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Analysis of Stray Current, its Aetiology, Propagation, Relevant Measurement Protocols and Mitigative Efforts at a Pig Farm in Northern Denmark

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Abstract: ***As the occurrence of stray-current affected farms in Denmark are sharply rising, further research efforts are required to fully understand the phenomenon and develop relevant mitigative strategies. Results from a two-year research campaign at a stray current affected farm in Northern Denmark are reported, along with several novel findings relating to the propagation of stray current through specific soil layers and changes in water impedance characteristics caused by stray current.***

Keywords: Stray Current, Equipotential bonding, Pig Farm, Electrical Infrastructure

1. Introduction

Stray current is caused when electric current flows through other electrically conducting paths than the power lines designed to conduct this current. This can occur as a consequence of many different scenarios, some of which are explored later in this paper.

Levels of stray current vastly below levels capable of inflicting electric shock has been shown capable of inflicting different kinds of health problems for both humans and animals. Since 1984 a number of legal cases has been heard in the USA, where farmers has been awarded damage compensation for the problems inflicted on their livestock by the observed stray current. A certain variation through the years can be observed in the data, but the distinct upwards overall trend is nonetheless worrisome, as the combined amount granted as damage compensation has risen from $36,500 in 1984 to over $14 millions in 2017. Some of this growth might be explained by growing farm sizes, but the successful litigation also points to a considerable increase in problem awareness.

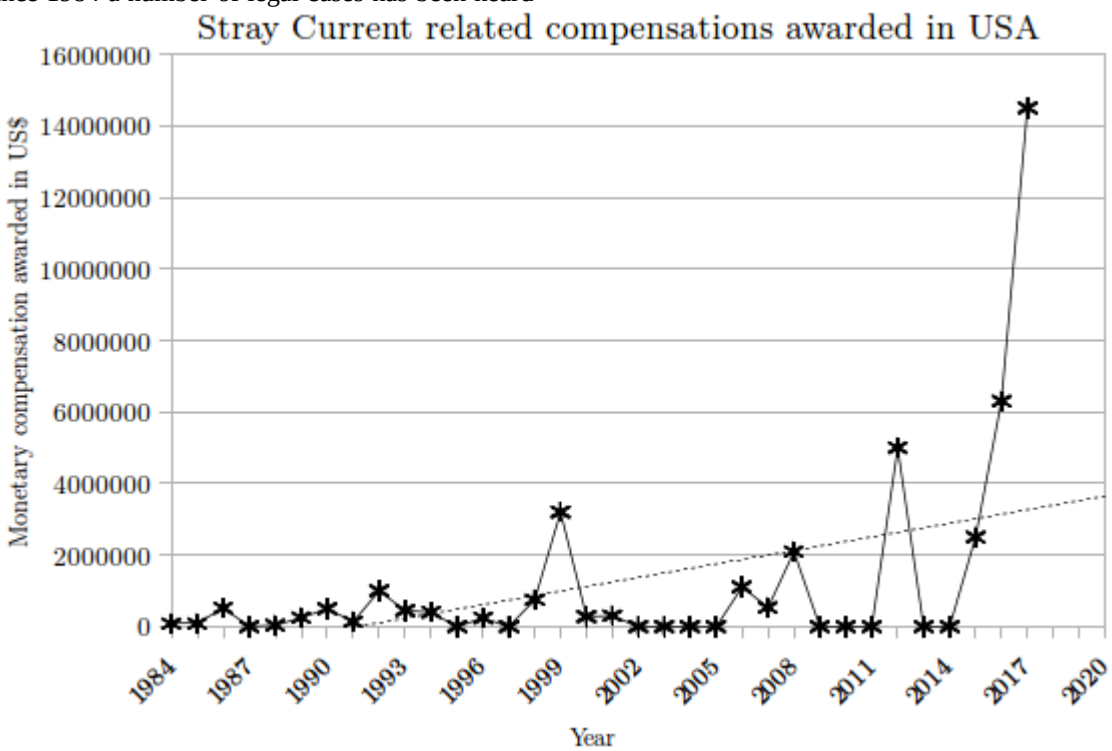

Figure 1: Graphical representation of the evolution of stray current damage compensation awarded to farmers in USA. Data from [1]

2. Literature Survey

Most of the research literature regarding stray current related problems has focused solely on AC-related stray current. At the researched farm both DC and AC-based stray current has been identified, which exacerbates the problem as most of the successful mitigating strategies found in published literature are quite specific to AC-based problems.

From a purely technical perspective AC based problems are well understood and mitigative strategies are well described and well explored [2]. In such scenarios the natural focus is elevated levels of Neutral-to-Earth voltage, which can be caused by either primary systems (the electric utility company's distribution system), secondary systems (the farm's electric system) or a fault developed in any grid-connected electrical apparatus - even at neighbouring farms.

As the star point of the transformer in a modern 3-phase electrical power distribution system is connected to ground some levels of stray current will nearly always be present in areas with centralized electrical power supply, but there are significant disagreement as to which levels of stray current should warrant caution and implementation of mitigating strategies. Contact current down to 50 uA has been correlated to adverse health effects for domestic animals. [3], [4]. Contact currents down to 18 uA has been correlated with increase in cancer incidence for humans [5]. Other research has indicated negative behavioral changes for livestock at stray current levels between 0,5-2mA [6]. Successful mitigation of stray current related problems may lead to productivity increase in the order of 20 to 30 per cent [ibid]

The difference in electrical potential between two measuring points is labeled *voltage* and is measured in volts (V).

The flow of electric charge measured per time unit is labeled *current*.

F*requency* is related to the number of complete cycles pr second and measured in Hertz (Hz). Voltage or current demonstrating a periodic change in polarity viewed in the time domain is labeled Alternating Current (AC). Direct Current (DC) nominally shows no periodic polarity change when viewed in the time domain. Electric power distribution companies in the USA nominally use 60Hz AC as the power frequency, while most European countries use 50Hz AC as the nominal power frequency.

C*ontact Voltage* [7] is the difference in electrical potential between two points which may concurrently be contacted by a human being or an animal. Contact voltage can be measured between any electrically conducting surfaces, between electrically conducting surfaces and the earth and between two points directly connected to earth. Contact voltage is measured in volts (V) and should nominally be close to zero, but measured values up to 10 V is becoming typical. Contact voltage can be either AC, DC or a combination hereof. For AC based contact voltage the sources energizing the system are often related to neutral-to-earth voltages. For DC based contact voltage sources are often related to HVDC (High Voltage Direct Current) power lines, cathodic protection systems for underground pipelines and terragenous rectification of anthropogenic AC by dielectric soil substrates. If such two points are touched simultaneously by either animal or person the electrical path is closed enabling the flow of an electrical current.

Contact current is the current flowing in an human or animal when the electrical path described under 'contact voltage' is closed and thereby enabling the flow of a electrical current.

In contemporary 3-phase electrical distribution systems the star point of the transformer (substation) is labeled the neutral. This is designed as the return path for all phases in the system. The neutral is coupled to ground at all transformer (substation) installations [8]. When a difference in electrical potential can be measured between the grounded neutral conductor of either the primary or secondary electrical power distribution system and the earth it is labeled *Neutral-to-Earth Voltage* (NTEV) [9]. The current flowing is labeled N*eutral-to-Earth Current* (NTEC) or G*round current.* Ground current may flow in all electrically conducting parts of buildings, pipes, barn fixtures or other technical installations. Ground current may be AC or DC, dependent on sources. For AC based electrical power distribution systems such voltage should nominally be AC. Current regulation permits up to 10V NTEV [10].

S*tep voltage* is the difference in electrical potential between two points of contact one step apart [11]. Conversely *step current* is the current flowing between two points of contact one step apart. These measurement can be very important, as the length between the front and back hooves/hoofs of most domesticated animals used as livestock is considerably larger than that of a standard man. Fault scenarios where step voltage reaches acute hazard levels for animals, yet are unnoticed by humans, has been encountered.

S*tray current* is man-made current flowing in the soil of the earth. It is sometimes labeled anthropogenic telluric current or just earth current. It has been documented by Minnesota Electrical Utilities [12] that a large fraction of the return current from the electrical power distribution systems return to the substation through the soil rather than though the neutral conductor.

Depending on sources, and the possibility of rectifying substrates in the soil, such stray current may be either AC or DC. 50 Hz / 60 Hz AC is always anthropogenic (man-made), whereas DC can be both anthropogenic and terragenous (natural).

T*ransients* are short events of sharp non-periodic pulses of either current or voltage, sometimes increasing normal values by a factor 10 in durations normally measured in milliseconds. Origin of such events can be related to initial power draw from starting large electric motors or charging large banks of capacitors.

E*lectric fields* are generated by electric charges. Measurement of such fields is usually done by measuring the forces the electric fields acts upon known electric charges. The electric field is characterized by its direction and its intensity. The direction of the field is the direction a positive charge moves when influenced by the electric field in question. The intensity is measured as the difference in

electrical potential between two points and expressed in volts per meter (V/m). An electric field can be measured around any intended or non-intended electrical transmission line. Static DC electric fields are common in nature, but 50 Hz AC (Europe) or 60Hz AC (USA) electric fields are always anthropogenic.

M*agnetic fields* are generated when an electric current flows in an electric conductor. Magnetic fields can be DC or AC. Sources can be both anthropogenic and terragenous. Detailed analysis of the curve shape seen over the time domain in an oscilloscope and the spectral composition seen in the frequency domain in a spectrum analyzer is usually necessary to determine the origin of the measured magnetic field. Magnetic fields are measured in Tesla (T) and can be measured around any electrically conducting item carrying a electrical current. This includes electrically conducting parts of buildings, pipes, barn fixtures or other technical installations.

When the soil conductivity (σ, S/m) is known (and uniform) the electric field (E, V/m) is related to the current density (j, A/m) by: $j = \sigma \cdot E$ [13]

The electric field and the voltage (U) measured between two earth rods (located d meters apart and angled Θ degrees in relation to j) is related by: $U = d \cdot r \cdot j \cdot cos(\Theta)$ [14]

In the present case low-level anthropogenic DC and AC stray current and magnetic fields exogenous to the specific farms electrical installations has been observed. Such fields may, even in situations where each field by itself would not cause biological reactions, cause measurable biological reactions when they act in combination [15], [16]. Further exploration of this phenomenon has revealed that the biological action is related to signal transduction involving calcium ions [17]

3. Problem Definition

The purpose of this study is to provide a overview of the results from the two-year research campaign undertaken at the farm “Hovmarksgaard” located in northern part of Denmark. The animal husbandry practice, pig feed formulation as well as general animal handling has been thoroughly examined by licensed veterinarians without pinpointing any probable cause for the productivity loss. The scope of this study is therefore solely focused on the technical investigations of the stray current problem.

4. Methodology

a) Safeguarding against confounder's
To safeguard against possible confounder's it should be ensured, at the very beginning of any research project, that the problems purported to be caused by stray current is not, in fact, caused by substandard husbandry, substandard electrical installations or other similar malpractice.

b) Initial Survey
The purpose of an initial survey of the complete compound of buildings, barns, and other technical installations is to ensure that 1) stray current actually is present and 2) subsequent measurements are taken at points representative of the "worst case" encountered at the specific farm.

c) Endogenous or exogenous etiology
The starting point for any deeper stray current related investigation is to determine whether the observed stray current is endogenous or exogenous to the electrical installations at the investigated site. In practical implementation such investigation is performed by making a set of measurements with electrical power switched on and off. If the problems persists when electrical power to the investigated site is turned off the observed stray current is documented to be exogenous in origin with respect to the electrical installations at the investigated site.

d) Descriptive measurements
By measuring voltage potential and related electrical currents between different electrical conducting parts of buildings, water pipes, barn equipment and earth rods the extent of the problem can be measured and documented. Concurrent measurement of ELF magnetic fields in the vicinity of any electrical conductive material is usually a very fast way of initial problem detection, as any current propagating in an electrical conductor will produce a magnetic field with a frequency corresponding to the electrical current. It should be noted whether the observed voltage potential and electrical currents are DC or AC

e) Gradients and Polarity
By measuring polarity, voltage gradients and electrical currents between ground rods in a specific geometric array it is possible to roughly determine the direction of stray current propagated through conductive soil layers. Similarly can polarity measurements between other electrical conductive points reveal the direction of current flow.

f) Time-dependent variations
Data logging equipment for measuring voltage potential, electrical current and magnetic fields at relevant points can be utilized for pinpointing the exact time of recurrent incidents related to stray current.

g) Electrical conductive strata in soil
During the course of the research campaign it was discovered that the observed stray current is conducted through quite narrow and specific paths related to strata of biogenic carbon deposited after sea-level rises during the warming period at the end of the Weichselian glaciation and start of the Holocene. The extent of these stray-current propagating soil strata can be readily investigated and mapped, as the electrical current produces a measurable magnetic field disturbance.

h) Local significant magnetotelluric abnormalities
Underground strata of different substrates may confer a measurable effect on both man made and natural terragenous magnetotelluric currents and magnetic fields at the specific site. Such variations should be investigated, both to enable reliable distinguishment between terragenous and anthropogenic fields and to make further research into plausible combination effects of natural and man-made telluric currents possible

i) Investigation of potential sources
Measurement logs from the data logging equipment can be utilized to investigate possible correlation between problem magnitude and utilization scheme of relevant electrical grid connected implements in the nearby area. Any hypothesis regarding a specific piece of electrical infrastructures possible involvement in the problem can be confirmed or rejected by noting the similarity or dissimilarity between usage patterns and data logged measurements.

j) Effects on livestock
Effects on livestock can be measured in two different ways. The affected livestock can be tested for relevant stress biomarkers or one can attempt statistical correlation between data logged measurements and the growth curve for the affected livestock

k)Mitigative strategies
Different mitigative strategies can be employed. A number of such strategies has proved successful, while others experiments actually worsened the experienced problems.

l) Effects on water
Earlier research (described and referenced in more detail in section V-L) has suggested the possibility that stray current may affect specific parameters for water when analyzed in a vector network analyzer. Ethical approval: The conducted research is not related to either human or animals use.

5. Results & Discussion

a) Safeguarding against confounder's
Several independent veterinarians and electrical engineers has surveyed the site and concluded that the problems encountered at the site are not related to either substandard animal husbandry or substandard electrical installations.

b) Initial Survey
The initial survey demonstrated both AC and DC based stray currents, AC magnetic fields and AC electrical fields present not only in the buildings but also in nearby fields. Contact voltages in extreme cases exceeding 10 volts has been measured between public water supply pipeline and nearby ground.

c) Endogenous or exogenous etiology
No significant difference in measured parameters exist when electric power to the farm is switched ON or OFF. The subsequent measurements confirm this initial assessment, as indicated below.

d) Descriptive measurements

***Contact voltage / contact current*:**
Both contact voltage and contact current is present everywhere on the farm. As a measuring points for continuous measurements the stopcock of the public water supply has been selected, as the values observed here are representative of the values observed generally at the site. Measurements has been data logged for more than a year - averages are noted in the table below. This measurement is repeated with electrical power turned off - to ensure that the problem is, indeed, exogenous to the farms own installations.

Table 1: Contact voltage / contact current

Contact voltage / Contact current Stopcock at public water supply			
Power ON			
AC V	0	DC V	1.54
AC uA	0	DC mA	1.58
Power OFF			
AC V	0	DC V	1.59
AC uA	0	DC mA	1.63

The considerable current carried through the water pipe propagated to all connected water bowls/pipes in the building complex. It is quite remarkable that the contact voltage/current is exclusively DC-based, which is rather uncommon.

Neutral-to-Earth Voltage (NTEV) / Ground current
This parameter is measured between neutral and earth. The measurement is performed with electrical power to the farm both ON and OFF.

Table 2: Neutral to Earth Voltage / Current

Neutral-to-Earth Voltage (NTEV) / Ground current Power distribution panel			
Power ON			
AC V	0.172	DC V	0.347
AC uA	72	DC uA	301
Power OFF			
AC V	0.05	DC V	0.331
AC uA	50	DC uA	267

As expected, per initial analysis performed by electrical engineers, the electrical installations on-site presents a quite low NTEV emission. The measurements furthermore documents that the observed DC-based component is exogenous to the farm.

Step voltage / step current
Step voltage/current is measured water bowl and electrically conductive slatted floor panels at the pigs hind hooves. The measurement is performed with electrical power to the farm both ON and OFF.

Table 3: Step voltage / step current

Step Voltage / Step Current Water bowl and floor panel			
Power ON			
AC V	0	DC V	0.1
AC uA	0	DC uA	20
Power OFF			
AC V	0	DC V	0.132
AC uA	0	DC uA	123

No AC voltage or current was encountered, although the DC-based component is present both when electrical power to the farm is turned ON and OFF. The level of DC current actually rises as the electrical power to the farm is turned OFF.

Stray current

This is measured between two earth rods located east/west to the farm. The earth rods are solely for measurement purposes and are therefore only connected to the measuring equipment. The measurement is performed with electrical power to the farm both ON and OFF.

Table 4: Stray current

Stray Current Earth Rods			
Power ON			
AC V	0.049	DC V	0.059
AC uA	0	DC uA	30
Power OFF			
AC V	0	DC V	0.049
AC uA	0	DC uA	23

Certain levels of DC voltage potential are naturally occurring, but any DC potential difference between nearby earth rods with associated electrical current measurable above a few uA has anthropogenic origin.

Biological systems both generates and senses DC voltages and DC currents. These naturally occurring electrical signals are affected by DC exogenous to the human body [18]. It is further known that some biological tissue can act as a natural rectifier, enabling measurement of electromagnetic exposure by elevated DC potential [19].

Electric fields

The ELF electric fields are measured both floating (without reference to earth potential) and referenced to earth potential.

Table 5: AC ELF electric field intensity

Electric field intensity			
Power ON		Power OFF	
Floating, potential free			
Field	19 V/m	Field	20 V/m
Barn	17 V/m	Barn	13 V/m
Referenced to earth potential			
Field	17 V/m	Field	17 V/m
Barn	22 V/m	Barn	12 V/m

No significant changes was observed when the electrical power was turned OFF. Note the quite large level of AC ELF electric field in the field - such levels should not be present in the middle of a field several hundred meters from nearest AC installation.

Magnetic fields

Magnetic fields was measured for both DC and AC - and in all 3 directions.

Table 6: AC and DC Magnetic field intensity

Magnetic field intensity (mG) Power ON				
	Barn		Field	
	AC	DC	AC	DC
X (north)	32.6	98	20.4	137
Y (east)	1.7	41.6	5.34	110
Z (down)	WF	481	WF	529
Power OFF				
	Barn		Field	
	AC	DC	AC	DC
X (north)	34.4	122	18.9	109
Y (east)	1.61	72.1	7	83.2
Z (down)	WF	475	WF	532

(WF) denotes "wildly fluctuating", as values between 4 mG and 1100 mG was recorded. The waveform is sharply rectangular with a quasi-periodic frequency around 275mHz.

a) Gradients and Polarity

By measuring relevant parameters in all cardinal directions from a center point both polarity and gradients for surface stray current can be analyzed.

Table 7: Gradients and polarity for surface stray current

	North 129 mV DC 38 uA DC 0.0 mV AC 0.0 uA AC 567 Ω	
107 mV DC 34 uA DC West 0.0 mV AC 0.0 uA AC Ω 641	Center	152 mV DC 48 uA DC 0.0 mV AC East 0.0 uA AC 568 Ω
	104 mV DC 54 uA DC 0.0 mV AC 0.0 uA AC 560 Ω South	

The measurements presented in table 7 were done at the same site as the field-based magnetic field measurements. No AC current can be measured from earth rods driven 1 meter into the ground, but a quite considerable AC magnetic field can never-the-less be measured at the same location. The current flow energizing the AC magnetic field must therefore be located quite deep in the soil.

b) Time-dependent variations

Data from last two months indicates no periodic fluctuation for either contact voltage or contact current measured from public water supply stopcock to ground, although several unexplained transients are present in the dataset.

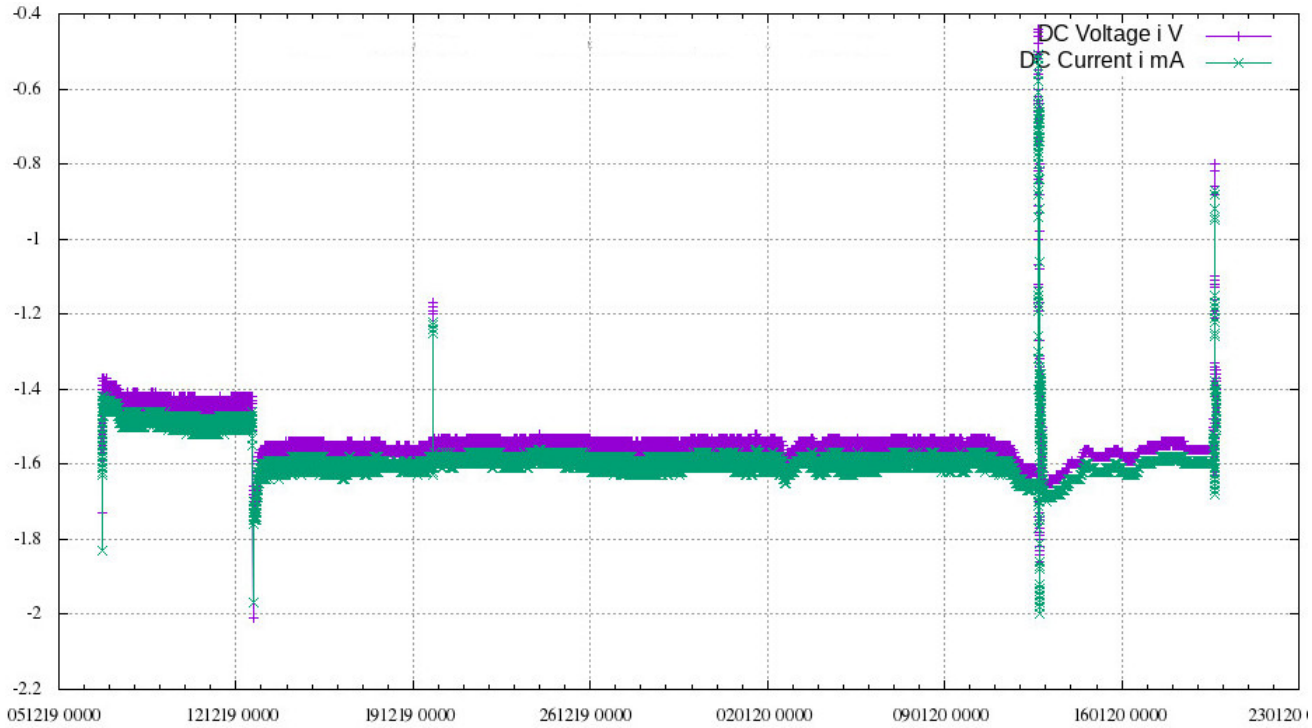

Figure 2: Contact voltage and contact current measurements for the time between 7. December 2019 and 20. January 2020

c) Electrical conductive strata in soil

During the investigation the farmer and his family has insisted that the stray current propagates through relatively confined paths through the fields. This hypothesis was checked using a Hall-detector (with a sensitivity down to about 100pT), and it was discovered that a magnetic field with a peculiar waveform is present everywhere on the farm, but presents the greatest amplitude along the "paths" suggested by the farmer. The magnetic field is Z-polarized, meaning that the field lines points upwards from the ground, as would be the case for a magnetic field created from a current flow in a electrical conductive layer several meters underground.

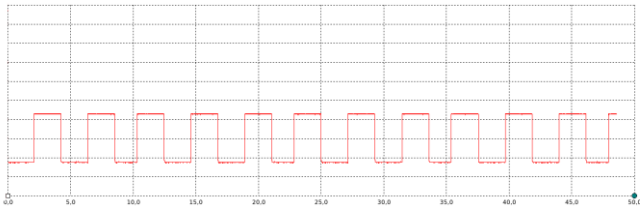

Figure 3: Waveform for the Z-polarized magnetic field encountered everywhere on the farm. Frequency ~0.275mHz

Several other farmers from stray-current affected farms has likewise insisted on the existence of such subterranean paths for stray current, but as far as known, this is the first published measurement documenting the presence of such subterranean conducting paths for stray current.

d) Local significant magnetotelluric abnormalities

One hypothesis regarding the origin of such sub-soil conducting paths for stray current could be geological deposits in several meters depth consisting of either electrical conductive carbon layers or electrical conductive layers of ocher. Samples from well drilling conducted in the area supports this hypothesis[20], as both layers of carbon and layers of ocher are present in the samples.

Figure 4: Ocher deposits in excavated soil from 2 meters depth

By excavating a trench a larger sample of the electrically conducting layers of carbon and ocher was acquired. Electrical resistivity for the samples was, with great difficulty regarding the actual measurement, measured to ~4.3×10^{-6} Ω•m for the ocher layer and ~2.7×10^{-3} Ω•m for the carbon deposits. These measurements supports the hypothesis that electrically conductive layers several meters underground can carry significant current flow.

The magnetic field measured from these stray current conducting paths has been measured to exceed 1100mG in short peaks. Such levels could conceivably confer a biological reaction by themselves, but other factors may also be present, as the extremely conductive layers produces a situation where stray current from sources far away readily can me measured. Many of these anthropogenic disturbances reaches levels several orders of magnitude larger than natural levels, which creates a situation where the

magnetotelluric environment life has evolved in is drastically changed over a relatively short time span.

All life on earth has evolved in the presence of the Schumann Resonance at 7.83 Hz. This frequency is the resonance frequency for standing waves contained in the resonance chamber formed by the earths electrically conducting surface and the ionized layers in the ionosphere. The resonance is energized by the roughly 3000 lightning discharges occurring in the earths atmosphere on a given day.

The Schumann Resonance has magnetic field strength at around 1 pT. The extremely low frequency ensures that all parts of the earth are in the reactive part of the near-field, making reception of this frequency possible everywhere on earth, providing measurement equipment with suitable sensitivity.

Modern research has shown that geomagnetic fluctuation represented by the Schumann Resonance can be correlated with changes in patterns of EEG in healthy test subjects [21]. It has even been suggested that the Schumann Resonance acts as the fundamental frequency for brain development and normal function[22] and further demonstrated that the brain of man actually can sense variations in the Schumann Resonance and that frequencies of neural oscillations are synchronized by means of the Schumann Resonance [23]. Changes in the Schumann Resonance has furthermore been documented to affect blood pressure in humans [24]. A correlation between solar activity and melatonine has been indicated [25], where it is suggested that solar activity acts upon the Schumann Resonance, and thereby making it possible for the human biologic system to actually sense solar activity variations.

As it is seen in figures 6 and 7 the intensities of man-made AC fields are vastly greater than the intensities at which the Schumann Resonances are measured. Even when these man-made fields, by themselves, are at a sufficiently low intensity to be of biological non-significance a biological reaction can be expected when such man-made fields disturb the biological systems synchronization against the Schumann Resonance mentioned in above paragraph. There may very well be further couplings between geomagnetic parameters and biological systems yet unknown [26], but it is worth noting that WHO/IARC categorized ELF electric / magnetic / electromagnetic fields as 2B carcinogen already back in 2002.

e) Investigation of potential sources

Several potential nearby sources has been thoroughly investigated. A nearby HVDC-line was initially suspected to be the cause of the observed DC stray current, but as the problems persisted when the HVDC-line was shut down for planned maintenance that hypothesis was abandoned.

A nearby wind turbine farm has been hypothesized to causally affect the DC-based earth potential rise observed in the area. Measurements documenting the wind turbines as point-sources for DC-based leak-current to earth has been made, but even on the basis of several months of logged measurements it has proved difficult to produce any significant correlation between wind speed and problem manifestation. Research in this direction continues, with the purpose of finally either confirming or rejecting that hypothesis.

As the earth itself has been made an integral part of the electrical distribution system it should be observed that there exist a distinct possibility that the observed stray current is caused by non-fault (normal) operation of the earth-connected electrical distribution system, as it has been proved in earlier research that 65 to 75 percent of the return current propagates through earth and not via cables [27], [28], [29].

Another hypothesis yet to be confirmed or rejected is the possibility of cable faults energizing the electrically conductive layers in the soil. Such cable faults are relatively common occurrence.

Faults developed on underground electrical cables due to scarring by excavators or lightning strikes can go undetected for several years, even though the current dissipated through the earth is considerable.

Figure 5: Remnants of a damaged 10KV cable. The above cable was operational and carrying nominal voltage/current in the depicted state until the fault was discovered by unrelated excavation work. The "lump" on the cable remnants is a piece of granite stone melted around the cable.

f)Effects on livestock

Several licensed veterinarians and pig feed specialists has been involved in the investigation and concluded that the farm is suffering a significant production loss compared to other farms of equal well-managed operation.

g) Mitigative strategies

One of the main strategies for mitigating stray current related problems are equipotential bonding of all electrical conductive surfaces at the farm. This strategy is primarily developed to mitigate endogenous AC-based problems - and may very well have some merit in some situations, although research in this subject quite clearly demonstrates that equipotential bonding does not improve productivity in farms affected by exogenous stray current [30]. One possible reason for the contradictory aspects regarding equipotential bonding is the possibility of stray-current carrying soil layers several meters underground. In such cases any work undertaken to provide fully equipotential bonding could be confirmed by resulting measurements to be really effective, although the farmer experiences that the problem persists. Some research actually indicates considerable increase in stray current related problems after equipotential bonding has been implemented [31]. This observation is similar to empirical evidence from the on-going investigation. There

are, however, some evidence that disconnecting all ground connections may lead to permanent problem solution and productivity increase [32], although such drastic maneuvers should be carefully considered in relation to the increased risk of acute electric shock.

It is currently planned to conduct further research into methods of dissipating the stray current before it reaches the farm. The results, whether positive or negative, will be reported at a later time, however, some research from USA [33] points to the possibility of such mitigative maneuvers providing lasting productivity increase at affected farms.

The only mitigative strategy employed in the current investigation with lasting positive effects was the drilling of a private water well and subsequent physical disconnection from the public water supply pipelines. The contact current present at the public water supply is not present in the private well.

h) Effects on water

Earlier published results from this investigation [34] indicated that the impedance characteristic for water which has flown along stray current exhibit significantly changed pattern distinguished from water unaffected from stray current. To test the preliminary results published earlier a 200 meters 15mm flexible water pipe was positioned along several of the underground conducting paths identified per magnetometer measurements. Water was sampled from both the private water well supplying the water pipe and from the end termination of the water pipe. The water samples was tested using the same equipment and methodology as described in the pilot study [ibid].

This experiment confirmed the initial hypothesis formulated on the basis of the earlier measurements, that stray current, by a yet unexplained mechanism, is able to affect electrical parameters for water.

Both samples were subjected to 10 full scans each with a 10000 point scan between 10MHz and 4 GHz. The results was averaged and further subjected to statistical analysis using a two-tailed paired t-test.

Table 8: T-Test (paired, two-tailed) p-values

Parameter	S_{21}	S_{12}
Impedance	0,0001 (*)	0,0062 (*)

Analysis of water impedance characteristics by the means of a vector network analyzer. (*) denotes differences significant at α=0.05

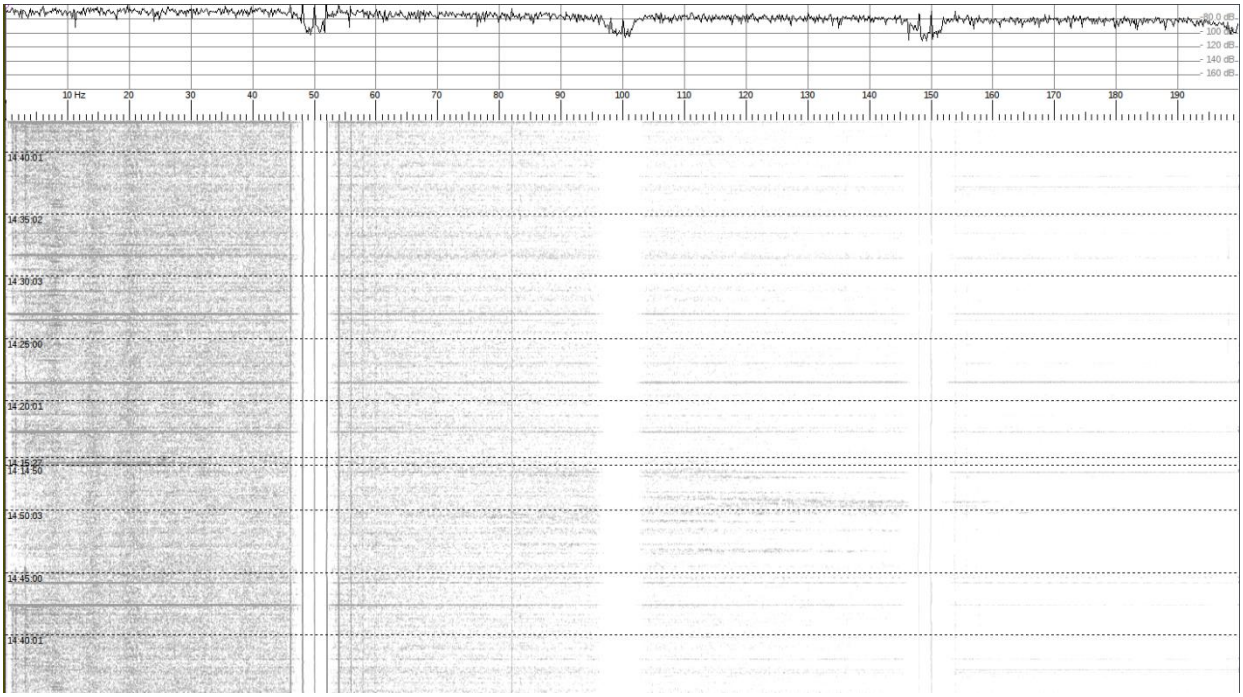

Figure 6: Extremely Low Frequency magnetic field spectrum analysis for the frequency range from 0 Hz to 200 Hz. The 3 first Schumann Resonances are clearly visible, while the next two are more faintly visible. 50 Hz (power distribution frequency in Denmark) and 100Hz (second harmonic) are blocked by a selective frequency filter, while 60 Hz (power distribution frequency in USA) is faintly visible next to the filter artifacts. The signal at 82Hz is the Russian Submarine communication signal ZEVS. Third harmonic is visible at 150Hz. Signals with sharp edges are generally man-made, whereas signal with more blurred edges generally has a natural origin

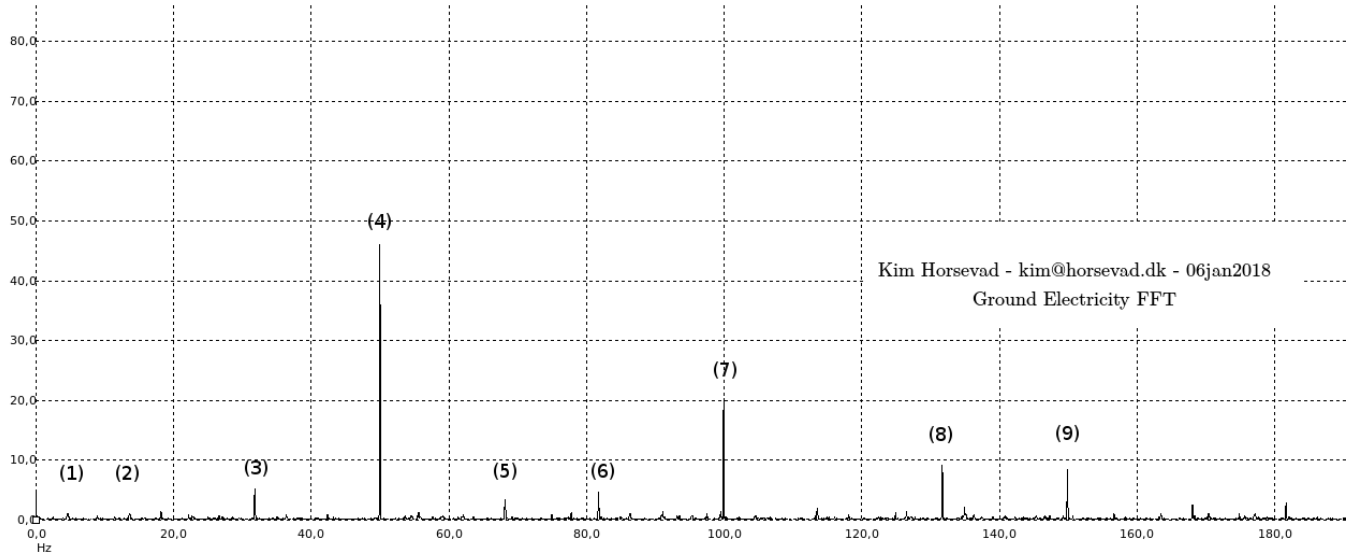

Figure 7: Stray Current Extremely Low Frequency spectrum analysis for the frequency range from 0 Hz to 150 Hz. The measurements are made upon voltage potential difference between two earth rods. (1): Possibly primary Schumann Resonance at 7,8 Hz. (2): 16,7 Hz. 1/3 of power distribution frequency in Europe. Used for electrified railroads, but might also be produced from switching circuits for large electric motors. (3): Unknown. (4): 50 Hz power distribution frequency. Clearly dominant even in fields several hundred meters from nearest AC installation. (5) : Unknown. (6): 82Hz - The Russian Submarine communication signal ZEVS (7): 100 Hz - Second harmonic of the power frequency. (8): Unknown. (9): 150Hz - Third harmonic of power distribution frequency. Note the differences in intensity between the faintly visible natural signal and the man-made signals

6. Conclusion

Several important questions are still unanswered, and more questions has arisen in the course of the two-year research campaign, but a number of the research objectives has been achieved.

The elevated DC potential is not directly caused by the nearby HVDC-line, as the problems persisted while the HVDC-line was off-line for planned maintenance.

As far as known this is the first published study confirming the existence of specific paths of subterranean electrically conductive layers originating from ocher and carbon deposits capable of propagating stray current. The measurements shows Z-polarized AC electric fields and AC magnetic fields present at the surface, but no AC are present in the surface when voltage potential is measured via earth rods. This means that the AC current flow must be flowing deeper in the ground than the earth rod reaches.

Combining the fact that no AC is present when step voltages are measured in the barn, and the fact that the contact voltage/current, step voltage/current and stray current encountered everywhere (except the public water supply, which is now disconnected) presents quite low levels of both voltage and current, supports a hypothesis that the adverse biological reactions encountered at the farm are mediated primarily by either very low levels of DC or the relatively high AC electric and magnetic fields originating from current-carrying subterranean conductive strata.

As far as known this is furthermore the first published study confirming changes in water impedance characteristic when exposed to stray current.

It should be noted, though, that much of the mechanisms for bioreactivity from either stray current itself, stray current related electric or magnetic fields, or stray current affected water are still only indicated and not fully researched. Further research into these subjects is deeply needed.

7. Future Scope

It is not known whether the observed adverse health effects emanates from the surface DC, subterranean AC, associated electric fields or associated magnetic fields, stray current affected water or any combination of above parameters.

It is not known by exact which mechanism stray current is able to affect water impedance characteristics. Further research is needed. One approach would be to model the situation under controlled laboratory conditions and thereby sequentially investigate which parameters affect water in which ways.

The origin of the DC stray current encountered at the surface is not known.

The origin of the AC stray current energizing the subterranean stray current conducting paths is not known.

The affected farmers are deeply in need of well-developed and well-functioning mitigative strategies.

The contradictory situation regarding equipotential bonding should be resolved. With further research it should be possible to develop a protocol for relevant measurements for determining whether at given stray current related problem could be resolved by equipotential bonding or such efforts will actually worsen the problem. It is hypothesized that the viability of equipotential bonding as a mitigative strategy

against stray current largely depends on the electrical conductivity of the subterranean layers

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