Electrotechnical Characterization of a Stray Current Propagating Magnetotelluric Anomaly

Kim Horsevad

[1]Horsevad Independent Technical Research & Analysis, Tryvej 96, DK-9750 Denmark, www.horsevad.net
kim[at]horsevad.dk

Abstract: ***It is shown that stray current may propagate along conductive layers in the soil creating measurable magnetotelluric anomalies. A wide range of measurement methodologies are explored, including cross-sectional magnetic survey, which proves capable of both identifying and charting stray current propagating magnetotelluric anomalies. The effects of physical disconnection of the conductive strata are explored in relation to development of mitigative strategies for stray current, and it is shown that physical disconnection of the conductive strata yields attenuation values between -48db and -60dB.***

Keywords: Stray Current, Magnetotelluric Anomaly, Magnetic Field Survey, Electrical Infrastructure

1. Introduction

Stray current is a increasing problem for both pig and cattle farmers [1]. In earlier research (ibid) it was documented that stray current in some instances has exogenous origin in relation to the specific farm, and it was hypothesized that such exogenous stray current might propagate along conductive layers in the soil. Since the current flow in these electrically conductive layers causes a measurable disturbance in the magnetic field the term magnetotelluric anomaly was suggested.

2. Literature Survey

The mere concept of different soil substrates giving rise to magnetotelluric differences is very well known in the area of geophysical research. Many research methods developed for field work for identifying ground based stray current has a high degree of similarity with instruments and methods developed for geophysical research [2].

Utilization of natural telluric currents and natural magnetotelluric phenomenon for geophysical research has likewise been known for a long time. An impressive and rigorous mathematical treatment of the general magnetotelluric problem was published already in 1954 [3] and the use of magnetotelluric currents for mineral prospecting was well developed by 1960 [4]

Stray current can be produced by a number of technical faults, installation malpractice or infrastructure based on earth return [1]. Such stray currents are nominally AC-based. These AC based problems are quite well understood and mitigative strategies are generally well explored [2].

The stray current encountered at a number of researched locations in Denmark is, however, primarily DC-based (or extremely low frequency < 5 Hz), and exclusively exogenous [1], [5]. It has been observed that electrical installation practices aimed at mitigating AC based stray current increases DC based stray current [1].
It is known that contact current down to 50 μA has been statistically correlated to decreasing health status for domestic animals. [6], [7]. Cancer incidence rate in humans has likewise been correlated with contact currents down to 18 μA [8]. There is also evidence pointing to biological reactions from situations where different magnetic, electric or electromagnetic fields influence a biological system concurrently, even though each field by itself would be too weak to cause measurable effects [9], [10].

Viewed in comparison with both the implications for human health and the economical importance of livestock, a successful mitigation of stray current related problems seems paramount. Productivity increases in the order of 20% to 30% has been achieved by successful mitigation [12]

Although magnetotelluric research and magnetotelluric measurements has been utilized in geophysical research for some time it should be noted that the concept of magnetotelluric anomalies acting as propagation vectors for stray current - to the best of the authors knowledge - is a novel perspective and therefore relatively unexplored.

3. Problem Definition

The purpose of this study is therefore to act as a kind of pilot study in regards to exploring the electrotechnical parameters of the previously hypothesized stray current propagating magnetotelluric anomalies encountered at the "Hovmarksgaard" site and thereby - hopefully - laying the methodological foundation for a future deeper analysis

4. Methodology

4.1 Magnetic field survey and geographical overview

The area is (manually) scanned with a high resolution magnetic field analyzer with an axial probe, enabling magnetic field measurement down to 0.1 nT with directional information. Scanning is done in two different frequency spans, 0 Hz to 5 Hz and 5 Hz to 750 Hz. Utmost care should be observed in the placement of the probe for each measurement. Even half a degree of difference in sensor orientation might skew the measurement. The readings should be taken at the same height over the surface throughout the survey. Readings taken close to the surface will be strongly influenced by very local variations (small pebbles containing iron or similar disturbances). Taking the readings at a larger height tends to average out smaller differences. This averaging effect is, besides costs, the main reason for conducting magnetic field surveys from drones or airplanes. The measurements for this survey was taken at a height of 20 cm and with an interval of 0.5 m.

4.2 Magnetic field variations in the time domain

Specific areas identified in the magnetic field survey are further analyzed for magnetic field variations in the time domain. Measurements are made with a 3-axial probe and a sample frequency of 18 samples pr second. Measurement resolution for this instrument is 0.1 µT. All measurements are logged for further analysis.

4.3 ELF Spectrum compared to neutral

A sensitive magnetic field sensor composed of an air coil (5000turns of 0.22mm enameled copper wire, 30cm diameter) is connected to an spectrum analyzer. The low frequency (0 Hz – 750 Hz) part of the spectrum is recorded for further analysis, while the total received power is calculated by the spectrum analyzer automatic measurement facility.

4.4 Impedance, Capacitance and Resistance

To measure capacitance and impedance of the magnetotelluric anomaly across multiple frequencies the I-V method is used.

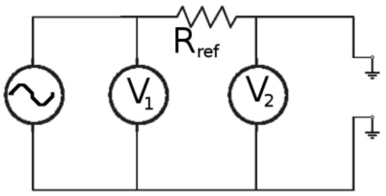

Figure 1: Classical I-V method diagram. Signal generator produces AC voltage, which are measured on each side of the precision resistor (500Ohm), whereby the current and impedance (Z) between the two earthing rods can be calculated for different frequencies by measuring V1 and V2 with an oscilloscope

Note that the current waveform leads the voltage waveform for capacitative impedance, whereas the current waveform lags the voltage waveform for inductive impedance.

4.5 Flow and direction of current at surface

The purpose of this measurement is to document the direction and intensity of current flowing at the surface. Five earthing rods are inserted into the ground at a depth of 1 meter. One in the center of the magnetotelluric anomaly and 4 others at the geographical cardinal points. Both resistance, AC voltage, AC current, DC voltage and DC current are measured between the earthing rods.

4.6 Flow and direction of current in the conducting strata

The purpose of this measurement is to document the direction and intensity of current flowing in the conductive strata at 3 meters depth in the magnetotelluric anomaly.

The exact depth has been verified by direct measurement in the conducting strata by digging. Two earthing rods are inserted into the ground at a depth of 3 meter. Resistance, AC voltage, AC current, DC voltage and DC current are measured between the earthing rods.

4.7 Ionizing radiation

A number of electrical measurement instruments (multimeters and portable oscilloscopes) has experienced unexpected and sudden fault conditions when used near the magnetotelluric anomalies. After the faults has been analyzed by the instrument retailer it was suggested that the damage sustained to the instruments could be caused by ionizing radiation. Although no plausible explanation correlating magnetotelluric anomalies and increased ionizing radiation is known at present time it was nevertheless decided to log ionizing radiation measurement for two locations directly on top of an magnetotelluric anomaly and two neutral locations. The ionizing radiation was logged digitally for 1000 seconds at each station.

4.8 Effects of physical disconnection

To acquire further knowledge about possible mitigation strategies involving direct physical disconnection of the conductive strata in the magnetotelluric anomaly it was decided to implement a physical disconnection by digging a 5 meter deep trench across the magnetotelluric anomaly.

Ethical approval: Although the results of the ongoing investigation of the stray current problem ultimately has a definitive goal of improving conditions for the animals in the affected farms none of the measurements or other research work conducted in order to obtain the results analyzed in this paper are related to either human or animals use. At this phase of the exploration we are strictly in the domain of technical measurements.

5. Results & Discussion

a) Magnetic field survey and geographical overview

The initial survey identified a magnetotelluric anomaly localized in a field east of the building complex at the farm

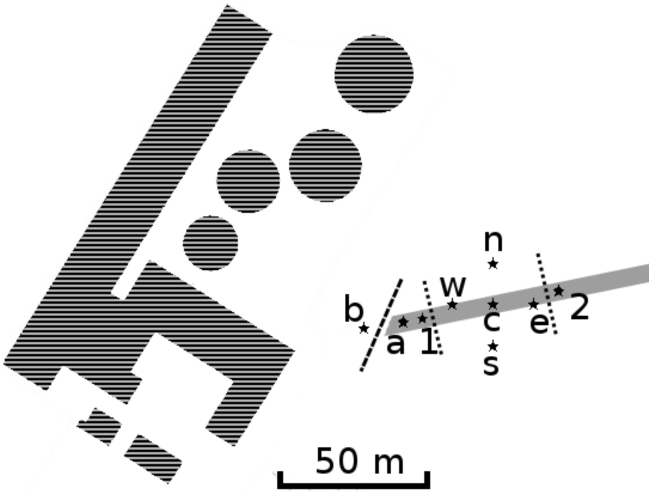

Figure 2: Geographical overview. The hatched area denotes the buildings and slurry pits on the farm. The gray line denotes the magnetotelluric anomaly identified by magnetic field survey. The two dotted lines denotes cross-sectional magnetic field line-surveys. The slashed line denotes area for physical disconnection of the conductive strata. The stars denotes earthing rods inserted in various depths. Earthing rods "a" and "b" are used to measure the effect of physical disconnection of the conductive strata. Earthing rods "1" and "2" are used to measure the impedance of the magnetotelluric anomaly. Earthing rod "c" is localized in the geographical middle of the magnetotelluric anomaly and the earthing rods "n", "e", "s" and "w" are located in the geographical cardinal points referenced to "c".

For both cross-sectional line surveys a distinctive pattern was discovered.

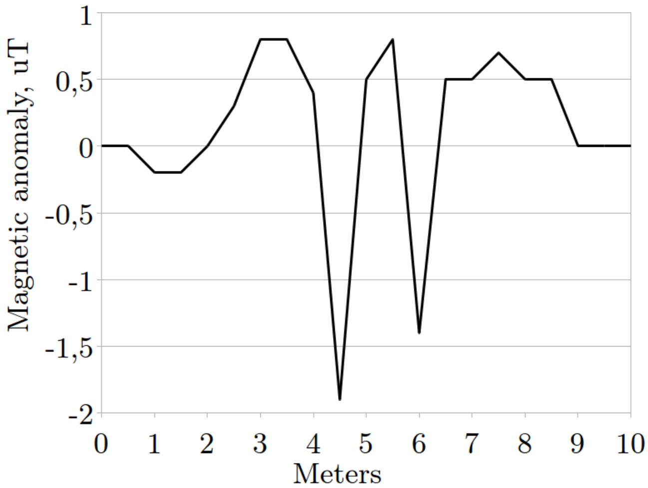

Figure 3: Cross-sectional magnetic field survey "1" Measurements are taked with an axial probe, whereby only the "Z"-component (perpendicular to the surface) is registered. Frequency response of the used probe is 0 Hz to 5 Hz. Measurements were taken for each 0,5 meters. 10 seconds of measurements were taken at each station and the average recorded.

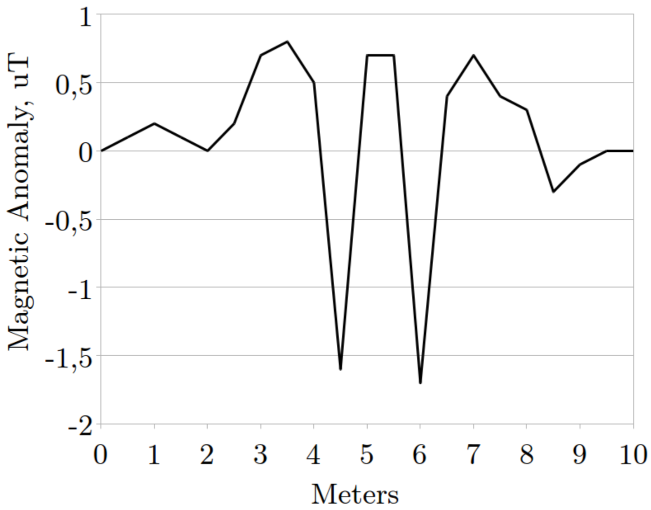

Figure 4: Cross-sectional magnetic field survey "2"

A peculiar double-negative magnetic field peak is elucidated for both cross-sectional surveys, pinpointing a distinctive pattern of variation across the magnetotelluric anomaly in the "Z" (up/down) axis of the magnetic field.

This distinctive pattern quite clearly demonstrates the utility of the low-frequency magnetic field survey for identifying magnetotelluric anomalies.

Scans with frequency response between 5 Hz and 750 Hz yielded no discernible results, probably due to the sharp pulsing in that frequency span shown in figure 5.

The magnetic field encountered just outside the conducting strata in the magnetotelluric anomaly reaches considerable intensity.

Figure 5: Detailed measurement of magnetic field directly on the conducting layer of ocher in an excavated magnetotelluric anomaly. In this instance a reading of 135,4 μT (1354 mG) was recorded.

b) Magnetic field variations in the time domain

Time domain analysis of magnetic field variation at a specific point over the magnetotelluric anomaly shows only very minor variations in the "Z"-axis, while both "X" (north/south) and "Y" (east/west) demonstrates quite considerable range of fluctuations. At present no explanation of the cause of this considerable variation can be presented, although it, by the very definition of electromagnetism, must be related to variations in the current flow in the conductive strata.

Only a small span of time is shown in the graph, but the fluctuations shown are fully representative of much larger time spans.

It is expected that the sharp magnetic pulses registered in the AC ELF spectrum also produces similar sharp pulses in AC ELF electrical spectrum, although the utilized instruments proved insensitive to reliable register patterns and variations below 1 V/m.

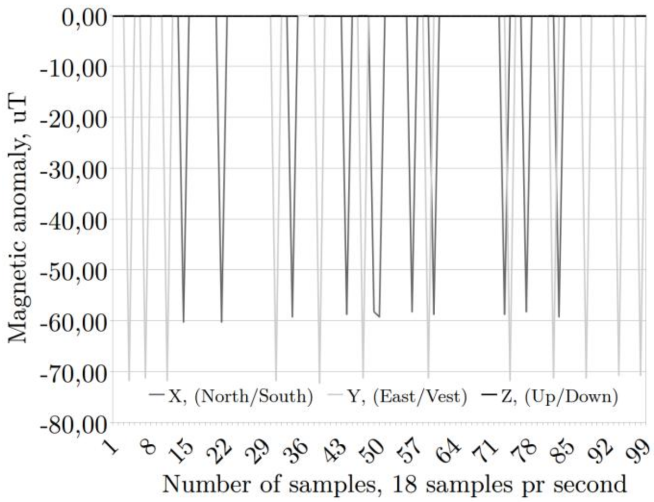

Figure 5: Magnetic field variation shown in the time domain. Measurements are made with a 3-axial probe and a sample frequency of 18 samples pr second. Probe frequency response is between 0 Hz and 5 Hz. Measurement resolution is 0.1 µT.

AC ELF magnetic field intensities at 0.3-0.4 µT has epidemiologically [12] been correlated to a doubled incidence in childhood leukemia.

It should be noted, though, that the magnetic field exposure in this research (ibid) origins from electrical infrastructure, not from stray current. This implies a more sinusoidal signal than the sharp pulses shown in figure 5.

The sharp pulses, which has been documented in relation to stray current in earlier research [1], are tantamount to a enigma, as there must be a tremendous amount of energy behind these signals, even though it is known for certain [1] that the pulses are unaffected by disconnection of electrical power to the farm.

Pulsed signals may convey an even greater potential for adverse bioreactivity than sinusoidal fields. According to the "Forced Ion Vibration Theory" [13]-[15] pulse modulated signals might affect irregular opening of voltage gated ion channels in the cell membrane and thereby disturbing the cells electrochemical function leading to formation of reactive oxygen species.

The theory has been experimentally verified [16]-[18] and explored by other researchers [19],[20].

It has even been proved that the effect can be blocked with VGCC-blockers [21].

The sharply pulsed fields are therefore of great concern in relation to the wellbeing of both the animals and humans at the farm location.

c) ELF Spectrum compared to neutral

Both spectrum composition and total received power differed between the magnetotelluric anomaly and a neutral location nearby.

Table 1: Total received power, 0-750 Hz

Total received power , averaged over 10 minutes 0 Hz - 750 Hz			
Neutral location			
Min	104,4fW	Max	1,495 pW
Average	669,8fW		
Magnetotelluric Anomaly			
Min	291,5fW	Max	1,54 pW
Average	1,172 pW		

Further analysis of the observed difference is required. Data logged from multiple locations over larger time span would be necessary to clarify any diurnal variation or other variations possible correlated to voltage/current flow or other observable phenomenon.

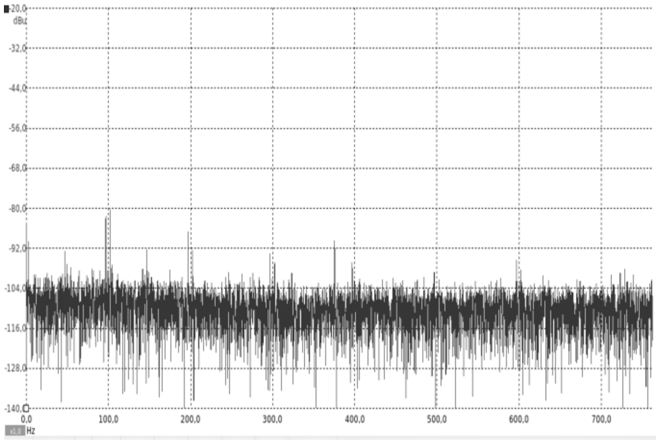

Figure 6: 0 Hz to 750 Hz spectrum analysis from neutral location.

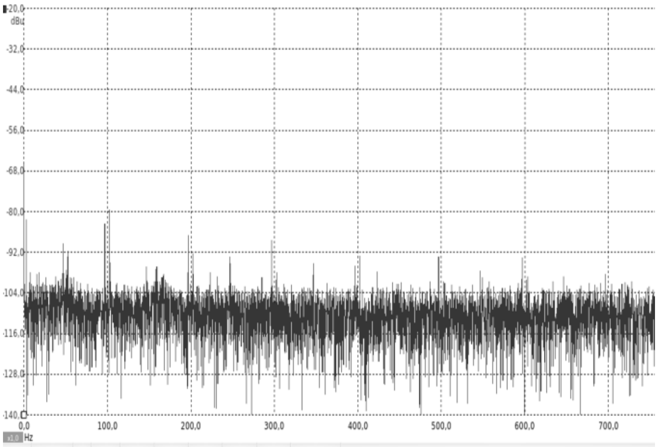

Figure 7: 0 Hz to 750 Hz spectrum analysis from magnetotelluric anomaly. Note the peak around 1Hz which possibly is related to the peaks with a quasi-frequency around 1Hz shown in figure 5. Note the double-peaks around the mains frequency (50Hz). Note the broad peak around 180Hz.

The spectrum analysis indicate enlarged presence of noise in the extreme lower end of the ELF spectrum for the magnetotelluric anomaly compared to the neutral location. Like the measured total power input difference both spectrums were averaged over 10 minutes.

d)Impedance, Capacitance and Resistance

The overall resistance (impedance) decreases slightly with increasing frequency.

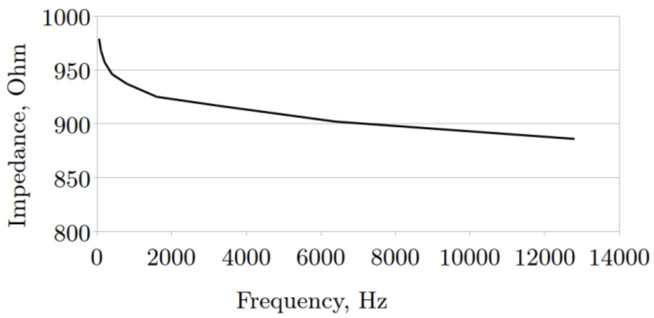

Figure 8: Impedance, measured in Ohm, for the frequency range between 40 Hz and 13000 Hz.

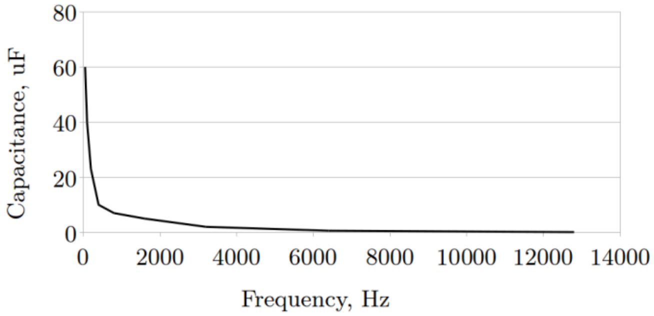

Figure 9: Capacitance, measured in uF, for the frequency range between 40 Hz and 13000 Hz.

At 40 Hz we see a capacitance of nearly 60 µF between the two earthing rods. Although no lower frequency than 40Hz was tested, the graph indicates increase in capacitance as frequency drops.

Overall this indicates that the soil, in particular in the magnetotelluric anomaly, acts like a capacitor with increasing capacitance as the frequency drops. This can be conceptually modeled by the equivalent circuit described below. At extremely low frequencies approaching DC the circuit is effectively purely resistive. With increasing frequency current starts flowing through the capacitor, decreasing total system impedance as indicated by the measurements.

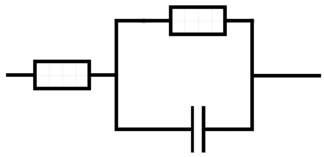

Figure 10: Equivalent circuit for the impedance observed at the magnetotelluric anomaly.

e) Flow and direction of current at surface

In earlier research we have used the gradient electrode array to chart current flow at the surface [1]. Although this measurement strategy was implemented at at point in the research where the neither the existence of nor the possibility of identifying the stray current propagating conductive strata was known the measurement is repeated here to compare the results obtained with direct measurement in the conductive strata.

Table 2: Gradients and polarity for surface stray current

		North			
		- 31 mV DC	- 9 uA DC		
		0.0 mV AC	0.0 uA AC		
		1911 Ω			
	- 23 mV DC			- 9 mV DC	
	- 9 uA DC			- 3 uA DC	
West	0.0 mV AC	Center		0.0 mV AC	East
	0.0 uA AC			0.0 uA AC	
	1453 Ω			1620 Ω	
		0.0 mV DC	0.0 uA DC		
		0.0 mV AC	0.0 uA AC		
		1863 Ω			
		South			

Negative probe is connected at "Center". The electron flow is therefore from the surface of the magnetotelluric anomaly and outwards, although the values registered are quite small.

f) Flow and direction of current in the conducting strata

Depth of the conductive strata was determined by digging. Afterwards earthing rods were inserted to a depth of 3 meters and the following values were recorded.

Table 3: Current flow in conductive strata

Resistance	437 Ohm
DC V	1,2
DC A	1173 uA
AC V	0,01V
AC A	2 uA

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The difference between measurements done directly in the conductive strata and the surface are quite remarkable. The gradient electrode array is therefore of relatively little value in determining current flow in the conductive strata of a stray current propagating magnetotelluric anomaly. The most extreme reading occurring during measurement in the dug trenches was a potential difference of 800mV DC over a 20 cm distance.

g) Ionizing radiation

None of the readings encountered was large enough to explain the instrument defects experienced while working around the magnetotelluric anomalies. But the results was nevertheless both interesting and surprising, as the logs for ionizing radiation at the magnetotelluric anomaly and a neutral location at 10 meters distance differs significantly with P (two-tailed) = 0.00235 at alpha = 0.05. This was quite unexpected. The average CPM for the magnetotelluric anomaly was 29.46 CPM, while the average for the neutral location was 22.44 CPM.

The largest 10-second reading (144 CPM) at the magnetotelluric anomaly corresponds to 1.1693 µS/h, which, although more than the double of the expected reading, should not cause instrument failure.

The average at the magnetotelluric anomaly corresponds to a yearly dose of 2.11 mS/y, while the average at the neutral location (10 meters distance) corresponds to 1.60 mS/y. None of these values should, by themselves, cause any concern, although the mechanism for producing a significantly increased amount of ionizing radiation at the magnetotelluric anomaly remains to be elucidated.

To further validate the unexpected finding we repeated the measurement on an another magnetotelluric anomaly. This second measurement yielded averages of 25.32 CPM (= 1.80 mS/y) and 11.4 CPM (= 0.81 mS/y) which differs significantly with P (two-tailed) = $6{,}4 \cdot 10^{-13}$ at alpha = 0.05

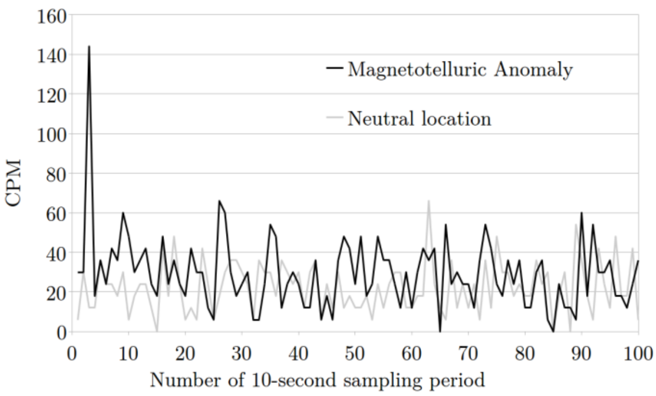

Figure 11: Comparison of ionizing radiation between magnetotelluric anomaly and neutral location. Even without the outlier (144 CPM) registered in sampling period 2 there is still a significant difference with p<0,003.

h) Effects of physical disconnection

Physical disconnection of the conductive strata in the magnetotelluric anomaly proved decisively effective in order to attenuate a signal transmitted through the earthing rods driven into the magnetotelluric anomaly. Attenuation of -48.72 dB was achieved at 80 Hz and -60,22 dB at DC.

We can, of course, only precisely quantize the attenuation of the test signal, but qualitative data hints at comparable attenuation of the stray current. Both the farm owners and veterinarians observing the animals at the farm has registered considerable positive effects after the disconnection.

This effectively validates physical disconnection as a viable mitigation strategy in situations where the financial burden of the construction work required for physical disconnection of the conducting strata at the magnetotelluric anomaly can be justified in terms of problem mitigation and subsequent increase in productivity.

6. Conclusion

The existence of stray current propagating magnetotelluric anomalies (which had only been merely hypothesized in earlier works) and viable methods for identifying and charting such stray current propagating magnetotelluric anomalies has been developed and demonstrated.

Detailed magnetic field survey proved most effective for identifying and charting magnetotelluric anomalies. It is not known to what extent the specific cross-sectional pattern revealed for this magnetotelluric anomaly is comparable to magnetic field variations for other stray current propagating magnetotelluric anomalies, but the existence of a very discernible pattern for this specific magnetotelluric anomaly is quite evident.

The magnetic field variations associated with the magnetotelluric anomaly deserves further attention. Magnetic pulses of this intensity might convey a biological reaction independent of the stray current related bioreactivity.

Survey of the ELF-spectrum only hinted at a measurable difference. Total power input differed between neutral location and magnetotelluric anomaly, but the measured difference is very small and only visible after averaging measurements over longer spans of time. Even if this difference is representative for all stray current propagating magnetotelluric anomalies it will be very difficult to realize any kind of simple detector based on these small differences.

Impedance drops as frequency increases, while capacitance increases as frequency drops. The equivalent circuit modeled on the basis of the measurement can be utilized as a conceptual framework for furthering understanding of the importance of capacitive coupling between both current propagating conductors (manmade or natural) and the earth and between the earth and animals/humans on the surface.

The gradient array used in earlier works has remarkable little value for neither identifying nor charting current flow in the conductive substrata, as long as conducting layers are isolated from the surface by less conducting layers. If the conducting layers are identified by other methods the gradient array, with electrodes placed in the correct depth, may still be a viable method for measuring current flow and extent of conducting layers, although a more traditional cross-sectional Schlumberger array may prove more worthwhile.

Neither of the implemented electrode arrays yielded measurements even hinting at the origin of the sharp variations in magnetic field, which may imply the existence of an even deeper (yet uncharted/unidentified) AC-based stray current propagating magnetotelluric anomaly.

The significant change in ionizing radiation between the magnetotelluric anomaly and neutral location was unexpected and deserves further attention. At present is the possible implications of this finding are unknown.

Physical disconnection of the conducting layers in the stray current propagating layers in the magnetotelluric anomaly proved decisively effective in attenuating both test signals and the stray current itself.

7. Future Scope

We have identified one propagation vector for stray current, and we have developed a measurement protocol able to chart the geographical extent of these propagation vectors. We have further established both quantifiable measured and qualitatively registered positive effects by physical disconnection of the identified magnetotelluric anomaly.

But at the same time it is clearly evident that much research in this area is needed before any kind of full understanding of the complex conglomerate of problems is fully achieved.

We have not been able to identify the source of the AC ELF magnetic fields.

The origin of both the DC-based stray current and the AC ELF magnetic fields are not known, although it is evident form earlier research that they are not endemic to the farm.

At present we have no specific knowledge about the ratio in which the AC ELF magnetic fields, DC-based stray current or AC based stray current contributes to the adverse health effects observed for farm animals. To complicate the matter further, both the electrical field and the magnetic field might convey adverse bioreactivity. Further research is needed to understand this issue deeper.

The increased levels of ionizing radiation at the magnetotelluric anomaly are, although the levels are not by themselves threatening, puzzling and deserves further attention.

References

[1] Horsevad, Kim. 2019. “Analysis of Stray Current, its Aetiology, Propagation, Relevant Measurement Protocols and Mitigative Efforts at a Pig Farm in Northern Denmark”, International Journal of Science and Research (IJSR), Volume 9 Issue 1, January 2020, 1234 – 1244
[2] Prystai, Andrii & Pronenko, Vira. (2015). Improving of electrical channels for magnetotelluric sounding instrumentation. Geoscientific Instrumentation, Methods and Data Systems. 4. 10.5194/gi-4-149-2015.
[3] Wait, J.R., 1954. On the relation between telluric currents and the Earth's magnetic field, Geophysics, 19, 281-289.
[4] E. M. Wescott, (1960), "Magnetic and telluric current disturbances in Alaska. Geophysics 25: 1242-1250
[5] Horsevad, Kim. 2019. “Pilot Study Indicating Possible Effects on Water Impedance Characteristics from Stray Current”, International Journal of Science and Research (IJSR), Volume 8 Issue 5, May 2019, 1154 – 1157
[6] Polk, Charles and Elliot Postow, Editors, CRC Handbook of Biological Effects of Electromagnetic Fields, 2 nd edition. CRC Press 1986. Inc. Baco Ratoon, FL.
[7] Minnesota Public Utilities Commission (MNPUC). Final Report of the Science Advisors to the Minnesota Public Utilities Commission. MNPUC, St. Paul, MN. July 31, 1998.
[8] Kavet, R., Zaffanella, LE., Daigle, JP. and Ebi, KL. The possible role of contact current in cancer risk associated with residential magnetic fields. Bioelectromagnetics 2000, 21: 538–553.
[9] Liboff AR. Cyclotron resonance in membrane transport. In Chiabrera A, Nicolini C, Schwan HP (eds): ‘‘Interactions between Electromagnetic Fields and Cells,’’,1985, London: Plenum Press, pp 281–296.
[10] Blackman CF, Benane SG, Rabinowitz JR, House DE, Joines WT. A role for the magnetic field in the radiation-induced efflux of calcium ions from brain tissue in vitro. Bioelectromagnetics 1985, 6:327–337.
[11] Lefcourt, A.M., ed. 1991. Effects of Electrical Voltage/Current on Farm Animals: How to Detect and Remedy Problems. USDA. Agricultural Handbook No. 696.
[12] Blank M, Goodman R. DNA is a fractal antenna in electromagnetic fields. Int J Radiat Biol. 2011 Apr;87(4):409-15.
[13] Panagopoulos DJ, Messini N, Karabarbounis A, Filippetis AL, Margaritis LH. A Mechanism for Action of Oscillating Electric Fields on Cells. Biochemical and Biophysical Research Communications 2000;272(3):634-640.
[14] Panagopoulos DJ, Karabarbounis A, Margaritis LH. Mechanism for Action of Electromagnetic Fields on Cells. Biochem. Biophys. Res. Commun 2002;298(1):95-102.
[15] Panagopoulos DJ, Margaritis LH. Theoretical Considerations for the Biological Effects of Electromagnetic Fields. In: Stavroulakis P. (Ed.) Biological Effects of Electromagnetic Fields, Springer, 2003:5-33.
[16] Panagopoulos DJ, Chavdoula ED and Margaritis LH. Bioeffects of Mobile Telephony Radiation in relation to its Intensity or Distance from the Antenna. International Journal of Radiation Biology 2010; 86(5):345-357.
[17] Panagopoulos DJ and Margaritis LH. Mobile Telephony Radiation Effects on Living Organisms, In: Harper AC,

Buress RV. (Ed.) Mobile Telephones: Networks, Applications and Performance. Nova Science Publishers, 2008:107-149.
[18] Panagopoulos DJ, Margaritis LH. Biological and Health effects of Mobile Telephony Radiations, International Journal of Medical and Biological Frontiers 2009;15(1-2):33-76.
[19] Li Y, Yan X, Liu J, Li L, Hu X, Sun H, Tian J. Pulsed electromagnetic field enhances brain-derived neurotrophic factor expression through L-type voltage-gated calcium channel- and Erk-dependent signaling pathways in neonatal rat dorsal root ganglion neurons. Neurochem Int. 2014 Sep; 75:96-104.
[20] Pall ML. Scientific evidence contradicts findings and assumptions of Canadian Safety Panel 6: microwaves act through voltage-gated calcium channel activation to induce biological impacts at non-thermal levels, supporting a paradigm shift for microwave/lower frequency electromagnetic field action. Rev Environ Health. 2015; 30(2):99-116.
[21] Pall, ML. Electromagnetic fields act via activation of voltage-gated calcium channels to produce beneficial or adverse effects. J. Cell. Mol. Med, 2013;27:958–965

Author Profile

Kim Horsevad (kim@horsevad.dk] is the owner and chief technical analyst at Horsevad Independent Technical Research & Analysis (www.horsevad.net). Current research focuses on developing measurement tools for quantifying interactions between electromagnetic fields and biological systems.