these houses than in the others.
- Actually the matter of the water pipe distribution has no relation with the contact current level.
- No correlation is observed between the contact current and the earth resistance value (except of course if no earth path exists).

- **Leakage current.**

A current electrical cable *transversal* losses can be represented by a resistor in parallel with a capacitor (Figure 41) .

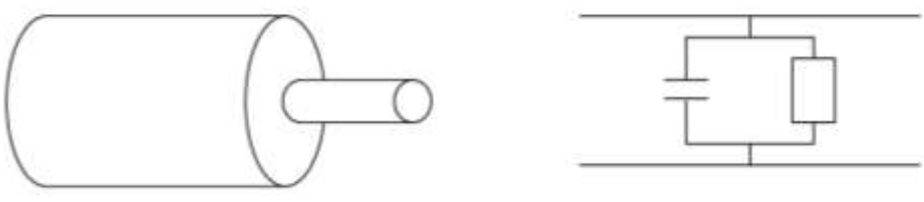


Figure 41: Typical low voltage single phase wire and its model.

An electrical cable can also be represented by different layers. In such case we would need to add more such circuits in series. In the following, we will consider a simple layer case, with one parallel capacitor and resistor as shown on Figure 41.

The formula used to calculate the leakage current is the following:

$$C = \frac{\varepsilon 2\pi h}{\ln\left(\frac{R_x}{R_1}\right)}$$

$$R = \frac{\rho \ln\left(R_x / R_1\right)}{2\pi h}$$

Where Rx is the inner radius of the cable and R_1 is the external radius.

Characteristics of VOB (2.5mm²) :

- Insulation resistor: 10^{20} Ω. Cm
- Relative permittivity: 3.5
- Rx= 0,9 mm (inner radius of the electrical wire)
- R1= 1,6 mm (external radius of the insulator)

- Resistor: 9 E19 kΩ
- Capacitor impedance: 9 410 kΩ
- Total impedance: 9 410 kΩ
- Leakage current per meter at 230 V between the conductor and the external sheath: **23 µA /m**

Leakage current experimentation.

To measure the leakage current of electrical cable at 230 volt, we tested an installation as shown on Figure 42 An electrical cable is wind up with kitchen aluminium foil to recover the leakage current.

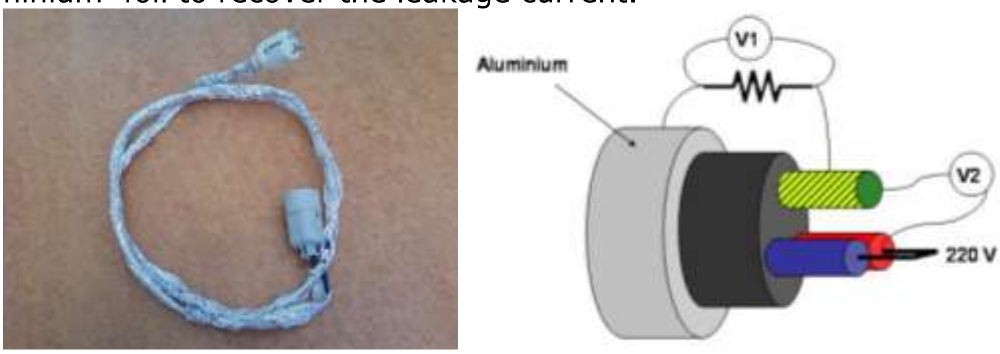


Figure 42 : three wires low voltage cable (Two wires (phase -bleu;neutral - red) and earth) as used in many houses. With applied 230 V and evaluation of leakage current

The phase and neutral are connected to the electrical network and the ground cable is connected to the earth. This one is the reference to measure de leakage current. To measure the leakage current of some µA, we realised a voltage measurement with three resistors (10kΩ, 47 kΩ, 100 kΩ). We know by calculation that the leakage current is mainly capacitive. For this reason the measurements are realised with a two entries oscilloscope. The first one measure the network difference potential (V2) and the other measures the leakage current by the voltage drop in a known impedance (V1). The measurements are realised with Tektronix TPS 2024 oscilloscope. The measures are also realised with a half cable to see if the current is well correlated with the cable length.

The results are the following:

Cable XVB (2.5mm²) :
The XVB cable (2.5mm²) is formed of three electrical wires (phase, neutral, ground wire). Each cable is rolled with one insulator layer and all cables are then rolled into a second insulator layer.

Cable length: 5m
Network voltage: $V_{0\text{-}P}$ =330V => V_{eff} = 220V
Leakage current with:

- 10kΩ : $V_{0\text{-}P}$ = 0,4 V V_{eff} = 0,28 V $I_{fuite\ eff}$ = 28 µA ± 0,12
- 47kΩ : $V_{0\text{-}P}$ = 2 V V_{eff} = 1,42 v $I_{fuite\ eff}$ = 30,2 µA ± 0,07
- 100kΩ : $V_{0\text{-}P}$ = 3,75 V V_{eff} = 2,66 v $I_{fuite\ eff}$ = 26,6 µA ± 0,12

Phase difference: 54 °

L/2 : 2,5m
Leakage current with:

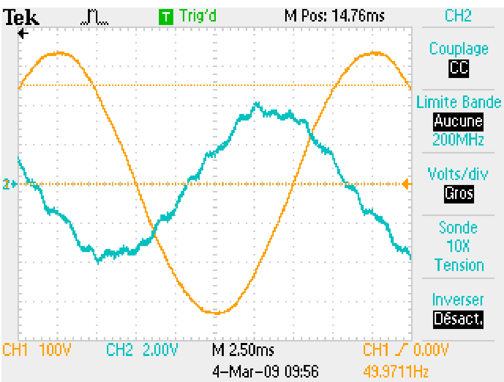
- 10kΩ : $V_{0\text{-}P}$ = 0,23 V V_{eff} = 0,16 V $I_{fuite\ eff}$ = 16 µA ± 0,11
- 47kΩ : $V_{0\text{-}P}$ = 0,9 V V_{eff} = 0,64 V $I_{fuite\ eff}$ = 13,6 µA ± 0,15
- 100kΩ : $V_{0\text{-}P}$ = 2 V V_{eff} = 1,42 V $I_{fuite\ eff}$ = 14,2 µA ± 0,07

Phase difference: 50 °

Average leakage current per meter = 5, 75 µA / m ± 0, 11

The phase difference should be 90°, others measurements must be realised to understand this effect.

Phase difference is represented in Figure 43:



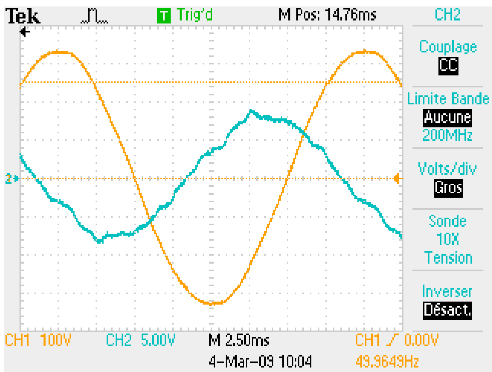


Figure 43: a) Phase difference for 47k resistor(cable lenght 5m)

b) Phase difference for a 100k resistor (cable lenght 5m)

Cable VOB (2.5 mm²) :
The VOB cable (2.5mm²) look like a mono cable for this experiments three mono cables are rolled into aluminum.

Cable length: 4 m
Network voltage: $V_{0\text{-}P}$ =330V => V_{eff} = 220V
Leakage current with:

- 10kΩ : $V_{0\text{-}P}$ = 0,6 V V_{eff} = 0,43 V $I_{fuite\ eff}$ = 43 µA ± 0,14
- 47kΩ : $V_{0\text{-}P}$ = 2,6V V_{eff} = 1,84 V $I_{fuite\ eff}$ = 39 µA ± 0,19
- 100kΩ : $V_{0\text{-}P}$ = 4,8V V_{eff} = 3,4 V $I_{fuite\ eff}$ = 34 µA ± 0,30

Phase difference: 90°

L/2 : 2m
Leakage current with:

- 10kΩ : $V_{0\text{-}P}$ = 0,3V V_{eff} = 0,21V $I_{fuite\ eff}$ = 21 µA ± 0,12
- 47kΩ : $V_{0\text{-}P}$ = 1,38V V_{eff} = 0,98V $I_{fuite\ eff}$ = 21 µA ± 0,25
- 100kΩ : $V_{0\text{-}P}$ =2,8V V_{eff} = 1,98V $I_{fuite\ eff}$ = 20 µA ± 0,09

Phase difference: 90°

The average leakage current per meter is 10µA / m ± 0,23µA

Cable VOB (2.5mm²) with an electrical duct:
Cable length: 4 m
Network voltage: $V_{0\text{-}P}$ =330V => V_{eff} = 220V
Leakage current with:

- 10kΩ : $V_{0\text{-}P}$ = 0,1V V_{eff} = 0,07V $I_{fuite\ eff}$ = 7µA ± 0,1
- 47kΩ : $V_{0\text{-}P}$ = 0,4V V_{eff} = 0,28V $I_{fuite\ eff}$ = 6µA ± 0,12
- 100kΩ : $V_{0\text{-}P}$ = 0,75V V_{eff} = 0,53V $I_{fuite\ eff}$ = 5µA ± 0,32

Phase difference: 90°

L/2 : 2m
Leakage current with:

- 10kΩ : $V_{0\text{-}P}$ = 0,05V V_{eff} = 0,35 V $I_{fuite\ eff}$ = 3,5 µA ± 0,1
- 47kΩ : $V_{0\text{-}P}$ = 0,2V V_{eff} = 0,14V $I_{fuite\ eff}$ = 2,9 µA ± 0,1
- 100kΩ : $V_{0\text{-}P}$ =0,4 V V_{eff} = 0,28 V $I_{fuite\ eff}$ = 2,8 µA ± 0,12

Phase difference: 90°

The average leakage current per meter is 1, 51 µA /m ± 0, 14

Numerical simulation of leakage current:
We have used the finite element method to simulate the leakage current. The geometries and the condition are adapted to bond with the experimental measurements. We used a meshing generate by GMsh (Figure 44).

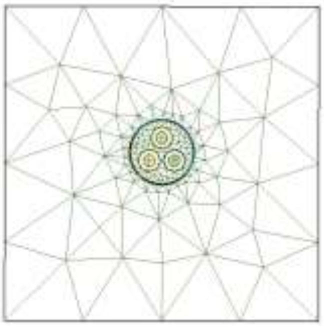


Figure 44: example meshing for XVB cable

For the simulation of the XVB cable, the phase is set at 220V, the neutral and ground are fixed at 0 V. The dimension of each layer and there electrical caracteristics are the following:

- Insulator resistance (first and second layer) : 10^{20} Ω. Cm
- Permittivité relative (first and second layer)= 3.5
- Rx (radius of section cable)= 0,9 mm
- R1 (first insulator layer)= 1,6 mm
- R2 (second insulator layer) = 3,6 mm

The characteristics for air and the aluminum part are the following:

Air:
- Relative permittivity : 1
- Resistivity: >>>

Aluminum:
- Relative permittivity : 8,8
- Resistivity: 2,65 E-8 Ω.m

Electro kinetic simulation: Electrodynamic simulation:

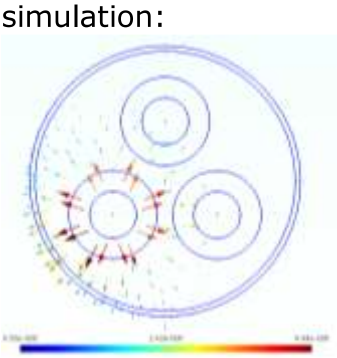


Figure 45: charge repartition (C)

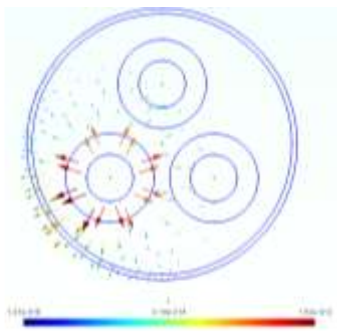


Figure 46 : current density A/m²

The results of this simulation is a capacitive current of 6, 82 µA/m and a resistive current equal to 7, 23 E-9 µA/m.

With this simulation the distribution of electrical current in different wire is also avaible:

Phase to outside	Phase to ground	Phase to neutral
6,82µA	1,91 µA	1,78 µA

VOB cable:
The VOB cable (2.5mm²) look like a mono cable for these experiments three cables are rolled into aluminum. One of three electrical wires is the phase set at 220V, the others are the neutral and ground both fixed to 0V. For simulation the characteristics cable like permitivity of layer are. :

- Insulation resistor: 10^{20} Ω. Cm
- Relative permittivity: 3.5
- Rx= 0,9 mm (inner radius of the electrical wire)
- R1= 1,6 mm (external radius of the insulator)

By simulation the capacitive current is 10, 5 µA/m and the resistive current = 2, 18 E-9 µA/m. In each case, the resistive current value are insignifiant.

The current distribution in the other cables is:

Phase to outside	Phase to ground	Phase to neutral
10,5 µA	2,06 µA	2,09 µA

VOB cable with an electrical duct:
Taken into account of regulation VOB cable alone can not be use for electrical installation. The cable must be enclosing into a protective duct. This one in old house is in copper and in new installation is in plastic (1 cm radius and a tichness of 2mm). For this simulation, we also have three wires one set to 220V and the others are to 0V. The caracteristics of the cables and the duct are the following:

- Insulation resistor (for cable and electrical duct): 10^{20} Ω. Cm
- Relative permittivity: 3.5
- Rx= 0,9 mm (inner radius of the electrical wire)
- R1= 1,6 mm (external radius of the insulator)
- R2 = 1cm (radius of the protective duct)
- R3 = 1,2 cm (external radius of the protectiv duct)

Capacitive current in that configuration may change with the position of the cable in the duct.

Current distribution in the following configuration (Figure 47):

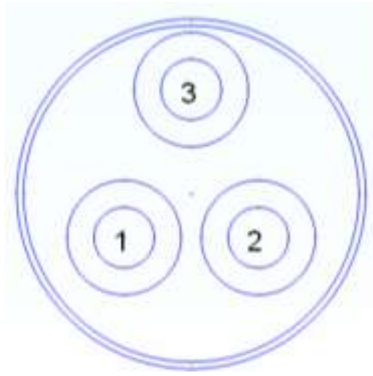


Figure 47 : Example of configuration for VOB cable in a electrical duct

Phase to outside	Phase to ground	Phase to neutral
	1 set at 220 V	
2,89µA	1,23µA	0,64 µA
	2 set at 220V	
2,63 µA	1,24 µA	0,64 µA
	3 set at 220V	
4,74 µA	0,64µA	0,64 µA

Results and conclusion:
We can calculate the relative errors for different cables:

Relative error for XVB cable: 16% ± 2%

Relative error for VOB cable: 5% ± 2%

Relative error for VOB cable with electrical duct: 55% ± 3%

The leakage current of electrical cable is a possible explanation to justify the leakage current in house. This current has the same order of amplitude as contact current level for some hundreds of meters of cable. Houses are indeed made of some hundreds meters of cable. This track can not be neglected.

Electric interactions between ambient ELF fields and body

Origin of biological effect near power line

At 50 Hz and within the considered field levels, there are neither thermal effects nor any ionising radiation effects (WHO, 2007; WEB.13). Induced heat has been evaluated (WEB.13), for 100 µT and 1 kV/m 50 Hz ambient, near avery small fraction of µW (compared to endogenous 100 W generation).

Ionising radiations (like X ray, gamma ray) are electromagnetic radiations that cause atoms to release electrons and become ions, owing to energy transfer from a photon. That energy E (eV) is given by the formula $E = h \times f$ where "h" is the Planck constant and f the frequency (Hz) of the electromagnetic wave (electromagnetic waves propagate in the air and vacuum at the speed of light). E is close to 1 eV for the visible light (obviously non-ionising) and may reach billions of eV for X Ray (wavelength 1 nm). If the same formula is applied with f equal 50 Hz (wavelength 6000 km), the amount of energy is at least one billion times lower than for visible light, thus 50 Hz waves are non ionising radiations.

Electromagnetic fields can only act in human body through biological mechanisms, though. When people are exposed to electric and magnetic fields created by power systems, imperceptible electric currents are induced in their bodies. There are a lot of biological interactions linked to endogenous alternative currents in the body, as electrocardiogramor electroencephalogram may easily show. The frequency content of the body signals is below 50 Hz (Alpha rhythms from 8 to 12 Hz, Beta rhythms 13 to 30Hz, others (Delta, Theta) at much lower frequencies). The most well known is heart beat around 1 Hz.

In general, these signals are complex and far from being completely understood. Signals are exchanged between cells owing to the change of TMP (transmembrane potential). And this may be one source of disturbance due to non-endogenous signal (WHO, 2007, page 94; Wang et al, 2005; Chiu et al, 2005).

TMP may be disturbed by the internal E-field in the tissues and the latter is thus a key value to estimate potential disturbances. Concerning leukemia, the internal E-field in the bone marrow is of essential importance.

The spontaneous opening and closing of voltage-gated channels cannot occur for internal E-field lower than 10 mV/m (WHO, 2007, page 101).

Chiu & Struchly, 2005 determined that a local body internal E-field of 1 V/m (1000 mV/m, hundred times the WHO threshold) can produce 0.2 mV across the gap junction connecting two bone marrow stromal cells. These cells orchestrate hematopoiesis that includes lymphocyte precursor cellular proliferation (LeBien, 2000; Bertil et al, 2001).

Thus, internal E-field, whatever the original source is, must be over several tens of mV/m to get a potential biological effect (which obviously would not necessarily come along with adverse health consequences).
There is nowadays no biological evidence indicating that such internal Efield within the bone marrow is either carcinogenic or stimulates the proliferation of initiated cells. However, there are some clues supporting the proposed hypothesis.

There is a secondary issue, concerning the duration of application of the “disturbance”. Up to now, we have no clear answer to that. Certainly a few seconds exposure would have no biological consequences as the auto-regulation mechanism is able to control most external attacks. Taking this phenomena into account, there are few ways to study transient short time effects, like ESD (electrostatic discharge) and electromagnetic transient (due to switching impulse, lightning impulse...).

It is a recognized fact that even during ionising radiations; several hours are needed to provoke irreversible effects excepted for extremely high levels. It seems reasonable to consider at least a similar duration to get potential effects with non ionising radiations.

We do not know if there is a doseresponse effect and how to combine different excitations at different time. More research on the subject is needed. Current investigations on epidemiological observations are based on mean 24 h exposure. A minimum of 8 h corresponding to sleep time is particularly concerned and thus bedrooms are the location where precautionary measures could be taken.

It must also be pointed out that it is extremely easy, for laboratory purposes, to apply a given E-field to Petri boxes with appropriate biological material. Unfortunately, only few labs performed such experiments.

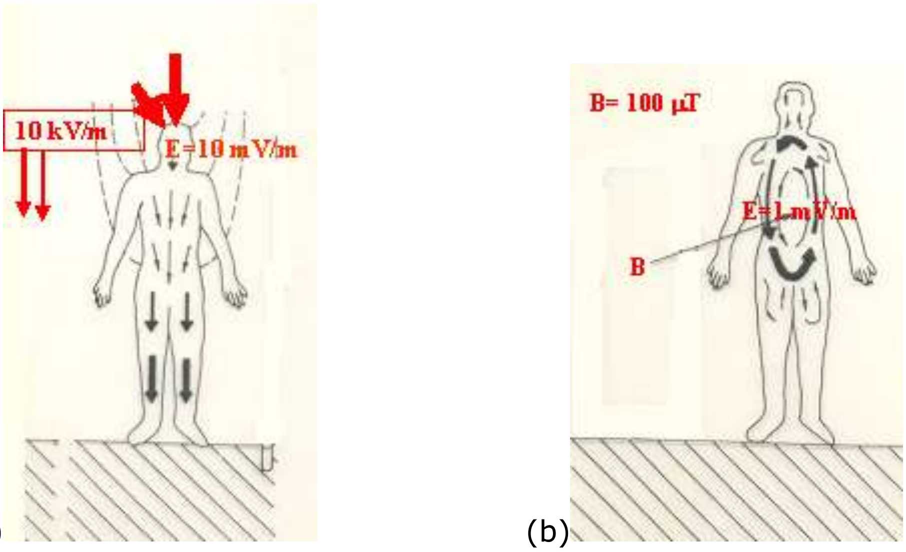
- **First potential source of internal E-field: the human body response to direct effect of ELF fields**

As just explained, the inside body locally induced internal E-field (due to either external E- or B-field) is of particular interest because it is related to the stimulation of excitable tissues.

E-field

Alternative external E-field, generally vertical (near ground) in typical situations, induces alternative current paths (mainly vertical) in the body (Figure 48(a)). Indeed alternative external E-field is strongly influenced by the presence of a body into the field. As a body is much more conductive than the surrounding air, there are charge distributions on its surface which partially annihilate the E-field inside the body. The internal Efield is quasi-null due to the joint effect of the external field and the induced surface charges. Due to the frequency (50 Hz), there is a permanent migration of charges which produces an alternative current within the body. As these charges, and hence the current, depend on external conditions, there exist an internal E-field which corresponds merely to an ohmic voltage drop due to the resistivity (inverse of the conductivity) of the body parts. The so-called "electrostatic induction current" follows more or less vertical paths through the body. Some of these paths go through the bone marrow.

In fact the E-field inside the body is about six orders of magnitude (1 million times) smaller than the external Efield: kV/m outside, mV/m inside. The order of amplitudes in the bone marrow (see later for further details) is of 10 mV/m for a body embedded in an external E-field of 10 kV/m.



(a) (b)

Figure 48: External E-field (a) and B field (b) effect on human being and resultant internal current and E-field due to current densities appearing into the bdy. The large arrows on the head (a) indicate a significant increase of the external E-field (compared to ambient field) due to peak effect (a factor 10)

B-field

Alternative external B-field induces a current in the body and thus an internal E-field (given by Ohm's law) as in any conductive material. External B-field, horizontal in typical situations, induces current loops in the body (Figure 48 (b)).

The order of amplitudes (see later for further details) of induced internal Efield is 1 mV/m for external B-field around 100 µT.

The order of amplitude of internal Efield (V/m) may be given by basic electric laws. In a simple case of a circle of radius *R* (m), embedded in a perpendicular B-field (T) at a given frequency *f* (Hz), the induced E-field is determined by the following formula: $E_i = p \times R \times f \times B$ Corresponding current density *J* (A/m2) is given by Ohm's law (σ being the conductivity in S/m):

$J = \sigma \times E_i$

Both these values (due to E- and Bfield) can be combined. The resultant is an internal E-field of some mV/m.

- **Could external ELF fields be directly linked to biological effects?**

This is impossible in a typical situation in Belgium, even below a 400 kV power line (the maximum power line voltage level in Europe) at its maximum load transfer (typically 2.2 kA), or even over a 150 kV underground cable at its maximum load transfer (typically 1.1 kA). Indeed these lines, as stated above, generate a maximum of rated B field (2.2 kA for 400 kV power lines) of 15 µT and a maximum of E-field of 9 kV/m, thus creating a combined value of internal E-field lower than 10 mV/m. Even lower if we consider the recommended annual average values, for health effects.

- **Other source of internal E-field: the contact currents**

To limit the existence of internal E-field to external E-field and/or B-field is not exhaustive. There is another source which has been first pointed out by Kavet et al, 2000, 2002, 2004, 2005; Bowman et al, 2006: the contact current like explain in the firs section.

With a contact current of 0.1 mA, the order of amplitudes of the E-field in the bone marrow (see later for further details) is several hundreds of mV/m for the arm and several tens of mV/m for the spinal backbone. Contact currents can give rise to possibly hazardous internal field levels higher than the established safety threshold (ref: part 1.1) and seems thus to be the only potential source of biological effects. This contact current, which may induce relatively large internal E-field, cannot be detected by most of the population as its level is lower than the perception level, though, except for hypersensitive people (see next section). Furthermore, the occurrence of contact currents is relatively limited, but when they appear, that may happen for several hours every day, which is particularly delicate for foetus, babies or small children. It must also be pointed out that there is no epidemiological evidence linking the risk of childhood leukemia and contact currents. Nevertheless, such epidemiological study would be particularly difficult to be performed due to the complexity of the measurements involved.

- **Evaluation of internal E-field in the bone marrow for ELF fields and contact current cases**

From 1996, many authors evaluated internal E-fields in different configurations (Barchanski et al, 2006; Struchly et al., 1996, 2005; Dawson et al., 1997, 1998, 2001, 2002, 2003; Dimbylov, 1998, 2000, 2005; Cech et al., 2007, 2008; Caputa et al., 2002; Jart et al., 1998). Currently, we are not aware of any measurements done inside the body of a living human, thus results are obtained by numerical simulations.

Different human models can be found worldwide, from children to adults, and including even pregnant women. Available software allows accounting for detailed models of the whole body, with different electrical characteristics (e.g. conductivity, permeability) for the different tissues.

Finite difference and finite element models are mostly used. The 3-D model is discretized in so-called "voxels", of about 3 mm size. Sources may be initial B-field, or E-field or both, or contact current between any parts of the body.

The output of interest for our purpose is, namely, the internal E-field in the bone marrow.

The conductivity of the bone marrow (there are yellow and red marrows) changes with age. Most common values as stated by Reilly, 1998 vary between 0.05 S/m to 0.2 S/m (foetus).

Eventually, the calculated effects of Efield, B-field and contact currents may be summarized as follows:

1) as the "material" is considered as linear, everything is proportional to the value of the external fields. A double external field generates a double internal field.
2) An E-field of 10 kV/m generates an internal E-field of about 30 mV/m in the bone marrow (adult).
3) A B-field of 100 μT gives rise to an internal E-field of 1 mV/m in the bone marrow (adult).
4) A contact current of 0.1 mA produces an internal E-field up to 500 mV/m in the arm for adult and up to 1500 mV/m for foetus.

It must be pointed out that these values depend strongly on the conductivity so that only an order of magnitude has to be considered. Moreover, working power frequency is either 50 Hz or 60 Hz, but 20 % shift in either ways has no significance here.

Based on previous physical observations, we may argue the following:

	model	**External source**	**Effect**
Struchly, 1996	simplified model		
Dawson, 1997	voxel of 3.6 mm for man of 76 kg, 1,77 m	E field only (60 Hz) 10 to 20 kV/m	1 mA/m^2 of current density (means internal E-field near 20 mV/m)
Dimbylov, 1997	voxel of 2 mm		
Dawson, 1998		B-field only (60 Hz) 1 μT	about 10 mV/m in the bone marrow
Hart &Gandhi, 1998		combination of E-field of 10 kV/m plus B-field of 33 μT	Induce about 3 mV/m in the spinal liquid.
Dawson, 2001	virtual child (18 kg, 1,1 m)	contact current of 0.1 mA	internal E-field : in the arms up to 500 mV/m in the spinal backbone marrow up to 45 mV/m
Caputa, 2002	"Brooks man" (104 kg, 1, 8 m)	B-field only at 1 μT	internal E-field in the bone marrow : from 0.02 to 0.29 mV/m
Dimbylov, 2005	"Naomi" (60 kg, 1,63 m)	B-field only of 1 mT	internal E-field in the bone marrow : from 6 to 48 mV/m
		E-field only of 1 kV/m	internal E-field in the bone marrow : from 3 to 56 mV/m
Cech, 2007 and 2008	"SILVY" pregnant women 30 weeks (89 kg, 1,8 m)	B-field only of 100 μT	internal E-field in the foetal bone marrow about 3 mV/m. (current density of 0.6 mA/m^2)
		E-field only of 5 kV/m	internal E-field in the foetal bone marrow about 20 mV/m. (current density of 3,3 mA/m^2)
		Combination of the two actions together	Induce 3, 5 mA/m^2 which means 20 mV/m

1) Concerning external E-field and/or B-field effects on bone marrow internal E-field:

- as WHO considers 10 mV/m as a basic minimum level able to potentially disturb biological mechanism (WHO, 2007, page 116, "…based on current evidence threshold values around 10-100 mV/m seem more likely"),
- as maximum E-field (just under a 400 kV line) is close to, and most generally lower than, 10 kV/m,
- as maximum B-field (just under a 400 kV line) is close to 20 μT, then, there is no way to consider any more direct effects of E-field or B-field on any mechanism which could be the source of childhood leukemia.

Indeed, E-field in critical situations, i.e. close to a threshold value, is very much influenced inside home by the walls, metallic tubes or plates; there is no way to observe a value as high as 10 kV/m inside residential houses. It is just a few tens of V/m, what means 1000 times lower than the potential threshold.

2) Concerning contact currents effect on bone marrow internal E-field:

- Contact currents may induce a significant internal E-field in the bone marrow and must be more deeply investigated.

- **Model of human body**

We have analysed and compared 15 studies dealing with human modelling in an electromagnetic environment.

Special attention is paid to the different sources of induced electric field in the body. This classification is based on the source influence on the induced electric field level in the bone marrow. We distinguish environments outside and inside a building.

The models used in these studies are quite different; they include men, women, a pregnant woman and a child:

- the biggest man (HUGO) measures 1.87 m for 114 kg;
- the smallest women (HANAKO) measures 1.61 m for 53 kg;
- the child measures 1.1 m for 18 kg.

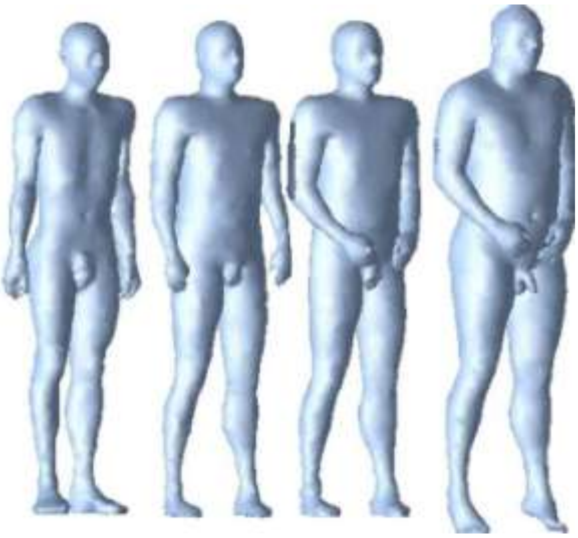


Figure 49 : Some of the human models used in studies on the influence of electromagnetic environment.

In each study, we take into account the field direction and the contact current path, which generates the maximum induced electric field or current density:

- for the electric field, it is from above the model to the ground;
- for the magnetic field, it is from front to back;
- for the contact current, it is from one hand to the feet.

Summary of the results (sources at 50 or 60 Hz):

- for an applied electric field of 1 kV/m, the induced electric field is ≅ 1 mV/m in the body and ≅ 3 mV/m in the bone marrow;
- for an applied magnetic field of 1 µT, we have ≅ 18 µV/m of induced electric field in the body (≅ 3 µA/m² of current density) and ≅ 12 µV/m in the bone marrow (≅ 1.6 µA/m² of current density);
- for an applied magnetic field of 1 mT, we have ≅ 10 mV/m of induced electric field in the body and ≅ 6 mV/m in the bone marrow;
- for a combination of an electric field of 5 kV/m and a magnetic field of 100 µT, we have ≅ 10 mA/m² of current density in the body of a pregnant woman;
- for a combination of an electric field of 10 kV/m and a magnetic field of 33 µT, we have ≅ 3.2 mV/m of induced electric field (≅ 4.8 mA/m² of current density) in the cerebrospinal fluid;
- if the electric field source is internal (e.g. heart beating, frequency range 40 to 70 Hz), we have ≅ 30 µV/m of induced electric field (≅18 µA/m² of current density) in the cerebrospinal fluid;
- for a contact current of 0.1 mA,
    - in an adult, the induced electric field varies from 0.7 to 537 mV/m in the body, from 0.5 to 166 mV/m in the bone

marrow of the arm and from 4 to 6mV/m in the bone marrow of the spinal column;

- in a child, the induced electric field varies from 20 to 1552 mV/m in the body, from 1 to 500 mV/m in the bone marrow of the arm and from 10 to 16 mV/m in the bone marrow of the spinal column.

The main parameters that influence the different results between models and people are thus:

- the conductivity of tissues,
- the body shape,
- the position of the body,
- the corpulence/stoutness of the body.

Consequently, considering the induced electric field level in the body is a much more sensitive approach than just focusing on external parameters and sources. At the end of this section, we include the bibliography of the 15 studies used in this comparison.

Furthermore, a simple electric model of a human being, based on the man of Brooks[Caputa K. et al., 2002], is developed. It is a male model of 1.8 m height and 104 kg weight. This model is widely used in other computational studies on electromagnetic field. We transform this model into a simple electric model as shown in Figure 50.

Each tissue in each part of the model is transformed into an equivalent resistance. We make some cuts in the arm, torso and legs. In each cut, we calculate the surface of each tissue, which allows determining an equivalent resistance of a cylinder.

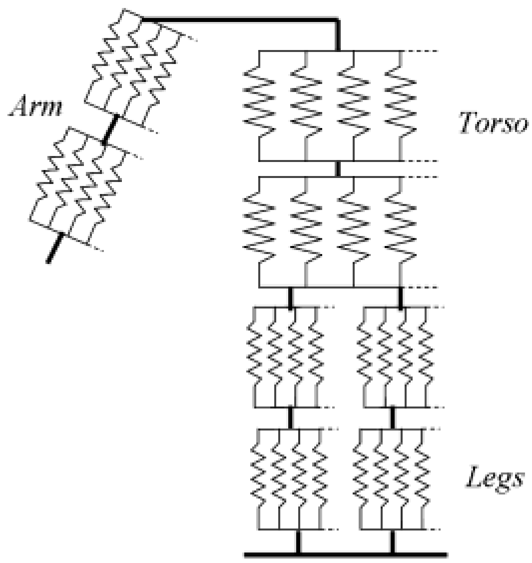


Figure 50 : Simple electric model of a human.

To compare the results with one of the studies on contact currents, we inject a current in the arm of the model. This simulates a contact current flowing through the model to the feet. For each part of the model, we calculate the current density and the induced electric field.

We obtain for a current of 0.1 mA an induced electric field in the bone marrow of the:

- arm up to 71.5 mV/m;
- torso up to 1 mV/m;
- legs up to 2.3 mV/m.

This simple electric model gives a good estimate of the induced electric field level in the bone marrow[Dawson T.W. et al., 2001].].

The 15 studies show that specific data of the induced electric field in the body is very difficult to obtain for human. Our simple electric model gives a good estimate of a middle level of the induced electric field by a contact current. A more detailed model would only provide additional information on the precise distribution of the induced electric field.

References of the 15 studies

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Sensitivity to electricity : the development of an apparatus to study the human body response to current injection.

Our aim is to measure the smallest human being perception current intensity; the current is flowing between two electrodes placed on the forearm of this person. This procedure is close to the one of Leitgeb et al., who tries to show a link between the "hypersensitivity to electromagnetism" and the sensitivity to electricity. [Leitgeb & Schrötner 2003; Leitgeb & al.].

In this study, we focused on the sensitivity to electricity of a person with two different protocols. The goal is thus to develop an apparatus making it possible to measure the electric sensitivity. And this with an aim of using it to reinforce the study carried out by Leitgeb showing a group which can be hypersensitive with electricity (Figure 51).

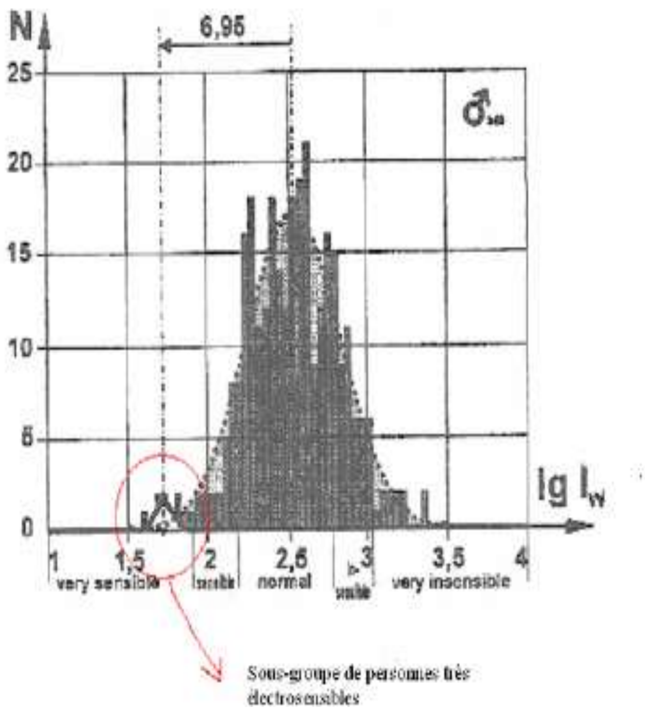

Figure 51 : Amout of people versus the perception current (expressed in log, 2 means 100µA)

Technical specifications

Components:

- A computer
- A home-made current injector
- A separated power supply for the current injector
- Two medical electrodes


Figure 52: Picture of the experimental setup

A home-made program is used (ULg courant); it creates a audio signal (wave file) which will be transmitted by the sound card to the current injector. This one converts the voltage in a stable current flowing between the two electrodes (Figure 52).

- **Protocol**

We have tested 150 volunteer with the first protocol we used. It is exactly the method described in the section II.1. These measurements showed a clear difference to the Leitgeb's results. Thus, it was very important to know if the results were different because of a difference in protocol or for another reason. We decided to use a protocol closer to the one of Leitgeb.

Basis

The two protocols present common basis that can be described as the following:

1. The computer and the alimentation of the current injector are turn on. The ULg current program is launched.
2. Two electrodes are placed on the forearm of the patient.

First evaluation

3. An increasing current is applied between the electrodes.
4. When the patient sense the current, he pushes the space bar of the computer and the current flowing is stopped.
5. The computer stores the value of current at this time.
6. The steps 3 to 5 are started again five more times in order to obtain the mean value of the perceived current.

Refinin

7. The steps 3 to 6 are started again, but with a more precise range of current, according to the first evaluation

Differences between the two protocols

During the first measurement campaign (150 cases), we were testing only one arm and the currents were increased by trains that were increased exponentially (see Figure 53)

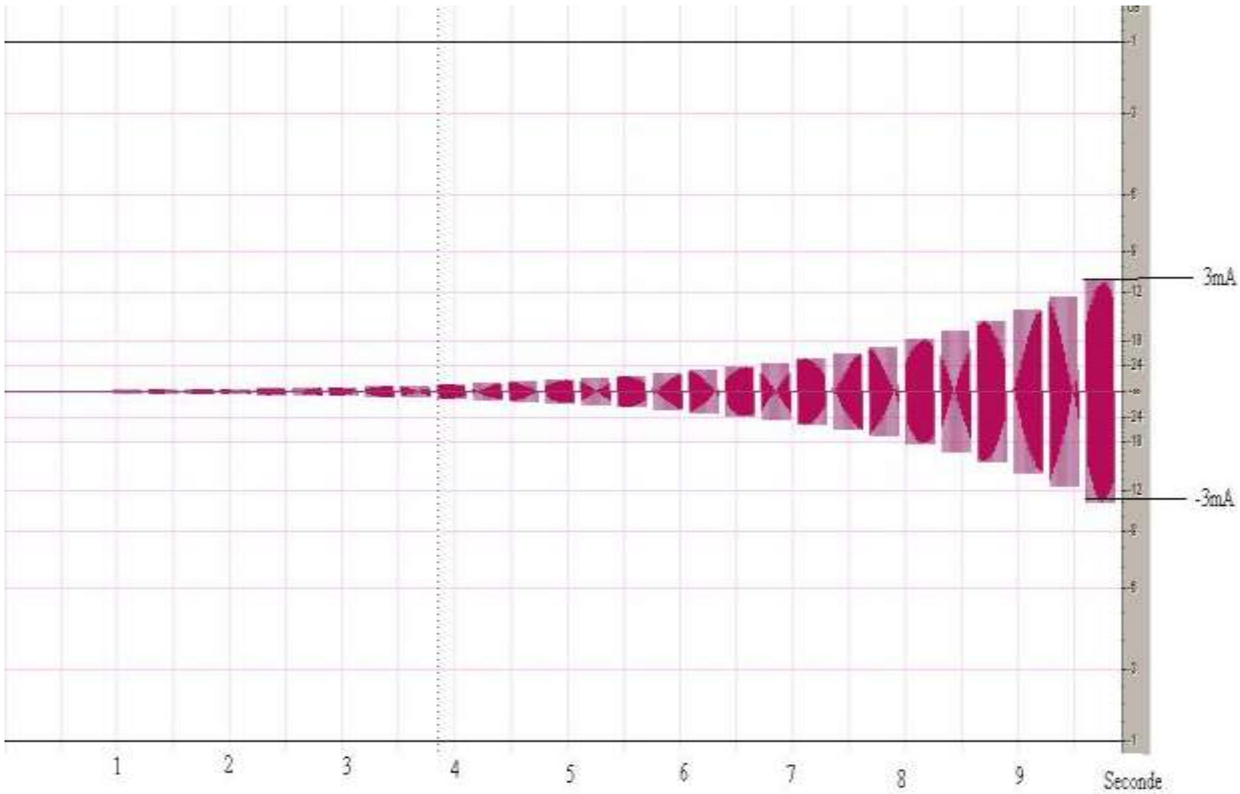

Figure 53: Increasing current in protocol 1 (logarithmic scale, current values are informative)

During the second set of measurements, Electrodes were applied at both forearms with only one side activated randomly. The volunteer then pushed on the keyboard with the arm where he felt the current. The currents were increased by trains that were increased linearly (see Figure 54).

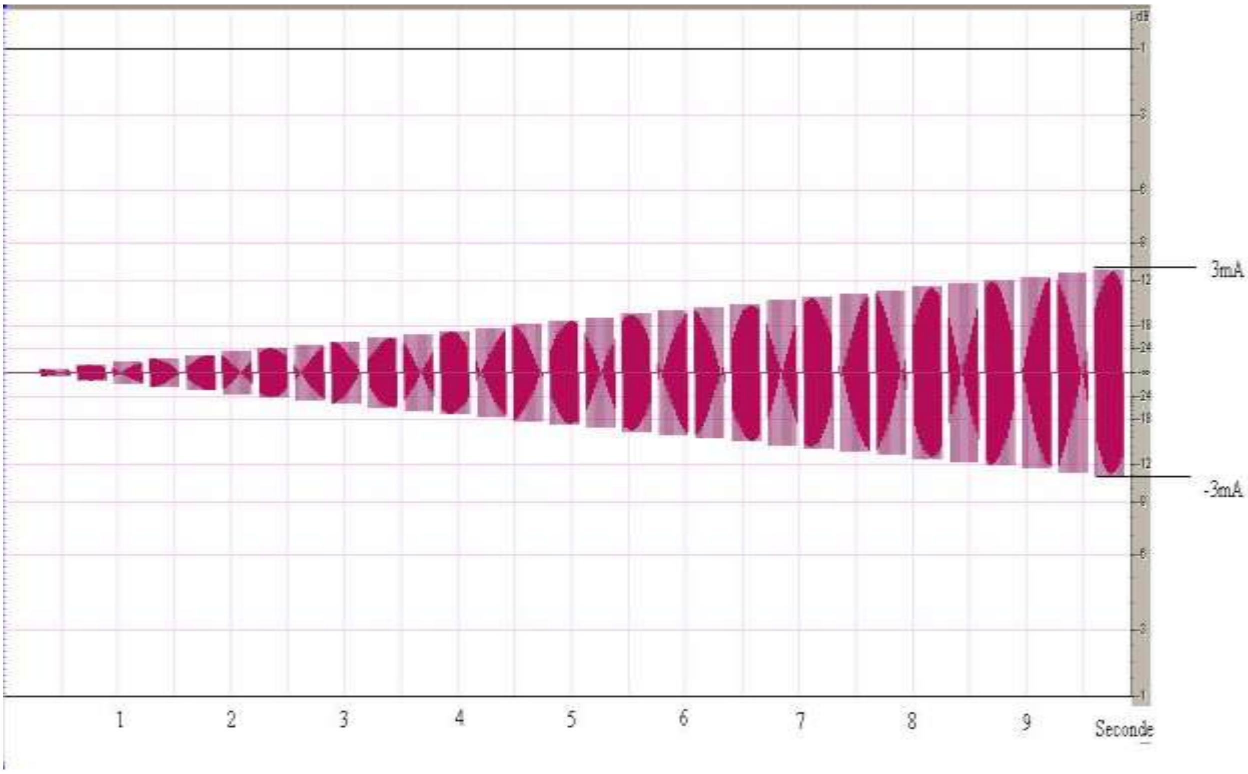

Figure 54: Increasing current in protocol (logarithmic scale, current values are informative)

- **Results**

The results of the first campaign were quite different from the one found by Leitgeb and his team [Leitgeb N. & Schrötner J.]. The results of this first campaign can be seen in Figure 55. The results don't follow a log-normal law and the mean value of the threshold current is quite different (760 µA compared to 313µA).

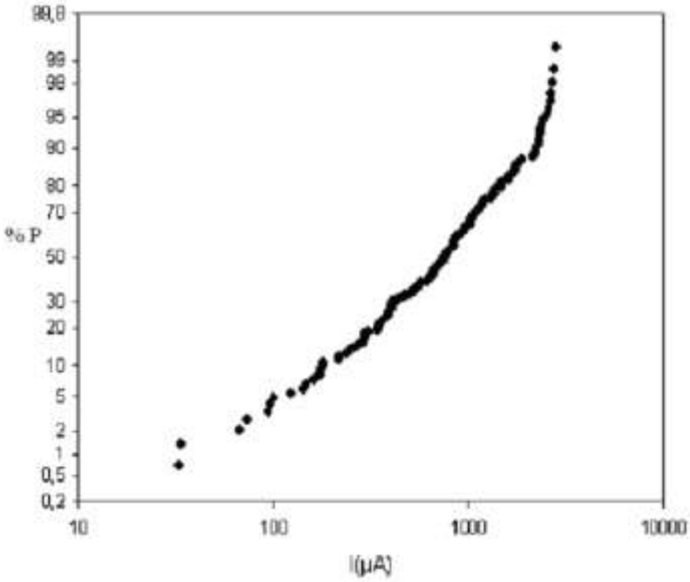

Figure 55: Results of the first measurement campaign (cumulative probability)

The results of the new campaign, with 30 volunteers showed a closer result from Leitgeb's. The hypothesis of a log-normal law can't be rejected. And the mean value of the measurements is 374µA. The results are shown on the Figure 56.

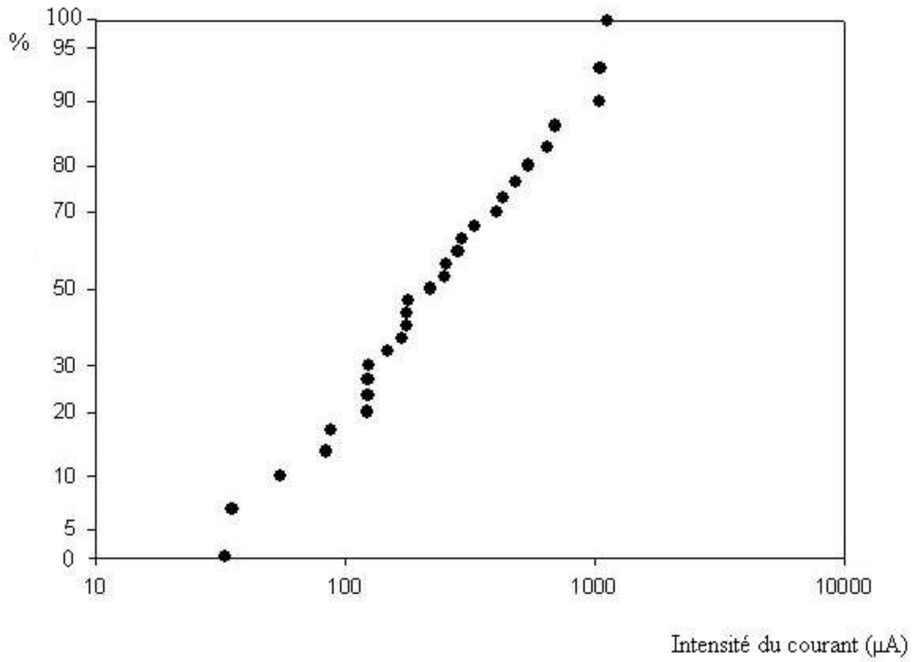

Figure 56: Results of the second measurment campaing (cumulative probability)

The Figure 57 shows the results of our measurements compared to the results of Prof. Leitgeb.

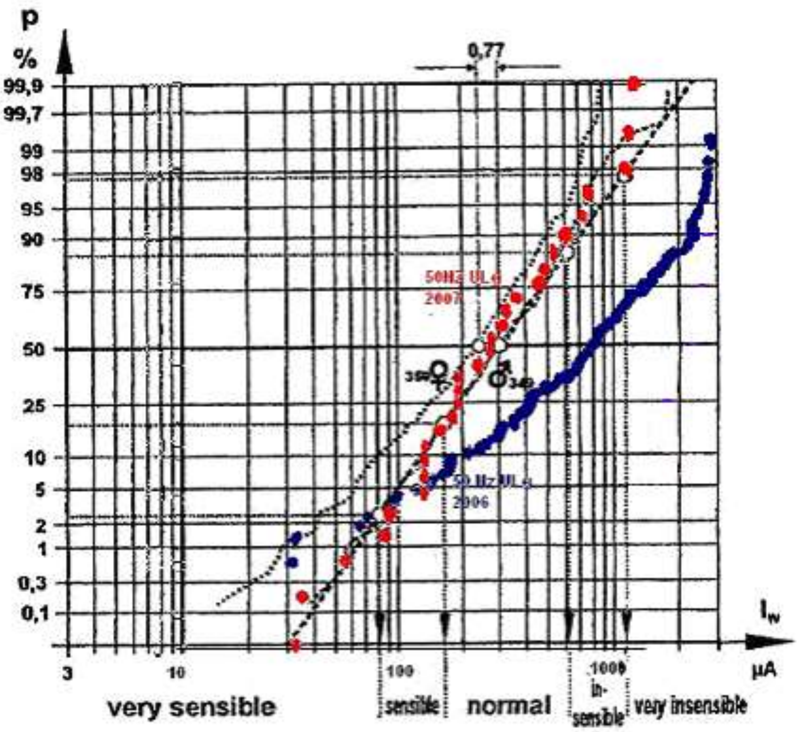

Figure 57: Comparison of our results to a similar study (Leitgeb)

The results of Leitgeb are in black; our results (2006) are in blue and our most recent study (2007) in red.

It can be seen that our last results fit quite well the study of Prof. Leitgeb. The mean value of our second measurement campaign (374µA) is close to the value found in the literature (313µA) [Leitgeb & Schrötner, 2003]. We thus assume that are device and protocol are now reliable.

- **Future work**

The device and the method are now able to give us reliable results, it can be used by the biomedical team to test the "hypersensible people" and to determine if there is a correlation between the people pretending to suffer from hypersensibility and their perception threshold when a current is flowing trough their arms. We are also searching a biological signal, maybe the impedance of the subject, which can tell us the exact moment when the volunteer sense the current. We wish to dispose of a biological signal instead of the conscious response of the people, in order to dispose of a kind of "output signal" to study.

Conclusion and future projects

We have realised a measurement campaign to evaluate the contact current level in Belgium private houses. We observed a mean contact current of about 10 µA. But many houses (about 10%) can reach some hundred of µA, which is a level that would need some considerations. Until now, the investigation shows no correlation between contact current and ambient magnetic field.

An important observation concerning the private house electrical installation, is that many (50%) of them have no or bad earth. And equipotential link are often missing, these links would certainly reduce the contact current level.

In the observed cases, we nevertheless found no clear relationship between contact current level and the existence of the equipotential link, thus other sources of contact current have also been investigated : the leakage current.
An electrical cable, even of good quality, can generate leakage current of some µA/m. We have planned to look into that direction more deep fully in the future.

In parallel numerous investigations have been done by simulations, to better understand the measured level of contact current. Simulations very much help to separate different influences, like single house, multiple houses, house orientation to a power lines, electrical circuits inside houses, TN or TT scheme. Simulations show higher sensitivity of TN scheme with B-field on contact current but the maximum induced contact current (by very high B-field) cannot justify the measured values which are far over the simulated ones in many cases.

Another important task was to find an appropriate channel to be able to compare potential biological effects between different sources(E-field, B field, and contact current). All of these sources can be converted into a single one into the body : **THE INTERNAL E FIELD**.
Based on that, it must be pointed out that contact current of about 100 µA is the source that generates a much more important internal field (at least one order of magnitude, up to two order of magnitude) compared to actual WHO limits of 5 kV/m (as E-field) and 100 µT (as B-field). Obviously 0,4 µT, the epidemiological threshold has non sense with that indicator.

Coupled with contact current studies, which shows, up to now, no correlation between B-field and contact current, there will be no causal link between the epidemiologic threshold and internal E-field, neither direct nor indirect. But the size of the sample (nearly 100 homes investigated) is probably too small to conclude on that point.
Another observation which may need some information in the population is that too many private installations are not conform with regulation, which would need some actions.

Last but not least, we evaluate with our own test system, the sensitivity of people to electrical current. Two protocols were used for the current : one with a log increase and the other one with a linear increase. We have noticed that log increase is giving different outputs compared to literature. The linear increase giving the same output as observed by Leitgeb.

The future extension of BBEMG activities in the engineer team is developed in another document. It will be dedicated to :

- An extension of contact current statistics in Belgium.
- An evaluation both by model and measurement of the origin of these currents.
- An on site evaluation of contact current limitation by different techniques.
- A follow up of internal E-field effects on biological mechanisms.

National and international contacts and meetings

08/05/2008	BBEMG meeting at VITO with all partners
05/12/2008	BBEMG technical and scientific meeting at ELIA
13/05/2009	Journée grand public: "Environnement electrique de basse frequence: effets sur la sante? – Resultats de 4 années de recherche du BBEMG" "Zijn magnetische velden van 50 Hz een risico voor gezondheid? Resultaten van 4 jaren onderzoek door de BBEMG"
3-4/06/2009	International colloquium – Power Frequency Electromagnetic Fields ELF EMF, Sarajevo 2009

Publications

[Lilien J.L. et al., 2008] Lilien J.L., Dular P., Sabariego R.V., Beauvois V., Barbier P.P., Lorphevre, Effects of extremely low frequency electromagnétic fields (ELF) on human beings. An Engineer point of view. Revue E tijdschrift– 124ste jaargang/124ème année – n°3-2008 (september/septembre 2008)

[Lilien J.L. et al., 2009] Lilien J.L., Dular P., Sabariego R.V., Beauvois V., Barbier P.P., Lorphevre, Effects of extremely low frequency electromagnétic fields (ELF) on human beings. In Proceedings of International colloquium – Power Frequency Electromagnetic Fields ELF EMF, June 3-4, 2009, Sarajevo, Bosnia-Herzegovina

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Annex

Projet tension de contact	Université de Liège - Institut d'Electricité Montefiore - Transport et Distribution de l'Energie Electrique / SGS Bureau Nivelles ASBL					
1. Données administratives						
Nom:	Heure In :	KWh In :	Occupants		Age	Sexe
Date:	Heure Out :	KWh Out :	Nombre total :			
Adresse :		Province :		1		
Date des fondations :		Région :		2		
Date de l'installation électrique :				3		
Photos de la maison en annexe :				4		
Tension d'alimentation : 2 x 230 V / 3 x 230 V / 1 x 400 V + N / 3 x 400 V + N				5		
Type de réseau : TT - TN - IT	Distributeur :			6		
Différentiel(s) :	général :	supplémentaire(s) :		7		
Type d'alimentation : aérien nu / aérien torsadé / souterrain				8		
Utilities :	Type de raccordement eau : PHD / plomb / acier / pas visible			9		
	Type de raccordement gaz naturel : PHD / acier / pas visible			10		
	Type de raccordement aux égouts : PVC / béton / acier / pas visible			11		
2. Mesures						
2.1. Courant de fuite à la terre :	mA	Si courant de fuite important (> 300 mA), faire une mesure des courants harmoniques de fuite				
			DDP (V)		**DDP avec R=1,02**	**Pièce**
2.2. DDP entre	2.2.1. terre tableau et arrivée d'eau :					
	2.2.2. arrivée d'eau et décharge à l'égout :					
Indiquer le type de raccordement à l'égout: PVC / acier ainsi que le type de canalisations d'eau	- compteur					
	- douche :					
	- baignoire :					
	- évier cuisine					
	2.2.3. terre prise évier et robinet salle de bain					
	2.2.4. terre tableau et autres structures métallique (poutre, escalier, ...) :					

	2.2.4. terre tableau et autres structures métallique (poutre, escalier, ...) :							
	2.2.5. terre tableau et piquets auxiliaires extérieures :							
	2.2.6. arrivée d'eau et piquets auxiliaires extérieures :							
	2.2.7. égout principal et piquets auxiliaires extérieures :							
	2.2.8. Masse de la machine à laver et piquets auxiliaires extérieures :							
	2.2.9. Masse du sèche linges et piquets auxiliaires extérieures :							
	2.2.10. Masse du lave vaisselle et piquets auxiliaires extérieures							
	2.2.11. chauffage central et terre tableau							
3. Champ d'induction magnétique								
3.1. au centre de toute les pièces, à 1 m de haut (indiquer le nom des pièces sur le schéma d'implantation)								
	hall :	µT		cuisine :	µT		garage :	µT
	salle à manger :	µT		salon :	µT		bureau :	µT
	salle de bain :	µT		chambre 1 :	µT		chambre 2 :	µT
	chambre 3 :	µT		chambre 4 :	µT		chambre 5 :	µT
3.2. à l'extérieur, à 1 m de haut et à X m de la maison (perpendiculairement au milieu de la façade, et limité à la propriété)								
(indiquer en commentaire la présence éventuelle de lignes HT et la distance par rapport à la maison ainsi que leur orientation)								
	2 m :	µT		5 m :	µT		10 m :	µT
4. Prise de terre et continuité		prise de terre : Ω		équipotentielle principale :			équipotentielle supplémentaire : Ω	
		mise à la terre par :		piquets ☐			boucle de fond de fouille ☐	
5. Commentaires :				**6.Plan:**				