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Health Hazard Investigation of a Transformer Station

Wellington Dufferin Guelph Public Health

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Appendices

1 Introduction

In July 2012, the Ontario Ministry of the Environment (MOE) requested the assistance of Wellington-Dufferin-Guelph Public Health (WDGPH) in following up on health complaints of a group of residents in the Wellington-Dufferin-Guelph area in relation to a wind turbine sourced step-up transformer located in proximity to their homes. In response to this request, WDGPH initiated an investigation as per the "Identification, Investigation and Management of Health Hazards Protocol" in the Ontario Public Health Standards.

The purpose and scope of the investigation was to collect and review existing information including all available test results to determine if a human health hazard exists and to make recommendations based on the currently available peer reviewed evidence to date. WDGPH proceeded with the investigation without prejudice and is responsible for the recommendations contained within the report.

2 Background

Ontario was the first jurisdiction in North America to legislate the phasing out of coal fired electricity. The Green Energy Act, 2009, was created to encourage and expand renewable energy sources within the province of Ontario. As a part of this new provincial strategy, several wind turbine developments have been established throughout Ontario. Complaints of residents living in the vicinity of such developments are not uncommon, and various agencies and Ministries have been involved in the follow-up and investigation of such complaints.

In 2006, in southwestern Ontario, one such wind-turbine development went into operation in two phases. The first phase of the operation (referred to hereafter as Phase I) began in March 2006 and included 45 turbines and the first of two step-up transformers, hereafter referred to as Transformer A, at a transformer station located approximately 7 km away from the wind turbines. In March 2006, shortly after Phase I went into operation, the MOE began to receive complaints from residents living near the transformer station (containing Transformer A) associated with the operation. In September 2006, the MOE determined that Transformer A did not meet the applicable noise limits. The MOE directed the owners of the wind turbine development to implement noise reduction measures to address this issue. In December 2006, the owner of the transformer station erected noise walls.

In 2008, transformer A was replaced with a different make and model, hereafter referred to as Transformer B. Also in 2008, a second transformer was installed at the transformer station. This second transformer was the same make and model as transformer B, and is hereafter referred to as Transformer C.

The second phase (Phase II) went into operation in the Fall of 2008, and included an additional 88 wind turbines and the second transformer (Transformer C), so that the completed development contained 133 wind turbines and a transformer station containing two step-up transformers (Transformers B and C).

In 2009, Ontario Regulation (O. Reg.) 359/09 came into effect. This regulation required transformer stations associated with renewable energy generation facilities to be set back greater than 1,000 m from the nearest noise receptor, or 500 m if an acoustic barrier is installed. The set back does not apply if the applicant prepares noise study reports in accordance with the regulation. The four residences closest to the transformer station containing Transformers B and C were located between 360 m and 490 m from the station, and the complaints received by the MOE in relation to this transformer were all from families in three of these four homes. The fourth residence was a participating receptor (receiving financial compensation from the owner of the transformer station) and, to our knowledge, never filed a complaint to the MOE. In accordance with the regulation, the owner of the wind turbine development completed the necessary noise study reports over the course of 2007, 2008, and 2009. In addition, the local MOE District office conducted inspections and field testing to assess noise levels. From the results of these tests, the MOE determined the transformer station to be in compliance with required noise levels under MOE regulations, and in accordance with O. Reg. 359/09. However, following these assessments, the MOE continued to receive complaints from the residents living near the transformer station.

Complaints received by the MOE included mention of symptoms being experienced by the residents living in proximity to the transformer station, that the residents believed were a result of exposure to the transformer site. Symptoms were reported to be so severe that in 2009, the residents in two of the three homes involved in the original complaint to the MOE left their homes. Residents attempted to find the reason for these symptoms by requesting various testing of their residences.

In the spring of 2012, the MOE approached WDGPH to request assistance with the investigation and follow-up of complaints received from the residents, and to answer questions related to the health effects of electrical phenomena, including electric and magnetic fields, dirty electricity and stray voltage. To answer the question of health effects associated with electrical phenomena, WDGPH initiated discussions with the MOE and with residents to gather more information, and requested an expert review of current literature on the health effects of exposure to electrical phenomena associated with transformers. The purpose was to collect and understand existing peer reviewed evidence to inform conclusions and recommendations in addressing the concerns raised.

A summarized timeline of events related to the transformer station can be found in Appendix A.

3 Methods

In the spring of 2012, Wellington-Dufferin-Guelph Public Health (WDGPH) was contacted by the Ontario Ministry of the Environment (MOE) with questions related to the human health effects of electrical phenomena and for assistance in following up on health complaints of residents living in proximity to a wind turbine sourced transformer station.

Because of the low number of individuals living close to the transformer and the variety of symptoms reported by the residents, the use of an epidemiological (statistical) study to investigate the complaints of the residents was ruled out by WDGPH. The small numbers of individuals reported to be exposed to effects of the transformer station would have resulted in a study with very low statistical power to detect any effect of exposure, or lack thereof, and any such study would have been made more difficult by the range of symptoms reported by the residents.

As per item 4 of the Identification, Investigation and Management of Health Hazards Protocol in the Ontario Public Health Standards (OPHS), the health unit collected information to:

(i) assess the possible hazards to determine potential health effects;
(ii) assess the possible exposures by identifying sources, exposure routes, and potential levels of exposures (when testing information was available); and
(iii) characterize the level of risk by comparing to available standards where they existed.

To this end, WDGPH took the following actions to follow-up on the complaints of the residents.

3.1 Methods: Gathering of Background Information

Following the referral of this case to WDGPH in July 2012, Public Health met with staff of the MOE in August, 2012. The purpose of this meeting was to review the nature of the complaints filed by the residents to the MOE, and to gather information on the background of the issue, including the events summarized under 'Background' above. Information gathered included the history of the complaints, the description of the wind turbine development and location of the homes of the residents who had filed complaints, in relation to the location of the turbines and transformers, and the testing done at the various sites up to that point in time.

In addition to meeting with the MOE, WDGPH was contacted by the residents of two of the four homes nearest to the transformer station in the summer and fall of 2012. In October 2012, WDGPH met in person with the two households individually, in order to gather additional information on symptoms experienced by the residents, and on testing done at the residents' homes up to that point in time. Reports of testing completed were only available for one home and these results were provided to WDGPH by the residents.

Public Health also consulted with an Electrical Engineering Professor at an Ontario university, and requested the assistance of that professor in understanding and reviewing some of the field testing results.

3.2 Methods: Literature Review

During the preliminary stages of information gathering, it was noted that the transformers installed to power the wind turbine project were large (two 100 MVA transformers); and that transformers produce low frequency sound. Consequently, it was decided a literature review needed to be conducted not only for the nature and health effects of certain electrical phenomena, but also for the health effects of low-frequency noise (LFN). These literature reviews were conducted by the Environmental and Occupational

Health Team at Public Health Ontario (PHO) at the request of WDGPH. To provide Public Health with the information necessary to make an objective assessment of the matter at hand, PHO was asked to review the published literature for information on:

- sources and potential exposure routes for electrical phenomena and LFN
- any recognized health effects from exposure to electrical phenomena or LFN
- any existing standards (recommended or mandatory) for electrical phenomena or LFN

3.3 Methods: Review of Available Testing Results

The following tests (Table 1) were performed at the homes of the residents by other organizations and individuals. All testing (except for the December 2012 testing) was conducted prior to the referral of this matter to WDGPH. The December 2012 testing that occurred after WDGPH's involvement was carried out independently of the health unit's investigation.

An overview of the findings of these tests is presented in results section 4.3 below.

Table 1: Summary of testing carried out at the homes of residents involved in the complaints up to and including December 2012

Nature of test	Date(s) of Test(s)	Site of Test	Test Performed by:
Magnetic field	April 2007	One residence	Hydro One
Dirty electricity	April 2009	One residence (same as above)	Private consultant
Neutral to earth and stray voltage	Early and late May 2009	One residence (same as above)	Hydro One
	October 2010	One residence (same as above)	Hydro One
Neutral to earth voltage	March-April 2012 (10 days)	One residence (same as above)	Private consultant
	December 2012	One residence (same as above)	Hydro One
Acoustical audits	Multiple testing events over 2007, 2008, 2009	All three residences involved in the original complaint to the MOE	Engineering consulting firm

4 Results

4.1 Results: Gathering of Background Information

In addition to information on the history of the issue (summarized in section 2) and the nature and results of testing performed at one of their homes (summarized in Table 1), residents from the two homes involved in the complaint at the start of the WDGPH review provided Public Health with information on the symptoms they had been experiencing since the transformer station went into operation in March 2006. These symptoms were given as the reason for the complaints filed by the residents with the MOE. Symptoms were described by the residents to be initially less severe, but to have become noticeably more severe in late 2008 and early 2009 after Phase II of the development went into operation with the installation of the two transformers B and C. Self-reported symptoms most commonly cited by the residents during conversations with the health unit were headaches, difficulty sleeping, ringing in the ears, and the sensation of internal vibrations. In addition to reporting sensing internal vibrations, residents also reported sensations that their homes were shaking or vibrating.

In April 2009, as a result of the symptoms experienced, the residents from one of the three homes involved in the original complaint to the MOE decided to leave their property and move in with family living in a nearby town, returning to their property twice daily after the move to tend to their animals. These residents noted that they began to feel increasingly better once they began spending nights away from their home, but that symptoms returned when they visited their property. These residents attributed feeling better in part to the fact that they were able to get much better sleep when staying with the nearby family. The resident of another of the homes, who did not move away but remained at their property near the transformer station, reported severe sleep disruption that adversely affected their ability to perform their job and resulted in a decision to retire early.

Residents also reported that for two days in 2011, they noticed that their homes returned to what one household described as a “quiet state”. An inquiry by a resident to Hydro One about these two days revealed that the transformer station near the homes had been out of service for a short period that included those two days.

Residents from the two households that had contacted WDGPH provided letters from their respective family physicians, which corroborated the symptoms reported by the residents themselves. One of the two physicians emphasized that his patients living near the transformer station had experienced a significant degree of sleep deprivation and notes that the sleep deprivation had left patients with severe anxiety, mental and physical exhaustion and an inability to focus and cope with stress.

Residents from both homes reported that they had been keeping animals (both pets and livestock) on their properties at the time the transformer station and turbines went into operation. Residents from both homes reported that they had noticed changes in the health and behaviour of their animals. Changes reported by the residents were:

- Infertility (goats): corroborated by a letter from a veterinarian in 2011; onset unknown; management of goat herd described as excellent
- “Undiagnosed reproductive failure” (cattle): corroborated by a letter from a veterinarian in 2011; onset approximately 2009; no known change in management
- Refusal to sleep indoors; preference for sleeping outdoors: dog; onset reported as February 2009
- Uncontrollable shaking for extended periods: dog; onset reported as April 2009
- Eye infections: horses; onset unknown
- ‘Very panicked and easily spooked’: horses; onset unknown

4.2 Results: Literature Review

Public Health Ontario (PHO) conducted a literature review in the fall of 2012 on specific electrical phenomena and low frequency noise. This analysis provided objective peer-reviewed current background information to complete an objective assessment of the complaints filed with the MOE regarding the health risks to residents living close to the transformer station. The topics reviewed included electric and magnetic fields, dirty electricity (or high frequency voltage transients [HFVT]), stray voltage and low-frequency noise (LFN).

A summary of the findings of the literature review is shown in Table 2, and more detailed results are available in Appendices B1 through B4.

Table 2: Summary of the findings of the literature reviews conducted by Public Health Ontario

Noise/ Electrical Phenomenon	Definition/explanation of Noise/Phenomenon	Potential Exposure Routes	Existing Standards or Guidelines	Recognized Health Effects of Exposure	Comments
Extremely Low Frequency Electric and Magnetic Fields (EMF) from 60 Hz Electrical Sources	Generated by any source where electricity is being used or distributed (e.g. power lines, home wiring, and appliances; radiates outward from the source. The voltage component of electricity produces *electric fields, whereas* the flow component of electricity (current) produces *magnetic fields*. The EMFs produced have the same frequency as the electric source producing them. In Canada, electrical operates at a frequency of 60 Hz. Fields with frequencies of less than 300 Hz (such as 60 Hz fields) are referred to as *extremely low frequency EMFs*.	Electric fields are shielded by most materials, including wood and metal, while magnetic fields can pass through most objects. People are exposed to extremely low frequency magnetic and electric fields when they are in proximity to sources of electricity (power lines, home wiring, appliances, etc.). The electric and magnetic field strengths are highest at the source, and diminish quickly with distance as one moves away from the source. Average exposures in residences range around 1-3 milliGauss (mG).	Guidelines exist, produced by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and the Institute of Electrical and Electronics Engineers (IEEE). These exist to protect against known effects of short-term exposure to high levels of extremely low frequency EMF.	Extremely low frequency magnetic fields have been classified by the International Agency for Research on Cancer (IARC) as "possibly carcinogenic", defined as having limited evidence of carcinogenicity in humans and less than sufficient evidence of carcinogenicity in animals. The overall body of evidence suggests that exposure to extremely low frequency EMFs at levels typically experienced by the public poses low risk to human health.	Typical field strengths encountered in residences, near transmission lines, appliances and other sources are provided in Appendix B1. Transformer stations will generate EMF. Typically, beyond a transformer fence the strength of fields produced by a transformer station are comparable to background levels experienced away from transformers. For more information, see Appendix B1.

Noise/ Electrical Phenomenon	Definition/explanation of Noise/Phenomenon	Potential Exposure Routes	Existing Standards or Guidelines	Recognized Health Effects of Exposure	Comments
Dirty electricity (High Frequency Voltage Transients (HFVTs))	Dirty electricity refers to distortion in an electrical signal that is produced by interruptions in the electrical current flow from connected electrical equipment or from events such as lightning strikes, short circuits and switching on home appliances. This can cause voltage transients: short bursts or surges of energy. Transients may superimpose a high frequency signal (1-100 kHz or 1000-100,000 Hz) on the usual 60 Hz electrical supply. A high frequency voltage transient (HFVT) could make the usual 60 Hz waveform appear fuzzy.	If HFVTs are present in the electricity supply, humans may be exposed to radiofrequency magnetic and electric fields when they are in proximity to sources of electricity (power lines, home wiring, appliances, etc.). Like extremely low frequency EMFs (above), radiofrequency EMFs associated with dirty electricity (or HFVTs) are strongest at the source and diminish quickly with distance as one moves away from the electrical source.	There are guidelines for exposure to EMF (including the radiofrequency range), produced by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and the Institute of Electrical and Electronics Engineers (IEEE). These exist to protect against known effects of short-term exposure to high levels of EMF.	There have been a limited number of studies published on health effects associated with dirty electricity, but a review in 2010 indicated there were serious methodological problems in the design of all these studies and hence they could not be used to support a causal link between dirty electricity and adverse health effects. To date there is insufficient evidence to support a link between health effects and dirty electricity (or HFVTs).	Dirty electricity is a known power delivery concern, as it can damage electrical equipment. For more information, see Appendix B2.

Noise/ Electrical Phenomenon	Definition/explanation of Noise/Phenomenon	Potential Exposure Routes	Existing Standards or Guidelines	Recognized Health Effects of Exposure	Comments
Stray Voltage	In general usage, this refers to voltage differences in or around a home or building that can result in the completion of an electrical circuit if a person or animal comes into contact with two structures, objects or points with differing voltages (electrical energy potentials) at the same time (and therefore resulting in the flow of an electrical current resulting in an electric shock).	People or animals can be exposed to stray voltage when two points of contact at differing voltages are made simultaneously with two parts of the body (e.g. different feet, or hands and feet). Contact points include grounded/ electrified metal structures or equipment and/or the earth. Cattle are usually especially susceptible because of the wider spacing of their feet and the lack of coverings on the feet. The wearing of rubber-soled shoes by people usually provides sufficient insulation to prevent electric shock.	The Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) recommends a level of 1 volt (1 V) as the safe exposure limit, based on research on sensitivity in livestock. The Ontario Energy Board (OEB) specifies that voltage levels of less than 1 V are of no concern.	Limited studies on health effects in people. No studies on the physiological effects of small electrical currents in people. Animals are thought to be more susceptible to stray voltage than humans because of lower measured body electrical resistance in farm animals. Experimental studies have demonstrated behaviour change and minor changes in milk yield in cattle exposed to stray voltage. Behavioural reactions to electric shock may also be observed (e.g. avoidance of certain areas, or reaction to sensation e.g. involuntary muscle contractions).	For more information, see Appendix B3.

Noise/ Electrical Phenomenon	Definition/explanation of Noise/Phenomenon	Potential Exposure Routes	Existing Standards or Guidelines	Recognized Health Effects of Exposure	Comments
Low Frequency Noise (LFN)	Low frequency noise (LFN) refers to sounds in the frequency range of approximately 10 Hz to 200 Hz. Low frequency (low pitch) noises are usually perceived as humming sounds.	LFN is common background noise in urban environments. Many man-made sources such as airplanes, industrial machinery and air movement machinery (e.g. wind turbines) often produce LFN. Transformers also produce low-frequency noise. Whether or not the human ear can hear a sound depends not only on the frequency (pitch) of the sound but also on the loudness of the sound.	Ontario Ministry of Environment (MOE) guidelines exist for stationary sources in rural areas. For noise sources with a large proportion of low frequency sounds, the World Health Organization (WHO) recommends a lower guideline than 30 dBA indoors, but does not suggest a specific value. For more details, see Appendix B4.	A 2010 review of LFN conducted by the UK Health Protection Agency (HPA) concludes that there is no evidence to suggest that low pressure levels of low-frequency noise have a direct physiological effect on the body. The HPA concludes that any effects of low-frequency noise on health are the result of stress and frustration experienced by the sufferers in attempting to find a solution to the problem, which can be worse at night and affect sleep.	For more information, see Appendix B4.

4.3 Results: Review of Available Testing Results

Results for testing performed at one of the two homes involved in the complaint at the time of the start of WDGPH's involvement were provided to the health unit by the residents of that home. Residents from the other home indicated that similar tests were conducted at their property and that similar results were found; however, no documented test results were provided by those residents.

Testing results based on the statements and conclusions drawn in written reports prepared by Hydro One and the private consultant are summarized below and in Table 3 below. These results are discussed further in the discussion section further below.

Table 3: Summary of results of testing carried out at the homes of residents involved in the complaints up to and including December 2012

Nature of test	Date(s) of Test(s)	Site of Test	Test Performed by:	Brief Overview of Results
Magnetic field	April 2007	One residence	Hydro One	Indoor magnetic field strengths ranged from 0.2 milliGauss (mG) in the centre of the living room, to 46 mG 30 cm from the microwave when it was switched on. Outdoor measurements ranged from 0.2 mG on the front porch of the house to 7.5 mG at a concrete pole on which a small transformer was mounted in front of the house.
Dirty electricity	April 2009	One residence (same as above)	Private consultant	Graphs produced by the consultant showed waveforms with a 10,000 Hz (10 kHz) frequency wave superimposed on the 60 Hz electrical signal.
Neutral to earth (NEV) and stray voltage	Early May 2010 (NEV and stray voltage)	One residence (same as above)	Hydro One	Average NEV measurements taken for the Hydro One system did not exceed 2.0 V, and the maximum voltage did not exceed 3.5 V. Stray voltage measurements at tested locations on the property were 'significantly below' 0.1 V.
	Late May 2010 (NEV and stray voltage)	One residence (same as above)	Hydro One	
	October 2010 (stray voltage)	One residence (same as above)	Hydro One	Stray voltage measurements were less than 1 V.
	March-April 2012 (10 days) (NEV)	One residence (same as above)	Private consultant (same as above)	Primary NEV readings periodically exceeded the CSA limit of 10 V. NEV readings correlated with power output from the wind turbine project during a 2-day period in the course of testing.
	December 2012 (NEV)	One residence (same as above)	Hydro One	Results similar to previous Hydro One NEV results: no exceedances of acceptable limits recorded. NEV correlation with wind turbine output corroborated.
Acoustical audits	Multiple testing events over 2007, 2008, 2009	3 residences involved in original complaint to the MOE	Engineering consulting firm	Transformer station determined to be in compliance with MOE noise limits (daytime limit of 40 dBA (7:00-23:00) and night-time limit of 35 dBA (23:00-7:00))

Magnetic Field Testing

A Hydro One technician measured magnetic fields inside and outside one home in April 2007. The meter measured the field strength of 60 Hz magnetic fields, such as those produced by 60 Hz sources of electricity found in the home. Magnetic fields measured inside the residence in the centre of the kitchen and living room were 0.3 mG and 0.2 mG, respectively. Magnetic field readings were higher near appliances (8.2 mG and 46 mG at a distance 30 cm away from stove and microwave respectively), but were significantly lower (1.3 mG and 7.1 mG respectively) at a distance of 100 cm from those appliances. Outside the home, the lowest reading was taken at the front porch, which was recorded at 0.2 mG, which is comparable to the expected indoor range of readings taken at the centre of rooms. Magnetic field readings were higher near electrical devices outside, including the transmission lines and transformer pole (transformer here refers to a small pole-mounted transformer on property).

Dirty Electricity Testing

The private consultant visited the residence in April 2009 to test for dirty electricity. Graphs produced from tests by the consultant showed waveforms with a 10,000 Hz (10 kHz) frequency wave superimposed on the main 60 Hz signal.

Neutral to Earth Voltage (NEV) and Stray Voltage Testing

Hydro One visited the residence to conduct neutral-to-earth voltage (NEV) and stray voltage testing over a 48-hour period in early May 2009 as well as in late May 2009 (using more accurate instruments than those used in early May) and early October 2010. During each testing period, NEV and stray voltage measurements were taken. NEV and stray voltage measurements are similar measurements, both involving measuring a voltage differential between two points. NEV is measured between the neutral wire and remote earth. Stray voltage is measured at locations on a property where there is potential for direct contact (by a human or animal).

Hydro One compares their NEV and stray voltage measurements to the following applicable limits:

- NEV limit: The Canadian Standards Association (CSA) has set a limit of 10 V for NEV measurements.
- Stray voltage limit: The Ontario Energy Board (OEB) has legislated a limit of 1 V for potential animal contact voltages (stray voltage) (explained further in the literature review section above and in Appendix B3)

Hydro One measurements taken in May 2009 showed the average NEV measurements did not exceed 2.0 V, and the maximum NEV did not exceed 3.5 V. Stray voltage measurements were reported to be ‘significantly below’ 0.1 V. Hydro One concluded that measurements remained below the applicable standards and that there was not a stray voltage problem at the property.

In October 2010, 48 hour stray voltage measurements were again completed by Hydro One at the residence, and it was reported that measurements at selected locations were less than 1 V, the acceptable limit set by the OEB.

A private consultant measured the primary NEV at the same residence for a 10-day period from late March to early April 2012. The NEV readings recorded during the 2012 testing periodically exceeded the CSA limit for NEV of 10 V during the 10-day testing period. These results contradicted previous Hydro One measurements. Consequently, in December 2012, Hydro One returned to the residence to repeat NEV testing on the property. Results reported by Hydro One following this period of testing were similar to those reported following previous testing carried out by Hydro One at the residence, with no exceedances of acceptable limits recorded.

Both the private consultant and Hydro One agreed that NEV readings correlated with power generation output of the wind turbine project.

Acoustic Audits

The following section outlines key findings of acoustics audits that were performed to measure the noise levels at nearby residences. Acoustic audits were not intended to specifically assess LFN. Although, as per (O. Reg. 359/09), transformer noise limits include a 5 dB penalty because the type of noise the transformer produces is tonal. (Transformer noise is typically made up of lower frequency tones. This means that the sound pressure level peaks at a specific frequency or at a few specific frequencies. These peaks are called tones, and the sound is characterized as tonal.)

To meet applicable MOE requirements, the developer was required to hire an independent consultant to perform acoustical audits to determine whether the transformer station was in compliance with applicable MOE noise regulations (daytime limit of 40 dBA (7:00-23:00) and night-time limit of 35 dBA (23:00-7:00); the 5 dB penalty noted above is incorporated into these limits).

Acoustical audits were conducted on the following dates: October 1-9, 2007; February 7-20, 2008; May 5-16, 2008; August 5-18, 2008; Jan 27-Feb 6, 2009, May 4-13, 2009; and August 26-Sept 4, 2009. The final three testing periods occurred during phase II when both transformers B and C were installed and in operation.

Several unattended sound meters were set up at various outdoor locations, including one meter at each of the three residences involved in the original complaint to the MOE. The results of each acoustic audit found the transformer to be in compliance with noise limits. Unattended sound meters were set up for the entire testing period and were used to evaluate compliance.

Some attended measurements were also taken at various locations for short intervals, including at locations near each of the three residences. Attended measurements were used for further investigation, and included taking a full noise spectrum reading. According to the consultant's report, the noise spectrum measurements demonstrated that the noise produced by the transformers at this site is predominantly composed of low frequency tones. According to the acoustic audit reports, the transformers currently in operation (Transformer B and C) have sound pressure level peaks (or tones) at 120, 240, 360 and 480 Hz, and that the strongest peak is at 120 Hz. The report also notes that the strongest peak for original transformer (Transformer A, which was replaced at the end of phase I of the project) was at a higher frequency: 360 Hz.

As part of the acoustic audit, residents were asked to keep logs. According to the consultant's report, residents' logs suggested that residents often considered noise objectionable when background sound is low, indicating that concerns may be related to audibility in a very quiet environment rather than the absolute magnitude of the sound.

5 Discussion

The sections below review the available testing results in conjunction with the evidence provided by the scientific literature review of the evidence to date.

The testing results related to dirty electricity as well as the NEV measurements taken in early 2012 were reviewed by an electrical engineering professor from the University of Toronto, Dr. Reza Iravani. This expert review is referenced in the sections below.

The purpose of this process was to collect and review existing information to assess whether there is an exposure to a health hazard and inform any potential follow up recommendations. Documented test results were only available from one of the three homes involved in the original complaint filed to the MOE. Verbal confirmation of similar tests and results at a second residence was given to Public Health, but no reports were presented to verify this verbal confirmation. The following discussion is therefore based on the results of testing at the one home for which documented results were available.

Electric and Magnetic Fields (EMF)

The reported magnetic field readings recorded at this residence were comparable with expected or typical magnetic field readings for the locations measured and are unlikely to be a cause of the reported symptoms.

As noted in the literature review, according to WHO (see Appendix B1) the approximate range of magnetic field readings in a typical residence is 1-3 mG. Readings taken near the microwave in the residence were also similar to expected values listed in Appendix B1.

These magnetic field measurements were taken in 2007, before the second transformer (Transformer C) was in operation at the transformer station. However, because magnetic fields decrease in strength rapidly with increasing distance, it is unlikely that magnetic field measurements at the residence would be impacted by the addition of a second transformer at the transformer station. The major sources of extremely low frequency (60 Hz) magnetic fields inside a home include home appliances and home wiring. Magnetic field strength is related to the amount of current, or power, that is being used, in this case, inside the home. Consequently, magnetic field readings would not likely be impacted by the number of transformers at the transformer station.

Any electric and magnetic fields produced by the transformer station would be expected to fall below background levels beyond the transformer station's fence, and the highest exposure of the residents to EMF would be expected to be from their household appliances. This was confirmed by the results of the tests carried out at the residents' homes. The fact that the magnetic field measurements recorded were all within the ranges expected for the locations at which the measurements were recorded, indicates that the exposure levels to magnetic fields of people within the home were similar to expected average levels of exposures in a home.

The overall body of evidence suggests that exposure to extremely low frequency electric and magnetic fields at exposure levels typically experienced by the public poses very little risk, and exposure to extremely low frequency electric and magnetic fields is unlikely to be associated with the reported symptoms.

Dirty Electricity

There is currently insufficient evidence to support a link between health effects and dirty electricity.

Graphs produced from tests by the consultant showed waveforms with a 10,000 Hz (10 kHz) frequency wave superimposed on the main 60 Hz signal. An independent expert review of these testing results noted that this 10 kHz signal was very weak (had a very small amplitude) and explained that the presence of this type of signal would not be unexpected or uncommon in a typical home (communication with R. Iravani on Friday, December 14th, 2012). There are many different potential sources for such signals, some of which include: wires from old telephone lines, motor starters, and televisions (communication with R. Iravani on Friday, December 14th, 2012). As discussed in the literature review, a weak 10 kHz signal in the electrical supply would generate radiofrequency (RF) electric and magnetic fields with a 10 kHz frequency. Similar to extremely low frequency EMF fields, the strength of RF fields decreases rapidly with distance. Consequently, any RF fields are likely to be strongest in close proximity to appliances. It should be noted that, in the literature review conducted by PHO, there is currently insufficient evidence to support a link between health effects and dirty electricity. Dirty electricity is primarily a concern for power delivery as the high frequency signals in the electrical supply can damage electrical equipment.

Neutral to Earth Voltage (NEV) and Stray Voltage

The NEV and Stray Voltage readings do not exceed the CSA Limit or OEB Limit, respectively.

The May 2009 Hydro One report, limits for NEV and stray voltage are described.

- NEV limit: The first limit is the Canadian Standards Association (CSA) limit of 10 V for NEV measurements.
- Stray voltage limit: The second limit applies to animal contact voltage (stray voltage), for which the Ontario Energy Board (OEB) has legislated a limit of 1 V (measured at potential contact points on the property).

As per the literature review (Appendix B3), the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) recommends a level of 1 V as the safe exposure limit. The value is based on research to date on sensitivity in livestock. Although, limited studies have evaluated the impacts of stray voltage on humans, current evidence suggests that stray voltage conduction creates higher currents in animals than in humans and consequently animals are likely more sensitive. This is based on measured values for resistance in cows and pigs, which was found to be lower than resistance in humans, making cows and pigs more sensitive to electric currents. Stray voltage is typically a concern for farm animals as they do not have coverings on their hoofs and consequently are more likely to make simultaneous contact with electrified metal farm equipment and wet concrete floors, which increases their risk of exposure to stray voltage. Rubber-soled shoes are sufficient insulation to prevent the transfer of ground voltage to humans, meaning that humans are less likely to be exposed to stray voltage in field settings. (See Appendix B3 for further details.)

In both 2009 and 2010, Hydro One documented that both the NEV and stray voltage readings were below the respective limits of 10 V and 1 V, concluding that there were no NEV or stray voltage concerns at this property and that no further investigation was warranted. These findings were contradicted by subsequent NEV measurements taken by a private consultant two years later, in the spring of 2012. However, further measurements of NEV by Hydro One in December 2012 upheld the previous findings and confirmed that NEV readings remained below the acceptable limit. Hydro One noted that December 2012 NEV results were essentially the same as the 2009 NEV measurements, indicating that stray voltage measurements would also have remained the same.

Both the private consultant and Hydro One noted that the NEV levels correlated with the output of the wind turbine project that sources the transformers. Hydro One indicated that this correlation is expected and not a concern since testing results demonstrated that at the maximum wind farm output observed during the December 2012 testing period, the NEV measured remained below the CSA limit of 10 V.

Overview of Electrical Phenomena Discussion

- Electric and magnetic fields: Measured values for magnetic fields (at 60 Hz) suggested that field strength at the residence tested were comparable to expected levels and within the range of average residences in North America. Exposure to electric and magnetic fields (at 60 Hz) at exposure levels typically experienced by the public poses very little risk, and is unlikely to be associated with reported symptoms.
- There is currently insufficient evidence to support a link between health effects and dirty electricity. Dirty electricity is primarily a concern for power delivery as the high frequency signals in the electrical supply can damage electrical equipment.
- Stray voltage measurements were below the OMAFRA and OEB exposure limit (1 V), which is based on sensitivity in livestock. Although, limited studies have evaluated the impacts of stray voltage on humans, stray voltage conduction likely creates higher currents in animals than in humans and consequently animals are likely more sensitive than humans.

Low Frequency Noise (LFN)

As outlined in the literature review in Appendix B4, transformers produce vibrations, and as a result noise, when in operation. The vibrations produced can travel through the earth, and the noise through the air. Acoustic audits confirm that the noise produced by the transformers at this site is predominantly composed of low frequency tones (specifically 120, 240, 360 and 480 Hz). The strongest peak measured for the current transformers (B and C) was at 120 Hz, whereas the strongest peak for the original transformer (A) at a higher frequency: 360 Hz. It is important to note, however, that the acoustics audits were primarily to determine compliance with noise limits, and therefore, did not specifically assess LFN.

As discussed in the literature review section, according the UK Health Protection Agency (HPA) there is no evidence to suggest that low level LFN has direct physiological effects on body. The HPA acknowledges that LFN can be annoying and that the effects of LFN may result in stress and frustration, which can be worse at night and affect sleep. A review prepared for the MOE on LFN, corroborates and further examines the relationship between noise annoyance and stress (HGC Engineering, 2010).

A wide variety of symptoms have been reported by residents; however, an inability to sleep was most frequency referenced. Residents have noted that they experience improved sleep when they spend nights away from their homes and subsequently feel better. Originally, complaints to the MOE were primarily related to the audibility of the transformers, and logs kept by the residents during the acoustic audits make mention of feeling vibrations in the house. Symptoms began when the transformer station went into operation and were reported to worsen in late 2008 and early 2009, after the two new transformers (Transformer B and C) went into operation. Residents also described two days in 2011 when their homes returned to a “quiet state”. Subsequent follow up with Hydro One revealed that the transformer station had been out of service for a period of time that included those two days.

As noted previously, because of the low number of individuals living close to the transformer and the variety of symptoms reported, the use of an epidemiological (statistical) study to investigate the complaints of the residents was not feasible. Consequently, it is not possible to statistically confirm a direct association between the operation of the transformers and residents’ self-reported symptoms. However, based on (1) the nature and chronology the complaints; (2) information related to the transformer station operation (changes between phase I and II, and shut down periods); as well as (3) information in the literature on LFN and transformers it is plausible that there is an association between LFN produced by the transformers and the symptoms described by the residents.

In the same recent review (HGC Engineering, 2010), the reviewers note that indoor low frequency sound levels and spectra can differ markedly from those outdoors. They go on to recommend that the MOE consider adopting or developing a protocol to guide responding to complaints. The authors highlight that there is potential for significant variation in sound impact from house to house and room to room, and consequently, acknowledge that a LFN-specific protocol would not replace existing noise guidelines, but may prove helpful in assessing unique situations.

In conclusion although the acoustic audits indicate the transformer station is in compliance, LFN has not been ruled out as a source of annoyance and stress for the residents and thus it remains plausible that some of the described symptoms may be the result of LFN.

Other considerations: Broader Determinants of Health

A review by Wolsink (2007) discusses the value of developing a comprehensive collaborative approach in decision-making. The author notes that the most important discussion point for stakeholders is typically the location of the new projects or facilities and suggests that multiple sites should be selected and evaluated as part of the community consultation process before selecting the site. Community consultation allows for broader dissemination of information about the project and provides opportunities for the public to discuss concerns and how to accommodate them. Community consultation also helps empower individuals, through providing an avenue to be involved in shaping their own circumstances, which is important for overall health.

In addition to health-related symptoms, residents expressed feelings of frustration and helplessness about decisions and actions that have impacted their home environment. Sleeplessness has forced some residents to find other locations to sleep at night; and another to retire early. Residents are certain that they will be unable to sell their homes, and this fear appears to have elevated stress levels. Residents feel that they have no options – that they have lost control over their own circumstances.

Academic literature has demonstrated that perceived self-efficacy (i.e. personal control over one's circumstances) impacts mental and physical health (Seeman and Lewis, 1995). Low self-efficacy is associated with depression, anxiety, and helplessness (Bandura, 1997). Individuals with a higher sense of perceived self-efficacy report better psychological health, in addition to better physical health outcomes (Taylor and Seeman, 2006). Conversely, persons in situations that affect them adversely and over which they have no personal control often experience poorer health outcomes (Taylor and Seeman, 2006; Seeman and Lewis, 1995). A perception of low self-efficacy has also been found to affect sleep quality, which in itself would adversely affect health in the long term (Beatty *et al.*, 2011; Elovainio *et al.*, 2009).

Health is multi-factorial, in that there are many factors, both physical and psychosocial, that influence the health of an individual. The WHO defines health as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" (Preamble to the Constitution of the World Health Organization, 1948).

In order to comprehensively evaluate health impacts, the broader determinants of health and psychosocial context may need to be considered as part of the bigger picture when assessing potential impacts of new facilities. This warrants that future policy considerations related to the implementation and siting of new developments take into account a broader health lens to create communities where all individuals are able to access the same quality of life and well being in a broader sense. The relationship between "exposure" and "effect" is complex and is not just based on the tangible and physical but on variables not yet quantified which may be best evaluated using a broader determinants of health lens.

Community consultation is currently part of MOE legislated processes for renewable energy developments. Nonetheless, the siting of this transformer station would have likely benefited from an enhanced collaborative and consultative approach that went beyond the legislated requirements. In addition to evidence that support the benefits of community consultation, the literature also contains a growing body of research that examines other factors that could also be used to guide project siting processes. Some of the factors identified include visual impacts, distribution of benefits, and pre-existing sound levels (Janssen *et al.* (2011); Johansson & Laike (2007); Musall & Kuik (2011); Pederson et al (2009); Pederson & Larsman (2008); Pederson & Persson Waye (2007)).

The community where these transformers are located is not densely populated, and it seems likely that through additional consultative efforts and assessment of multiple prospective sites the transformer station could have been sited in a location that would have minimized potential impacts on the local community and residences. For example, possible visual impacts may have been more effectively mitigated through an assessment of multiple sites.

The decision to locate this transformer in the current location resulted in 4 homes being within the subsequently introduced recommended setback of 500 m (O. Reg. 359/09). The setback does not apply in this case because noise audits have been completed and indicated the transformer was in compliance for applicable noise limits. However, MOE legislation and setbacks do not account for the broader determinants of health, thus less tangible effects such as the loss of self-efficacy, visual impacts and equitable distribution of benefits remain. Within the broader context of health the losses experienced by the residents could be a cause of stress and plausibly result in some of the symptoms they are experiencing.

6 Conclusions

a) **<u>Electrical phenomena assessed are not likely the cause of the symptoms. Potential impacts of LFN has not been assessed and it remains plausible that some of the described symptoms may be a result of LFN</u>.**

There is no evidence at this time from the literature that either electric or magnetic fields or dirty electricity present a health hazard to the residents or are a direct cause of their symptoms.

There is no evidence at this time from the literature that stray voltage, which has been measured and found to be within recommended values, presents a health hazard to the residents or are a direct cause of their symptoms.

The literature review conducted as part of this investigation did not identify studies that specifically assessed potential impacts of LFN produced by transformer stations on nearby populations. Moreover, during the literature search on LFN, PHO noted that there seemed to be an increasing number of studies appearing in the literature related to LFN. The health impacts of LFN remains an area of evolving knowledge.

The concern of LFN has not been adequately addressed both from a testing perspective as well as from the evolving scientific literature. Thus LFN cannot be ruled out as a source of annoyance and stress for the residents and thus it is possible that some of the described symptoms may be the result of LFN.

b) <u>There is a growing body of evidence that identifies other factors to consider when siting renewable energy facilities</u>.

The literature contains a growing body of research that examines factors that may be associated with community acceptance of renewable energy project, including community consultation, visual impacts, distribution of benefits and pre-existing sound levels. Findings from these studies could be used to inform policies that guide the selection and evaluation of prospective sites during the planning stages of new facilities, as well as policies that guide the community consultation process itself. For example, one review noted that among the most important discussion points for community stakeholders is the project location, suggesting that several different locations should be selected and evaluated as part of the community consultation process.

It is anticipated that this body of evidence will continue to grow. Policy makers will need to stay abreast of the emerging literature to remain informed and to ensure that policies continue to be based on the best available science.

c) <u>Mitigation efforts have focused on ensuring compliance with noise limits. A broader determinants of health approach has not been utilized</u>.

The three homes of the residents involved in the original complaint to the MOE are located within 500 m of the transformer station, which is the currently legislated minimum setback distance as per O. Reg. 359/09. This setback does not apply if acoustic mitigation strategies are followed (involving acoustics audits to confirm compliance with applicable MOE noise limits). There have been substantial efforts to ensure that the transformer station is in compliance with applicable MOE noise limits. However, considerations have not extended beyond compliance requirements to examine and assess potential losses from a broader health perspective. Most significantly, there has not been any assessment of broader impacts experienced by those living within the 500 m legislated minimum setback distance, including visual impact of the facility, extent of involvement in siting consultative process, equitable distribution of benefits, and the right of use/transfer/enjoyment of property all of which deal with an individuals self-efficacy. Loss of self-efficacy should not be underestimated as a significant loss which impacts on long term mental and physical health of individuals. This loss cannot be excluded as a source of stress and a possible cause of some of the residents' symptoms.

7 Recommendations

a) <u>Assess and better understand LFN produced by transformer stations.</u>

i. Develop methodology to assess LFN produced by transformers

Acoustic audits did not specifically assess LFN, and were limited to outdoor measurements. In a review prepared for the MOE (HGC Engineering, 2010), it is noted that the indoor LFN levels and spectra can differ significantly from outdoor measurements. These reviewers also recommended that specific protocols be developed to assess LFN. Given that transformer noise is predominantly low frequency in nature, it is recommended that the MOE develop protocols and methods to measure and assess LFN at residences near transformer stations.

ii. **Continue to monitor emerging evidence on LFN**

As there is currently an increasing number of studies assessing impacts of LFN appearing in the literature, Public Health research institutions should continue to monitor the literature for emerging evidence related to LFN.

b) <u>Policies that inform the siting of transformers stations need to be "evergreen" based on the results of scientific literature.</u>

i. Periodic comprehensive review of emerging literature

It is recommended that an independent and comprehensive review of the literature be conducted to evaluate how the siting process of new renewal energy developments or facilities impacts; key physical, social, and psychological factors and subsequent overall outcomes for community wellness. This periodic review could be used by policy-makers to enhance existing policies related to project siting and the community consultation process. More importantly, this review could help shape and improve processes that enable communities to achieve greater overall health and well-being.

ii. Utilize a robust collaborative approach for siting of new Transformer Stations.

Community consultation is currently guided by legislated processes for renewable energy developments. Nonetheless, an increasing number of research studies are examining the role played by community consultation and new evidence continues to emerge that needs to be considered. Evidence from the literature suggests that healthy community consultation can significantly mitigate community impacts of renewable energy facilities. Community consultation helps empower individuals by providing an avenue to be involved in shaping their own circumstances, which is important for overall health. Healthy community consultation may include provision of multiple site options, recognition of the visual impacts and pre-existing sound levels, meaningful involvement of local government in decisions, equitable distribution of benefits and a documented voice of those most impacted. Cost benefit analysis for the transformer station is only one of many variables which should be taken into consideration in the siting and approval process.

For the transformer station site in the current report, it seems plausible that through a more robust community consultation process, a location could have been identified that would have reduced overall impacts on this community's well-being.

c) **The developer of this transformer station should engage in facilitated discussion to address the indirect impacts of the siting of the transformer station on the health of those affected**. (This recommendation specifically refers to the transformer station that is the subject of this report.)

This recommendation goes beyond the immediate scope of this report, namely, the investigation of any direct health hazard presented by the transformer station. However, the possibility that the symptoms reported by the residents have been caused at least in part by indirect effects such as stress and diminished self-efficacy cannot be ignored.

A few years after the transformer station was built and in operation, new legislation (O.Reg. 359/09) came into effect that put in place a new 500 m setback for transformers with a noise barrier in place. O.Reg. 359/09 states that this setback does not apply in circumstances when noise studies have demonstrated that noise levels at nearby homes are in compliance with limits.

Residents have expressed feelings of frustration and helplessness from a situation over which they have little to no control and limited avenues of support. All of the residents who have come forward to express their concerns and who have described feelings of helplessness are located within 500 m of the transformer station.

Using a broader determinants of health approach, the residents of the 3 homes located within the 500 m mitigation zone have experienced a significant loss of perceived self-efficacy. The literature has identified links between loss of perceived self-efficacy and mental and physical health effects. It is plausible that some of the symptoms that the residents are experiencing may be attributable to stress induced by the loss of self-efficacy resulting in physical health effects.

In circumstances where a facility is built and in operation prior to the establishment of setbacks, it is recommended that an enhanced community consultation process be undertaken beyond noise studies, to identify any broader indirect effects on health, and to address any such concerns of residents within the project area who find themselves within the new setback. Any similar concerns that may have been expressed by residents outside the setback area should also be taken into consideration during this process.

It is further recommended that the developer of this transformer station participate in facilitated discussion with the residents involved in this complaint to discuss considerations beyond noise, and to identify options to mitigate impacts on the broader determinants of health experienced by the residents that are indirectly affecting their health. This enhanced consultation process should aim to remove or minimize any such effects related to the residents' proximity to the transformer station, and should aim to restore self-efficacy to the residents, thus improving their overall well-being.

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APPENDIX A

TIMELINE

Event Timeline Summary

Below is a summarized timeline of the main events that relate to: (1) the transformers installed at the transformer station, (2) noise compliance requirements for the transformer station, and (3) timing of the testing events for which results were provided to Wellington-Dufferin-Guelph Public Health.

March 2006	Phase I of Project goes into operation (Transformer A in operation)
March 2006	MOE begins receiving complaints from nearby residents, primarily related to noise
Fall 2006	MOE district office determines that Transformer A does not meet noise compliance levels MOE directs project developer to implement noise reduction measures
Dec 2006	Wind turbine project developer erects three noise walls
Apr 2007	Hydro One site visit to one nearby residence and magnetic field testing performed at that residence
Fall 2007	MOE grants a Certificate of Approval (CoA) for Transformer A. CoA requires that the developer conduct noise studies, as per MOE regulations, to meet compliance requirements for MOE noise limits
2008	Developer begins process of replacing Transformer A with Transformer B, which meets noise-related design specifications. A second transformer, Transformer C, is also installed (identical to Transformer B). A fourth noise wall is installed to complete the enclosure.
Fall 2008	Phase II of wind turbine development goes into operation (additional 88 turbines and a total of 2 transformers: Transformers B and C)
2009	O. Reg. 359/09 comes into effect, requiring transformers to be set back at least 1000m, or 500m if acoustic barrier present (includes an exemption to the set back requirements if appropriate noise studies are completed and demonstrate that noise compliance levels are met)
Apr 2009	Residents in one of the four nearest homes hires a private consultant to test for dirty electricity
May 2010	Hydro One site visit the same residence: Neutral to Earth Voltage (NEV) and stray voltage testing conducted
Oct 2010	Hydro One site visit to the same residence: NEV and stray voltage testing conducted
Dec 2010	Hydro One ships magnetic field meter to the same residence with instructions to residents on how to take magnetic field readings
Apr 2012	Private consultant site visit to the same residence: 10-day Primary NEV test completed
Dec 2012	Hydro One site visit to the same residence: NEV testing conducted

APPENDIX B1

Electric and Magnetic Fields Literature Review

Public Health Ontario | Santé publique Ontario

PARTNERS FOR HEALTH | PARTENAIRES POUR LA SANTÉ

DEC 28, 2012

TO: Bo Cheyne, Environmental Health Specialist, Wellington Dufferin Guelph Public Health

FROM: James Johnson, MPH, Environmental Health Analyst, Public Health Ontario
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Issue

Providing an overview of electric and magnetic fields.

Questions Posed

1. What is EMF?
2. How are EMFs produced/generated?
3. How can humans be exposed to EMF?
4. How can EMFs interact with the human body?
5. What adverse health effects may be associated with EMFs?
6. How are EMFs measured/detected?
7. Are there guidelines/standards for EMFs?
8. Are there mitigation measures to reduce exposure to EMFs?
9. Is there evidence that EMFs are generated/produced by or associated with transformers?

Search Strategy

In answering these questions, a grey literature search was performed using the following search terms: "Electromagnetic fields", "Electric Fields", "Magnetic Fields", EMF, "Extremely low frequency" and ELF. The literature focused on a number of national and international governmental and non-governmental research sites including NIOSH, OSHA, NIEHS, WHO the ICNIRP.

1. What is EMF?

Electric and magnetic fields (EMFs) are created whenever electricity is generated or used. Electric and magnetic fields exist on their own or together, depending on the source (1). EMF produced when electricity is produced is part of the electromagnetic spectrum. Electric fields and magnetic fields are explained below separately.

Electric Fields

Electric fields are produced by voltage. Voltage, in electrical terms is the potential to do work. Electric fields are measured in units of volts per meter (V/m) and will increase as a voltage increases. Electric fields are shielded by common materials, such as wood and metal.

Magnetic Fields

Magnetic fields result from the flow of a current through wires or electrical devices. Current in this case refers to the movement of electric charge and is measured in amperes (A). Magnetic fields will increase with strength as current increases. Magnetic fields are measured in units of gauss (G) in the United States. Internationally they are measured in units of tesla (T) or more commonly in millitesla (mT) or microtesla (µT). To see the conversion from tesla to gauss, see Appendix 1. Unlike electric fields, magnetic fields are not easily shielded by most material.

Static fields vs extremely low frequency (ELF) electromagnetic fields

A distinction should be made between static fields and ELF fields. Static fields will always have the same strength regardless of time, whereas ELF fields are oscillating (meaning they vary with time). ELF fields are defined as having frequencies below 300 Hz (Hz refers to oscillations per second). Electric power has an operating frequency of 50 or 60 Hz in most countries, and will create extremely low frequency fields as a result. (1) Examples of both static and ELF fields and typical strengths can be found in Tables 1 and 2 below. For this document, all references to EMF will refer to electric and magnetic fields in the extremely low frequency range.

2. How are EMFs produced/generated?

EMFs are produced or generated wherever electricity is distributed or used. Power lines and cables, residential wiring and electrical appliances all produce EMFs. (1)

Electric Fields

In the home, electric fields are often present from equipment even when the equipment is switched off, as long as the equipment remains connected to the source of power. Generally, electric fields will increase as a voltage increases, meaning that high voltage sources such as transmission power lines will have stronger electric fields than lower voltage sources such as residential wiring. The strength of electric fields will decrease rapidly with increasing distance from the source. (1)

Magnetic Fields

For most electrical equipment, current needs to be flowing for a magnetic field to be produced. Thus, a magnetic field will not be produced if the device is not turned on. Magnetic fields will increase with strength as current increases, and will thus be stronger in devices that draw more intense currents. As with electric fields, magnetic fields will decrease rapidly with increasing distance from the source. (1) For examples of how magnetic fields will drop off will distance, refer to appendix 2.

3. How can humans be exposed to EMF?

Humans can be exposed to electric and magnetic fields wherever electricity is being distributed or used. EMFs are more intense at the source, and decrease rapidly with distance. (1) A similar effect happens with sound from a small speaker or a pair of headphones; the energy is more intense at the source and becomes quieter and eventually unperceivable as you move away from it. In the case of a transformer station, EMF produced by the equipment is typically indistinguishable from background levels beyond the station’s fence or wall (1).

Table 1 – Typical field sources and field strengths for static fields, adapted from WHO, 2007) (2).

Typical Electric fields	
Atmosphere (naturally-occurring)	12-150 V/m
Near TV set, video display unit	20 kV/m
Under 500 kV transmission line	30 kV/m
Typical Magnetic Fields	
Earth's Geomagnetic field (naturally occurring)	300 -700 mG
Industrial DC equipment	500 G
Small bar magnets	10-100 G
Magnetic resonance imaging (MRI)	25 000 G

Table 2 – Typical field sources and field strengths for ELF fields, adapted from WHO, 2007) (2).

Typical Electric fields	
Naturally-occurring (50-60 Hz)	0.1 mV/m
Underneath AC transmission lines	12 kV/m
Around electricity generating stations	16 kV/m
Around Appliances	0.5 kV/m
Typical Magnetic Fields	
Naturally-occurring (50-60 Hz))	0.1 µG
Underneath AC transmission lines	100-300 mG
Around electricity generating stations	0.4-1.2 G
Around appliances	0.5-1.5 G
Industrial processes	1300 G
Average 50/60 Hz fields in residences	1-3 mG

4. How can EMFs interact with the human body?

Static fields

Static electric fields do not induce electric currents in humans. Strong static magnetic fields (like those found in heavy industrial environments) can induce currents in the body when a person moves. (1)

ELF electromagnetic fields

A person standing directly under a high-voltage transmission line may feel a mild shock when touching something that conducts electricity. These sensations are caused by the strong electric fields from the high-voltage electricity in the lines. This effect will only occur at a close range, because the electric field will rapidly become weaker as distance from the line increases. (3)

Alternating magnetic fields produced by AC electricity can induce a weak flow of currents in the body. However, these currents are estimated to be smaller than the measured electric currents produced naturally by the brain, nerves and heart. (3)

5. What adverse health effects may be associated with EMFs?

In October 2005, WHO created a task group of scientific experts to assess any risks to health that might exist from exposure to ELF electric and magnetic fields in the frequency range of zero to 100,000 Hz (100 kHz). The conclusions and recommendations of the Task Group are presented in a WHO Environmental Health Criteria (EHC) monograph (3).
Following a standard health risk assessment process, the Task Group concluded that there are no substantive health issues related to ELF electric fields at levels generally encountered by members of the

public. The remainder of the task group review addressed predominantly the effects of exposure to ELF magnetic fields.

Short-term effects

There are established biological effects from acute exposure at high levels (well above 1 G) that are explained by recognized biophysical mechanisms. External ELF magnetic fields induce electric fields and currents in the body which, at very high field strengths, cause nerve and muscle stimulation and changes in nerve cell excitability in the central nervous system. Exposure to high level sources such as welding equipment, power lines at electric generating plants, and rail transportation equipment can produce lower frequency EMF strong enough to interfere with some models of pacemakers and defibrillators. (1)

Potential long-term effects

The International Agency for Research on Cancer (IARC) published a monograph classifying ELF magnetic fields as possibly carcinogenic to humans. This classification is used to describe an agent that has limited evidence of carcinogenicity in humans and less than sufficient evidence for carcinogenicity in experimental animals. (4) In contrast, higher frequency radiation including sunlight and x-rays are confirmed to cause cancer in humans.

Other adverse health effects have been studied for possible association with ELF magnetic field exposure, and were also reviewed by the WHO task group in 2005 (3). These included depression, suicide, cardiovascular disorders, reproductive dysfunction, developmental disorders, immunological modifications, neurobehavioural effects and neurodegenerative disease. The evidence for a relationship between ELF magnetic field exposure and the above health effects and was found to be weaker than the evidence for a relationship between EMF and cancer. The WHO task group concluded that the evidence for all of these effects (cancer and non-cancer outcomes) was insufficient to support a causal association. (9)

6. How are EMFs measured/detected?

Several kinds of survey meters and personal exposure meters are now available. Electric fields are difficult to measure accurately because they are shielded by common materials such as wood and metal and by the human body. Because of this, magnetic fields are typically measured in surveys intended to investigate human exposures to EMF. A personal exposure meter will usually be worn at the waist or placed as close as possible to the person during the course of a work shift or day to determine a person's EMF exposure. Survey meters can also be used. For magnetic fields, these are sometimes called "gaussmeters". These will measure the magnetic fields in a given location at a given time. (1)

7. Are there guidelines/standards for EMFs?

Yes; guidelines have been established to protect against established short term effects (induced currents and tissue conductivity), which can occur as a result of short-term exposure to high levels of extremely low frequency EMF. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) produced a guideline most recently in 2010 (5). The Institute of Electrical and Electronics Engineers (IEEE) produced a guideline in 2002 (6). At present, these bodies consider the scientific evidence related to possible health effects due to long-term, low-level exposure to ELF fields to be insufficient to justify lowering the exposure limits they currently have (5,6).

8. Are there mitigation measures to reduce exposure to EMFs?

Personal exposure to EMF will depend on three things: (i) the strength of the magnetic field sources in an environment, (ii) the distance from those sources, and (iii) the amount of time spent in that environment. If a concern about EMF exposure exists, the first step would be to find out the major EMF sources and move away from them or limit the time spent near them. Magnetic fields from appliances decrease significantly at about an arm's length away from the source. In many cases, rearranging an area to increase your distance from an electric panel or appliance can reduce your EMF exposure. (1)

9. Is there evidence that EMFs are generated/produced by or associated with transformers? / Does the transformer size influence EMFs?

The strongest EMFs around the outside of a transformer station will generally come from the power lines that enter and leave the substation. The transformer size will influence EMFs, and the fields will increase with higher voltages and higher currents. The strength of the EMFs from the equipment such as transformers, reactors and capacitor banks will decrease rapidly with distance. (1) Beyond the substation fence or wall, the EMF that is produced is typically indistinguishable from background levels. (1)

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Appendix 1 – Conversion table for tesla to gauss units for magnetic fields

Conversion between units: tesla to gauss	
1 T	10.000 G
100mT	1.000 G
10mT	100 G
1mT	10 G
100 µT	1 G
10 µT	100 mG
1 µT	10 mG
100 nT	1 mG
10 nT	100 µG
1 nT	10 µG

Appendix 2 – Typical magnetic field strength of household appliances at various distances. (Adapted from WHO) Normal Operating distance is identified in bold. It was noted that actual exposure levels would vary considerably depending on the model of appliance and the distance from the appliance.
(2)

Electric appliance	3 cm distance (mG)	30 cm distance (mG)	1 m distance (mG)
Hair dryer	**60 - 2000**	0.1 - 70	0.1-0.3
Electric shaver	**150 - 15000**	0.8 -90	0.1-0.3
Vacuum cleaner	2000 - 8000	**20 - 200**	1.3-20
Fluorescent light	400 - 4000	**5-20**	0.2-2.5
Microwave oven	730 - 2000	**40 - 80**	2.5-6
Portable radio	160 -560	**10**	<0.1
Electric oven	10 - 500	**1.5 - 5**	0.1-0.4
Washing machine	8 - 500	**1.5 - 30**	0.1-1.5
Iron	80 - 300	**1.2 - 3**	0.1-0.3
Dishwasher	35 - 200	**6 - 30**	0.7-3
Computer	5 - 300	**<0.1**	
Refrigerator	5 -17	**0.1- 2.5**	<0.1
Colour TV	25 - 50	0.4 -20	0.1-1.5

APPENDIX B2

Dirty Electricity
(High Frequency Voltage Transients)
Literature Review

Public Health Ontario | Santé publique Ontario

PARTNERS FOR HEALTH | PARTENAIRES POUR LA SANTÉ

DECEMBER 28, 2012

TO: Bo Cheyne, Environmental Health Specialist, Wellington Dufferin Guelph Public Health

FROM: James Johnson, Environmental Health Analyst, Public Health Ontario
Ray Copes, MD, Chief, Environmental and Occupational Health, Public Health Ontario

Issue

Providing an overview of high frequency voltage transients (dirty electricity).

Questions Posed

1. What are high frequency voltage transients (HFVT) (dirty electricity)?
2. How are high frequency voltage transients produced?
3. How can HFVTs interact with the human body?
4. What adverse health effects may be associated with HFVTs?
5. How are HFVTs measured or detected?
6. Are there guidelines/standards for HFVTs?
7. Are there mitigation measures to reduce exposure to HFVTs?Search Strategy

A web of science database search was conducted using the following terms: ‘harmonic distortion’, ‘transients’ and ‘electricity’. This search produced 768 results. These results were then refined for the search term ‘dirty electricity’, producing two results. Additionally, Pubmed and Environmental Complete databases were searched for the term ‘dirty electricity’ producing eight results and six results, respectively. Results were then refined for reviews, turning up one result in all databases. EMF information was also searched for on a number of grey literature sites including the WHO, NIOSH, OSHA and Health Canada, as well as information from the radiation safety institute.

1. What are high frequency voltage transients (HFVT) (dirty electricity)?

The name ‘dirty electricity’ originates from the term ‘dirty power’, which was typically used in industry to describe the high frequency voltage transients cause by interruptions in the electrical current flow from connected electrical equipment, which can damage the equipment (1). The term ‘dirty electricity’ appears to be used to describe harmonics and transients in the lower radiofrequency spectrum, in the kHz range (approximately 1-100 kHz) (1).
Electric and magnetic fields are created where electricity is used or generated, regardless of the frequency. Deviations from the 50/60 Hz sine wave are generally in the lower radiofrequency spectrum and may be better described as electromagnetic fields generated by radiofrequency transients or ‘high

frequency voltage transients' (HFVT) rather than using the term dirty electricity (1) Regardless of the term used, the frequency referred to will be the same (approximately 1 – 100 kHz). HFVT (and the electric and magnetic fields (EMF) that these transients can produce) will be discussed in this document. For more details about the power system, harmonics, harmonic distortion, transients, the electromagnetic spectrum and where these transients would appear on the electromagnetic spectrum, refer to the Appendix.

2. How are high frequency voltage transients produced?

High frequency voltage transients (HFVTs) are produced by harmonics and transients in the electrical line (1). The reasons for these transients can vary; transients can be produced by lightning strikes, switching events and short circuits (2). Harmonics can also be introduced to the power system by electronic items that draw non-sinusoidal current from the power supply (3). This equipment can include computers, fax machines, dimmer switches and household appliances with electronic controls.

3. How can HFVTs interact with the human body?

Harmonics and transients in the electrical system are primarily a power delivery concern, as transients and surges have the potential to damage electrical equipment (2). As with other electric currents, human interaction with HFVTs would occur as the result of direct contact with an electric source, or due to exposure to electric and magnetic fields that exist wherever electricity is generated or used (1).

4. What adverse health effects may be associated with HFVTs?

At sufficiently high levels, adverse health effects are well known and documented for electric and magnetic fields in the kHz frequency range. For electric fields in the 3 kHz -100 kHz range, unintentional stimulation of excitable tissues can occur when electric or magnetic fields are strong enough (4). Direct contact with an electrical source (e.g. wiring) can result in both shock and burn hazards. These effects do not occur at levels normally present in residential environments.

There have been a limited number of studies published on health effects associated with HFVTs, but a review conducted in 2010 cited serious methodological problems in the design of all of the studies investigating HFVT to date, and stated that they could not be used to support the existence of a causal link between HFVT exposure and adverse health effects (1).

5. How are HFVTs measured or detected?

Electric and magnetic fields generated by HFVTs on main circuits can be measured using standard radiofrequency and low frequency EMF measurement equipment (1).

6. Are there guidelines/standards for EMF produced by HFVTs?

Yes; although specific guidelines or standards do not exist for HFVTs, the current international guidelines do limit exposure in the 1-100 kHz frequency range and would thus apply to EMF produced by HFVTs. Health effects related to short-term, high-level exposures have been established and form the basis of two international exposure limit guidelines. The Institute of Electrical and Electronics Engineers (IEEE) produced a guideline for Extremely low Frequency fields (0-3 kHz) in 2002 (5), and a guideline for radiofrequency electromagnetic fields (3 kHz – 300 GHz) (6). The ICNIRP has produced an updated guideline as of 2010 for limiting exposure to time-varying electric and magnetic fields from 1 Hz to 100 kHz(4). At present, these bodies consider the scientific evidence related to possible health effects due to long-term, low-level exposure fields in these frequency ranges to be insufficient to justify lowering the exposure limits they currently have.

7. Are there mitigation measures to reduce exposure to EMF produced by HFVTs?

In general, a positive correlation exists between the level of 50/60 Hz electromagnetic fields in environments and EMFs from HFVTs (3). Personal exposure to any type of EMF, including EMF produced by HFVTs will depend on three things: (i) the strength of the magnetic field sources in an environment, (ii) the distance from those sources, and (iii) the amount of time spent in that environment. If a concern about exposure to EMF produced by HFVT exists, the first step would be to find out the major EMF sources and move away from them or limit the time spent near them. Magnetic fields from appliances decrease significantly at about an arm's length away from the source. In many cases, rearranging an area to increase your distance from an electric panel or appliance can reduce your EMF exposure.

Filters have been developed for home or office environment that reduce or remove the amount of HFVTs on electrical circuits with an optimal filtering capacity between 4 Hz and 100 kHz (1) However, it should be noted that no data is available from any study on what effects the installment of these filters has on personal electric and magnetic field exposures, nor is there any data on changes to the spatial variability of electric and magnetic field exposure levels in rooms where these filters have been installed (1).

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Appendix – Relevant terms to electricity.

Electromagnetic Spectrum

Extremely Low Frequency (ELF) and Very Low Frequency - Electric and magnetic fields (EMFs) are invisible lines of force that are created whenever electricity is generated or used. Electric and magnetic fields exist on their own or together, depending on the source (2). Power frequency electric magnetic fields are usually in the frequency of 50 or 60 Hz. The very low frequency range can be produced both from electrical sources and as a type of radiofrequency. Because of this, the very low frequency range varies in definition and may be covered by more than one guideline. The ICNIRP definition of low frequency extends from 1 Hz to 100 kHz (**Error! Reference source not found.**) while the IEEE definition covers from 1 Hz to 3 kHz (5).

Radiofrequency (RF) - The term RF (radiofrequency) refers to part of the electromagnetic spectrum that is used for radio communications purposes. Figure 1 below shows where Radiofrequency fits within the electromagnetic spectrum (labeled radiowaves). It should be noted that the very low frequency part of the spectrum (the kHz range) is considered as part of the radiofrequency spectrum, by many regulating bodies. In Canada for example, the radio spectrum allocation ranges from 3 kHz to 300 GHz. (7)

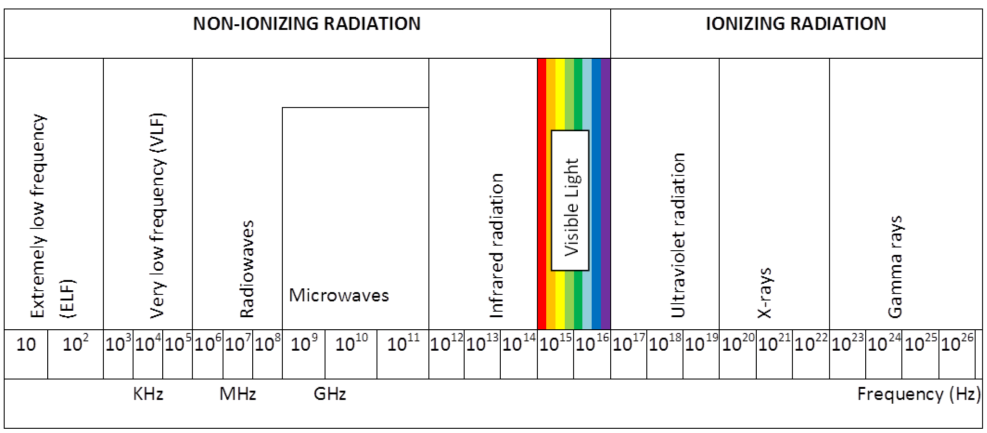

Figure 1- Electromagnetic Frequency Spectrum

The Power Supply

In Canada, the ideal voltage supply is 120 volts at a frequency of 60 Hz with a sinusoidal wave shape as seen in figure 2. In traditional power setups, consumers drew a current waveform from the system that was also sinusoidal. Such loads could include induction motors, incandescent light bulbs, stoves and most household appliances. (3)

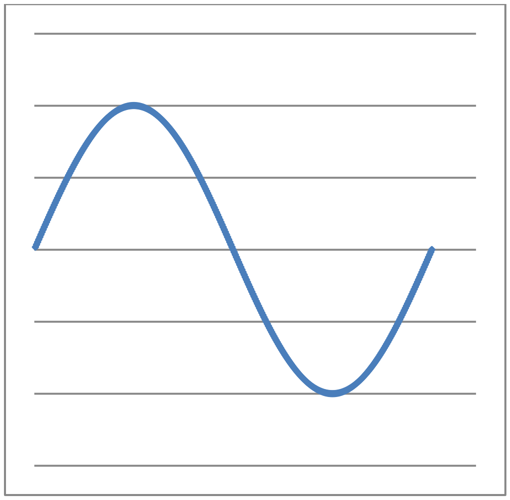

Figure 2 - Ideal 60 Hz Sine Wave

Harmonics

Harmonics are defined as components of electricity with frequencies which are a multiple of the fundamental frequency (60Hz). The second harmonic of 60 hz will be 120 hz (two times 60 Hz); the third harmonic will be 180 Hz (3 times 60 Hz) and so on. (3)

The nature of the electricity system and the way electricity is used means that some harmonics are more prevalent than others. In particular, the third harmonic (180 Hz) is usually the strongest, and even harmonics (2^{nd}, 4^{th}, 6^{th}, etc.) are usually stronger than odd harmonics (3^{rd}, 5^{th}, 7^{th}, etc.). Generally, harmonics above the third or the fifth are very small, but there are certain process which can lead to harmonics as high as the 23^{rd} and 25^{th}. Some harmonics result from the operation of the electricity system itself, but most occur as a result of the loads consumers connect to the electricity system. (3)

Harmonic Distortion

Harmonics are seen as undesirable in an efficiently operated electricity system. In many situations, harmonics are very small, adding up to a few percent or less of the fundamental frequency (60 Hz). However, with the proliferation of new electronic products since the 1960s, the customer load has changed in that the devices draw non-sinusoidal current. This equipment can include computers, fax machines, dimmer switches and household appliances with electronic controls. An example of a fundamental sine wave distorted by harmonics is included in figure 3. (3)

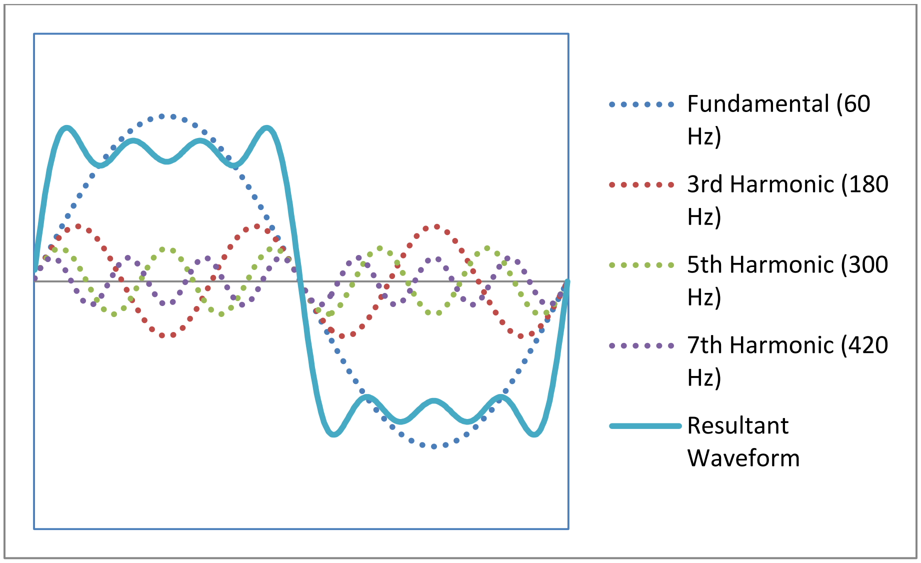

Figure 3 - Distortion of the sinusoidal waveform from 3rd, 5th and 7th harmonics

Transients

Transients are short-lived bursts of energy in a system caused by a sudden change of state. Transients can occur in electrical systems, causing temporary changes to the frequency and the intensity of the electric and magnetic fields produced. According to the WHO (2), transients are produced by the following causes:

- Lightning strikes to an overhead power line – can cause a very high voltage that will be rapidly dissipated by controls within the system.
- Switching events – when a switch in a circuit carrying a current is opened and the current is interrupted. Switching surges occur whenever circuits are interrupted, and can thus occur in distribution systems and in homes.
- Short circuits – are an electrical circuit that allows a current to travel along an unintended path. An example of this would be a drill cutting its own cable and connecting to the current. Short circuits in the home should usually result in the circuit being rapidly disconnected by the operation of a circuit breaker or fuse.

Some transients will only affect the circuit they are generated on. More frequently, they will also affect neighbouring circuits, but to a lesser degree. A lightning strike may cause a transient voltage in a power line that might be high enough to cause protection circuits to operate a circuit breaker and disconnect the circuit. This lightning strike could also cause transient voltages on nearby circuits but not large enough to cause the circuit protection to operate. On circuits further away, the transients could still occur but they would be negligible for practical purposes. In homes, switching on an appliance may produce a transient that affects adjoining homes as well. Electric and magnetic fields generated by transients will drop off rapidly from their point of origin, similar to other EMF sources.

APPENDIX B3

Stray Voltage
Literature Review

Public Health Ontario | Santé publique Ontario
PARTNERS FOR HEALTH | PARTENAIRES POUR LA SANTÉ

DECEMBER 28, 2012

TO: Bo Cheyne, Environmental Health Specialist, Wellington Dufferin Guelph Public Health

FROM: Sunil Varughese, MSc, Environmental Health Analyst, Public Health Ontario
Pamela Leece, MD, Resident, Public Health and Preventive Medicine, University of Toronto
Ray Copes, MD, Chief, Environmental and Occupational Health, Public Health Ontario

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Issue

Providing an overview of stray voltage

Questions Posed

1) What is the difference between hot, ground and neutral?
2) What is stray voltage and how is it produced?
3) How can humans be exposed to stray voltage?
4) What adverse health effects may be associated with stray voltage?
5) How is stray voltage measured or detected?
6) Are there guidelines or standards for stray voltage?
7) Are there mitigation measures to reduce exposure to stray voltage?

Response

Overview: Basic concepts of voltage, current, and resistance

An electronic circuit is a complete course of conductors through which current can travel. Circuits provide a path for current to flow. To be a circuit, this path must start and end at the same point forming a loop. All circuits can be distilled down to three basic elements: 1) a voltage source which causes current to flow like a battery; 2) a load which consumes power and represents the actual work being done by the circuit and can be as simple as a light bulb; and 3) a conductive path which provides a route through which current flows. The route for the conductive path begins at the voltage source, travels through the load, and then returns to the voltage source. This path must form a loop from the negative side of the voltage source to the positive side of the voltage source. An electric circuit needs both a power source and closed path in order to work. A closed path is one which forms a loop as described earlier. The relationship between voltage exposure and current conducted through the path is described by Ohm's Law. One way to think about electricity is that voltage is the driving force and current is the resulting movement of electrons through the resistance of the wire (or animal). It is possible to have a voltage source with no resulting current flow if the resistance value is infinite (as is the case when a switch is turned off, or a valve is shut). It is not possible to produce current flow in the absence of voltage, regardless of the resistance of the circuit.

1) What is the difference between hot, ground and neutral?

Standard line voltage wiring is done with plastic sheathed cables which usually have three conductors. One of the conductors is covered with black plastic insulation and is the hot wire which provides a 120V AC source. Another wire is covered in white plastic insulation and is called a neutral wire and it provides a return path for the current provided by the hot wire. The neutral wire is connected to an earth ground. A third wire is bare copper this is called the ground wire. Like the neutral wire, the ground wire is also connected to an earth ground but the neutral and ground wires serve two distinct purposes. The neutral wire forms a part of the live circuit along with the hot wire. The ground wire is connected to any metal parts in electrical equipment which is a safety feature in the event that the hot or neutral wires come in contact with metal parts. Connecting the metal parts to earth ground eliminates the shock hazard in the event of a short circuit. The term ground current does NOT refer to ground wire. Throughout this report, when the term ground is used, this refers to the ground that an individual or animal could be standing on and does NOT refer to ground wire.

2) What is stray voltage and how is it produced?

Stray voltage is defined by the Institute of Electrical and Electronics Engineers (IEEE)[1] as, "a voltage resulting from the normal delivery or use of electricity which may be present between two conductive surfaces that can be simultaneously contacted by members of the general public or their animals. Stray voltage is not related to power system faults, and is generally not considered hazardous."

In contrast, contact voltage refers to voltage that occurs when there are power system faults. As such, contact voltage is "not related to the normal delivery or use of electricity, and can exist at levels that may be hazardous. While the contact voltage is often used to describe animal exposure conditions, the resulting current flowing through animals' bodies is what determines the 'dose' and the resulting type and degree of nerve stimulation.[2] The exposure (voltage) and the dose (current) are related by the resistance (measured in Ohms) of various parts of the electrical circuit.

In practice, the term stray voltage is often used to include both stray and contact voltages from normal operation of electricity delivery and abnormal and correctible conditions, such as poor insulation or wiring errors.[3] In the literature, this term is most commonly used in the farm industry to refer voltages that exist at points of animal contact on a grounded electrical system at a farm.[2,4] Other terms are also used to refer to this concept, such as ground current, tingle or neutral to earth voltage (NEV).[2,4] These concepts can be used in the context of any electrical distribution system, including those connected to wind turbines.

For the purposes of this review, stray voltage as defined by IEEE, also known as tingle voltage, NEV, and ground currents will be the focus of this review. The source of stray voltage is a voltage that is developed on the grounded neutral wiring network of a farm and/or the electric power delivery system and the resistance of that neutral system. Grounding is provided to keep the voltage potential between the neutral system and the ground below levels that could be harmful to people or animals.

3) How can humans be exposed to stray voltage?

For humans to be exposed to stray voltage, two points of contact are necessary to complete a circuit and receive a shock. Cattle are more at risk in part because of the wider spacing of their feet, making them more likely to encounter a voltage differential. Also, rubber-soled shoes are sufficient insulation to prevent the transfer of ground voltage to humans, meaning that humans are less likely to be exposed to stray voltage in field settings. Stray voltage is typically a concern for farm animals as they do not have coverings on their hoofs and can also make contact with metal feeding troughs and wet concrete floors thus completing a circuit between a true earth ground for the power system and a grounded neutral network.

4) What adverse health effects may be associated with stray voltage?

Human Health

The two reviews on stray voltage by Hultgren[5,6] summarize very old studies on factors that affect electrical conduction on the body, and the perception of electrical current in humans. There were no studies of physiological effects of small electrical currents on humans reviewed. Their review did conclude that stray voltage conduction likely creates higher currents in animals than in humans, based on lower measured values for resistance in cows and pigs (mouth to all hooves) compared to resistance in humans (one hand to both feet). However, the literature is very limited for any health effects of stray voltage on humans. A case-control study examining the association of contact current exposure and the risk of childhood leukemia found no statistically significant association.[7]

Animal Health

A 2012 review on stray voltage found that many experimental studies have demonstrated behaviour change and some showed minor changes in milk yield, milk composition or stress hormones (especially cortisol) in cows exposed to stray voltage.[8] The direct effect of animal contact with electrical current presents in the form of behavioural reactions, which can range from mild to intense. More mild reactions would indicate sensation and could include involuntary muscle contractions or twitching; intense reactions would be indicative of pain. Certain indirect effects may occur in animals that are exposed to electrical current. For example, animals may avoid certain locations where they may receive a shock or have received a shock; if a shock is received in drinking or feeding locations then there may be reduced water intake or reduced feed intake. Currents of 3.0mA or more may lead to behavioural responses of the nervous system, based on findings in several studies.[9] Several studies have shown that increased concentrations of cortisol do not occur below voltage/current levels required for behavioural response.[8] Individual studies on dairy cattle have reported no long-term effects on milk production, immune or endocrine systems or other health parameters in cows as a result of internal currents.[9] The 1990 reviews on stray voltage by Hultgren[6,7] found that direct effects of stray voltage on animal health and milk production was inconclusive and effects on animal health and production appear to be mainly caused by behavioural changes.

5) How is stray voltage/contact voltage measured or detected?

Stray voltage can be measured and possible sources can be determined by electricians specializing in stray voltage investigations. Hydro One has a guidance document for electrical contractors testing for stray voltage.[10]
http://www.hydroone.com/MyBusiness/MyFarm/Documents/SVTestProcedureforElectrical_Contractors.pdf

6) Are there guidelines or standards for stray voltage?

The Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) recommends a level of 1 volt as the safe exposure limit stating that the vast majority of research on sensitivity in livestock to date supports this limit.[10] The Ontario Energy Board (OEB) has specified that voltage levels of less than 1.0 volt to be of no concern.[11] A literature review conducted for OEB mentioned that at 1.0V mild behavioural modification would be expected in the most sensitive cows in wet locations, while 2.5V would lead to a response in 50% of cows and 4V would lead to a response in the least sensitive cows.[2] After a licensed electrician has confirmed that there is a stray voltage problem, Hydro One will make a site visit upon request to carry out an animal contact test and then return for a second visit to install a farm stray voltage recording device.[11] A third visit two to three business days later will remove the recording device and analyze the data and discuss the results. If the measured threshold falls below 1.0 volt, the investigation will conclude. However, if the customer decides to purchase a stray voltage filter from Hydro One, this will be installed at no cost. If the stray voltage measured is above 1.0 volt, further OEB-defined testing during a fourth site visit will be conducted to determine whether corrective measures need to be taken by Hydro One. If corrective measures were implemented by Hydro One, the will return to the property to conduct final testing to see whether any additional corrective measures need to be taken.

7) Are there mitigation measures to reduce exposure to stray voltage?

Testing and mitigation procedures suggested by Hydro One in Ontario, focus first on detecting and correcting faults in secondary (or customer) distribution systems and if the problem persists, mitigation devices can then be applied.[10,12] Neutral-to-earth or stray voltage can be reduced in three fundamental ways: 1) reduce the current flow on the neutral system, 2) reduce the resistance of the neutral system, or 3) improve the grounding of the neutral system. However, the first step in a stray voltage investigation is to determine the major sources of neutral-earth voltage. Any major faults or code violations in the wiring system that could pose an electrical hazard or are a major source of neutral to earth voltage should be corrected immediately. If the wiring systems (on farm and from the utility) are operating correctly then the above three actions can be assessed to determine which is most practical, safe and efficient way to reduce neutral-earth voltage.

Hydro One has a guidance document on solutions to stray voltage.[12]
http://www.hydroone.com/MyBusiness/MyFarm/Documents/SVSolutionsGuideforElectrical_Contractors.pdf

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Definitions

IEEE Working Group on Voltages at Publicly and Privately Accessible Locations
Accessible: **http://grouper.ieee.org/groups/td/dist/stray/files/2010-05-Definitions-Stray-Contact-Voltage%20Working%20Definitions.pdf**
Accessed: September 10, 2012

Stray and Contact Voltage Working Definitions
(Pittsburgh - 07/21/2008)

Stray Voltage: A voltage resulting from the normal delivery or use of electricity which may be present between two conductive surfaces that can be simultaneously contacted by members of the general public or their animals. Stray voltage is not related to power system faults, and is generally not considered hazardous. (See also Contact Voltage)

Contact Voltage: A voltage resulting from power system faults which may be present between two conductive surfaces that can be simultaneously contacted by members of the general public or their animals. Contact voltage is not related to the normal delivery or use of electricity, and can exist at levels that may be hazardous. (See also Stray Voltage)

APPENDIX B4

Low Frequency Noise
Literature Review

Public Health Ontario | Santé publique Ontario

PARTNERS FOR HEALTH | PARTENAIRES POUR LA SANTÉ

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Issue

Providing an overview of low frequency noise (LFN)

Questions Posed

1) What is LFN
2) What are LFN sources?
3) What adverse health effects may be associated with LFN?
4) How is LFN measured?
5) Are there guidelines/standards for LFN?
6) Is there evidence that LFN is produced by transformers?
7) Are there mitigation measures to reduce exposure to LFN from transformers?

Response

Search Strategy

A mix of grey literature sources were consulted using Google search along with Pub Med using the search terms “low frequency noise” and “health effects” or “regulations” or “guidelines” or “transformers” or “measurement”.

1. **What is LFN?**

LFN covers a frequency range from about 10Hz to 200Hz but this range is not exact as there is no widely agreed upon standard.[1] Notes or tones at low frequencies are often described as humming while high frequency tones might elicit descriptions such as whistling, singing, or screeching.

2. **What are LFN sources?**

LFN is common as background noise in urban environments, and as an emission from many anthropogenic sources such as road vehicles, airplanes, helicopters, industrial machinery, artillery and mining explosions, and air movement machinery including wind turbines, and sources related to heating, cooling and ventilation of a building.[2,3]

3. What adverse health effects may be associated with LFN?

According to a 2010 review of low frequency noise conducted by the UK Health Protection Agency (HPA), there is no evidence to suggest that low levels of low frequency noise will have a direct physiological effect on the body.[1] Although high levels of low frequency noise may produce other sensations, the ear is the most sensitive receptor for sounds at all frequencies.[4]

LFN and Annoyance

Annoyance has roots in a complex of responses. According to a 2004 review, these responses are moderated by personal and social characteristics of the complainant. LFN annoyance in the home is considered as leading to a long-term negative evaluation of living conditions, dependent on past disturbances and current attitudes and expectations.[4]

According to the HPA, the effects of low frequency noise on health are a result of stress and frustration experienced by the sufferers in attempting to find a solution to their problem, which can be worse at night and affect sleep. Sufferers can be understandably resentful of the LFN and of whoever might be responsible for the source. In a 2010 publication on environmental noise and health, the HPA recommends sourcing and controlling of the LFN as a top priority, and also notes that established techniques of stress management may have an ameliorating effect on sufferers' reactions, leading to an improved quality of life.[1]

A number of field measurements and laboratory studies were carried out by Vasuden and Gordon in 1977 that investigated persons who complained of low frequency noise in their homes.[5] A number of common factors were identified:

- The problems arose in quiet rural or suburban environments
- The noise was often almost inaudible and heard by a minority of people
- Typically, the noise was only audible indoors and not outdoors
- The noise was more audible at night than during daytime
- The noise and a throb or a rumble characteristic
- The main complaints came from the 55-70 year age demographic
- The complainants had normal hearing
- Medical examination excluded tinnitus

The WHO stated in 2000 in a publication on community noise that typical measurements of assessing annoyance, based on A-weighted equivalent level may be inadequate for assessing low frequency noise. For noise with a large proportion of low frequency sounds, a still lower guideline (than 30 dBA) is recommended.[6]

4. How is LFN measured?

LFN is measured using sound level meters which measure sound pressure levels using decibels (dB) as a unit. The human ear is less sensitive to lower frequencies, and this is taken into account with an A-weighted scale (dBA). The A-weighting scale takes into account loudness as perceived by the human ear and is typically used in compliance measurements. A-weighting underestimates the sound pressure level of noise with low frequency components, and has been described in reviews as inadequate for low frequency noise assessments. Assessment strategies for the investigation of low frequency noise are still emerging, and there is currently no single strategy that is consistently used for the investigation of low frequency noise.[4]

5. Are there guidelines/standards for LFN?

The Ontario Ministry of Environment has a guideline for sound level limits for stationary sources (this would include transformer stations) in rural areas (NPC-232). Under these guidelines, no restrictions apply to a stationary source with a one hour equivalent sound level (L_{eq}) or a logarithmic Mean impulse Sound level (L_{LM}) below 45 dBA (or dBAI, a measure used for impulsive sound) between 0700h and 1900h and below 40 dbA (or dBAI) between 1900h and 0700h. There are no Ontario guidelines specific to low frequency noise.
The WHO makes the following recommendations for nighttime noise in Europe from a 2009 report: For the primary prevention of of subclinical adverse health effects related to night noise in the population, the night noise guideline is 40 dB of $L_{night, outside}$[i] while an interim target of 55 dB of $L_{night, outside}$ is recommended in situations where achievement of the night noise guideline is not feasible for various reasons in the short run.[7]
The WHO recognized in an earlier guidance document for community noise not specific to Europe that A-weighting underestimates the sound pressure level of noise with low frequency components, and recommends that a lower guideline is recommended for noise with a large proportion of low frequency sounds, but does not make an indication of what this lower level should be.[6]

6. Is there evidence that LFN is produced by transformers?

Yes, transformers create a low frequency hum through a phenomenon called magnetostriction.[8] This means that if a piece of magnetic sheet steel is magnetized it will extend itself and when the magnetization is taken away, it returns to its original condition. A transformer is magnetically excited by an alternating voltage and current so that it becomes extended and contracted twice during a full cycle of magnetization. This extension and contraction is not uniform and as a result the extension and contraction varies all over a sheet. A transformer core is made from many sheets of special steel and it is made this way to reduce losses and to reduce the consequent heating effect. If the extensions and contractions described above are taking place erratically all over a sheet and each sheet is behaving erratically with respect to its neighbor this gives a picture of a moving writhing construction when it is excited and is sufficient to cause a vibration and as a result noise. The vibration travels through the ground while the noise travels through air. Transformer noise is typically made up of frequencies of 120, 360, 600, and 840Hz with the 120Hz and 360Hz producing most of the transformer sound.

7. Are there mitigation measures to reduce exposure to LFN from transformers?

Noise is usually attenuated (reduced) as it tries to pass through a massive wall.[8] Erecting sufficiently thick walls around a transformer or enclosing a transformer will reduce the noise produced by a transformer. Typical buildings or homes are less effective at attenuating lower frequencies than higher frequency noise which makes controlling low frequency noise near the transformer important. Isolating the core and coils of a transformer from the ground will reduce vibration transfer to the ground and is another important measure in reducing transformer noise; some transformers are already designed to isolate the core and coils of the transformer from the ground.

[i] $L_{night, outside}$ is the A-weighted long-term average sound level determined over all the night periods of a year in which: the night is eight hours (usually 23:00h -07:00h local time), a year is a relevant year as regards the emission of sound and an average year as regards the meteorological circumstances.

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