EB-2012-0442

IN THE MATTER OF the Ontario Energy Board Act, 1998, S.O. 1998, c.15, Schedule B;

AND IN THE MATTER OF an application by Varna Wind Inc. for an order or orders pursuant to section 92 of the Ontario Energy Board Act, 1998 granting leave to construct transmission facilities in the Municipalities of Bluewater and Huron East.

AFFIDAVIT OF STEPHEN MCAULEY
(Sworn March 27, 2013)

I, Stephen McAuley, of the Town of Denfield in the Province of Ontario, MAKE OATH AND SAY:

1. I am the Chief Administrative Officer of the Municipality of Bluewater ("Bluewater"), and as such I have knowledge of the matters to which I herein depose, save and except where I have been advised of the same, in which case I believe such information to be true.
2. Attached and marked as **Exhibit A** is a true copy of my CV.
3. I have had many years of technical experience first with Stantec Consulting Inc. and subsequently with three municipalities.
4. A major concern of Bluewater in this matter is to ensure that its inhabitants are not impacted by any effects caused as a result of the construction, operation and eventual deconstruction of the electrical power lines relating to this Application. One possible impact that has been noticed and tested in other industrial wind turbine projects is stray voltage.
5. Attached and marked as **Exhibit B** is a true copy of "Wind Turbines Make Waves: Why Some Residents Near Wind Turbines Become Ill" by Magda Havas and David Colling.
6. Stray voltage is a serious issue in any setting but exacerbated by the rural environment in which these industrial wind turbines are proposed.
7. The effects of stray voltage on both humans and livestock are well-known to be detrimental.

8. Attached and marked as **Exhibit C** is a true copy of "Relationship of Electric Power Quality to Milk Production of Dairy Herds — Field Study with Literature Review" by Donald Hillman, *et al.*

9. In a community that relies on the health of its livestock to earn a living, the detrimental effects of stray voltage from above-ground power lines could have a direct impact on the lives of the residents of Bluewater.

10. In addition, the inconvenience and health risks associated with above-ground electrical power lines is a serious concern for Bluewater. As a municipality, the prospect of downed roadside power lines falling on a passing vehicle or causing a road to be closed until it is repaired is not one we wish to see.

11. I have been informed by the Roads Superintendent that there have been a number of incidents in recent years wherein municipal roads have been closed due to fallen power lines. It is necessary to close these roads until the power lines and supporting poles have been cleared away due to the risk posed to road users.

12. Our submission is that the power lines connecting the industrial wind turbines to the Hydro One electricity network should be buried in their entirety so as to ensure that the quality of the electricity provided under the FIT contract awarded to Varna Wind Inc. is preserved and so that residents of Bluewater are not made to suffer harm or inconvenience as a result of, but not limited to, stray voltage and/or downed power lines.

SWORN BEFORE ME at the)
Municipality of Bluewater in the Province)
of Ontario, this 27th day of)
March, 2013)

[signature]

A commissioner etc.

CHARLENE OVERHOLT
DEPUTY CLERK
MUNICIPALITY OF BLUEWATER
A COMMISSIONER, ETC.
IN THE COUNTY OF HURON

[signature]

STEPHEN MCAULEY

This is Exhibit "A" referred to in the Affidavit of STEPHEN MCAULEY sworn before me on this 27th day of March, 2013.

A Commissioner, etc.

CHARLENE OVERHOLT
DEPUTY CLERK
MUNICIPALITY OF BLUEWATER
A COMMISSIONER, ETC.
IN THE COUNTY OF HURON

Stephen McAuley, C.Tech.

[redacted]
Denfield Ontario
N0M 1P0

Res: [redacted]
Cell. [redacted]
Email: [redacted]

SUMMARY OF QUALIFICATIONS

- Proven managerial abilities within a municipal environment
- Effective communication and interpersonal skills
- Willingness to accept and undertake new challenges
- Fully versed in applicable municipal legislation
- Extensive experience in overseeing projects, concept to completion
- Wide range of technical experience in both design and construction
- Proven ability to effectively prioritize for a broad range of responsibilities

DEMONSTRATED AREAS OF EXPERTISE

Strategic Planning	**Public Presentations**	**Emergency Planning**
Program Development	**Negotiations**	**Human Resource Development**
OMB Expert Witness	**Interpersonal Skills**	**Leadership**
Multi-million Dollar Budgets	**Team Building**	**Productivity Improvements**

MAJOR ACHIEVEMENTS

Municipal Operations

- As the Manager of Public Works, I am responsible for the overall operation of the environmental services, transportation, and drainage divisions including 6 full time staff and 2 part-time staff with a total budget in excess of $3 million.
- Operated self-funded departments required to generate revenue through various activities.
- Responsible for all compliance issues related to the operation of the various departments.
- Responsible for subdivision review and planning negotiations and developer requirements during construction.
- Acted as municipal representative in arbitration between the First Nations and developers being carried out under the Cemeteries Act.

General Municipal Administration

- Acted as Chief Administrative Officer for Thames Centre for six (6) months while the Council conducted a search for a candidate to fill the position permanently.
- Interacted directly with all members of Council and departmental staff during this time to ensure the business of the Municipality was effectively carried out.
- Currently acting as an alternate Community Emergency Management Coordinator for the municipality.
- Designated as a Municipal Law Enforcement officer.

Budgeting

- Effectively created and managed municipal budgets up to $7 million dollar annually.
- Oversee and direct the fiscal, program and regulatory affairs of the Environmental Services and the Transportation Departments within the Municipality.
- Prepare and compile the annual estimates of revenues and expenditures required to effectively set a departmental budget.
- Approve all invoicing related to operating and capital expenditures
- Supervise contracts for external consultants.
- Negotiated contract renewals for various contracted services.
- Completed various successful grant applications for specific infrastructure projects.
- Developed a full fleet inventory replacement program and planned for capital costs replacement program.

Legislative Compliance

- Implement all necessary programs to ensure all regulatory requirements are met with regard to the Safe Water Drinking Act.
- Prepare and submit annual reports and applications as follows:
    - Annual Report required under the SWDA
    - Summary Report to Council required under SWDA
- Responsible for engaging and managing the necessary professionals and consultants as required to ensure regulatory compliance.
- Prepare and submit annual financial and tonnage data call for the recycling program.
- Responsible for ensuring Minimum Maintenance Standards are meet for all roads within the jurisdiction of the Municipality.

Human Resources

- Led a team of up to 14 fulltime employees and 5 part-time employees, to effectively deliver the core services of the Municipality.
- Recommend the appointment, employment, suspension or dismissal of employees.
- Involved in collective bargaining for unionized employees.
- Approve all vacation and sick time requests.
- Conducted performance reviews and recommended advancement on salary grid if warranted.

Capital Works

- Prioritized capital works projects based on Council objectives and regulatory requirements.
- Full cost estimates to establish budgets and monitor progress.
- Issue both Requests for Proposals to consultants and full tenders for construction.
- Ensure construction is completed in a timely and cost effective manner.
- Report to the Council and the CAO on the progress of all capital projects.

Certifications

- Member of the Ontario Association of Certified Technicians and Technologists as a Civil Engineering Technician.
- Participated in round table discussions with MOE representatives regarding the definition of "Standard of Care" as defined under the Safe Water Drinking Act.
- Completed the Community Emergency Management Coordinator Course as offered by Emergency Management Ontario
- Completed the Drainage Superintendents Course as offered by Ontario Ministry of Agriculture, Food and Rural Affairs.

HIGHLIGHTED EXPERIENCE

Professional

2007 – Present	Public Works Manager Township of Lucan Biddulph
Apr/05 – Sept/05	Acting Chief Administrative Officer Municipality of Thames Centre
2003 - 2007	Director of Operations Municipality Of Thames Centre
2001 – 2003	Project Manager Stantec Consulting Ltd.
1998 – 2001	Senior Design Technician Stantec Consulting Ltd.
1992 – 1998	AutoCAD Operator (Designer/Draftsman) Stantec Consulting Ltd.
1990 - 1992	AutoCAD Operator (Designer / Draftsman) MacLaren Engineers Ltd.

Education and Training:

Mechanical Engineering Technology, 1987
Fanshawe College, London, Ontario

Certified AutoCAD Operator, 1991
Autodesk

Operation of a Small Drinking Water System Course, 2002
Ontario Environmental Training Consortium

OWRA, 2002
Operator in Training certification in the following:

Wastewater Treatment, Wastewater Collection Systems, and Water Treatment

Filter Operation and Maintenance Seminar, 2003
Ontario Water Works Association

Asset Management Seminar, 2005
Ontario Public Works Association

Community Emergency Management Coordinator Course, 2005
Emergency Management Ontario

Drainage Superintendents Course, 2007
Ontario Ministry of Agriculture, Food and Rural Affairs

Las Energy Management Planning Workshop, 2011
Natural Resources Canada

Currently completing AMCTO Municipal Administration Program
Completed units 1, 2, 3 and 4 of the MAP program, waiting to complete the comprehensive exam

Accreditation:

Certified Engineering Technician (C.Tech.) – Ontario Association of Certified Engineering Technicians and Technologists

Certified Community Emergency Management Coordinator with Emergency Management Ontario

Certified Ontario Municipal Drainage Superintendant with OMFRA

Community Involvement:

President of the Middlesex County Roads Superintendants (member of AORS)
Past Director and member of the Ilderton Lions Club
Past President of the Elgin Middlesex Chiefs AAA Hockey Association

This is Exhibit "B" referred to in the Affidavit of STEPHEN MCAULEY sworn before me on this 27th day of March, 2013.

____

A Commissioner, etc.

CHARLENE OVERHOLT
DEPUTY CLERK
MUNICIPALITY OF BLUEWATER
A COMMISSIONER, ETC.
IN THE COUNTY OF HURON

Bulletin of Science, Technology & Society

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Wind Turbines Make Waves: Why Some Residents Near Wind Turbines Become Ill

Magda Havas and David Colling

Bulletin of Science Technology & Society published online 30 September 2011
DOI: 10.1177/0270467611417852

The online version of this article can be found at:
http://bst.sagepub.com/content/early/2011/08/24/0270467611417852

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Bulletin of Science, Technology & Society
XX(X) 1–13

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DOI: 10.1177/0270467611417852
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Magda Havas[1] **and David Colling**[2]

Abstract

People who live near wind turbines complain of symptoms that include some combination of the following: difficulty sleeping, fatigue, depression, irritability, aggressiveness, cognitive dysfunction, chest pain/pressure, headaches, joint pain, skin irritations, nausea, dizziness, tinnitus, and stress. These symptoms have been attributed to the pressure (sound) waves that wind turbines generate in the form of noise and infrasound. However, wind turbines also generate electromagnetic waves in the form of poor power quality (dirty electricity) and ground current, and these can adversely affect those who are electrically hypersensitive. Indeed, the symptoms mentioned above are consistent with electrohypersensitivity. Sensitivity to both sound and electromagnetic waves differs among individuals and may explain why not everyone in the same home experiences similar effects. Ways to mitigate the adverse health effects of wind turbines are presented.

Keywords

wind turbine, dirty electricity, power quality, ground current, contact current, electrohypersensitivity, noise, infrasound, vibroacoustic disease, wind turbine syndrome

Introduction

With growing concern about climate change, the carbon budget, depletion of fossil fuels, air pollution from dirty coal, radiation from nuclear power plants, and the need for a secure energy supply, more attention and funding are being diverted to renewable energy. Among the various types of renewable energy, wind has received a lot of attention due, in part, to opposition from communities earmarked for wind turbines and from communities that have experienced wind turbines firsthand.

Some people who live near wind turbines report difficulty sleeping and various symptoms of ill health and attribute these problems to noise and shadow flicker—two elements they can perceive. Indeed the U.S. National Research Council (Risser et al., 2007) identify noise and shadow flicker as the two key impacts of wind turbines on human health and well-being.

Not all health agencies, however, recognize that sound waves from wind turbines may cause adverse health effects. Following a review of the literature, the Chief Medical Officer of Health for Ontario (2010), concluded

> that while some people living near wind turbines report symptoms such as dizziness, headaches, and sleep disturbance, the scientific evidence available to date does not demonstrate a direct causal link between wind turbine noise and adverse health effects. The sound level from wind turbines at common residential setbacks is not sufficient to cause hearing impairment or other direct health effects, although some people may find it annoying.
>
> Low frequency sound and infrasound from current generation upwind model turbines are well below the pressure sound levels at which known health effects occur. Further, there is no scientific evidence to date that vibration from low frequency wind turbine noise causes adverse health effects.

What specifically is responsible for the illness reported near wind turbines is controversial; while some of this controversy is scientifically valid, some of it is politically motivated (Phillips, 2010).

It is intriguing that not everyone in the same home experiences symptoms, and the symptoms are not necessarily worse for those nearest the turbines. Indeed, the situation may be much more complex than noise and shadow flicker.

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Why do some people who live near wind turbines become sick while others feel no ill effects? What aspects of wind power generation and distribution are responsible for the health problems? What can be done to minimize adverse human biological and health effects? These are some of the questions addressed in this report.

Wind Turbines Make Waves

What aspects of wind power generation and distribution are responsible for the adverse health effects experienced by those who live near wind turbines?

The short answer to this question is that *wind turbines make waves*. They make pressure waves and electromagnetic waves. The pressure waves (or sound waves) generated by the moving turbines can be heard as noise and/or perceived as infrasound. The electromagnetic waves are generated by the conversion of wind energy to electricity. This conversion produces high-frequency transients and harmonics that result in poor power quality. These high frequencies can flow along the wires (dirty electricity) and along the ground, thereby causing ground current. These four types of waves—noise, infrasound, dirty electricity, and ground current—and shadow flicker are each likely to contribute to ill health among those who live near wind turbines.

Characteristics of Sound Waves and Electromagnetic Waves

Sound waves are longitudinal waves that require a medium for transport. They travel at the speed of sound (340 meters/second) through air and are much slower than electromagnetic waves that travel at the speed of light (300,000,000 meters/second) and can travel through a vacuum. Both sound waves and electromagnetic waves have a frequency (cycles per second) and an intensity (amplitude of the wave).

Frequency refers to the number of waves or cycles per second and is known as pitch for sound. The A above middle C, for example, is set to a frequency of 440 cycles per second (hertz, abbreviated as Hz). The audible range for the human ear is between 20 and 20,000 Hz. Frequencies below 20 Hz are referred to as "infrasound," and, although they cannot be heard, they can still have an effect on the body. Infrasound can travel much greater distances than higher frequency sound waves and could potentially reach and affect a much larger population.

The frequencies of electromagnetic waves, generated by wind turbines, fall within two ranges of the electromagnetic spectrum: extremely low frequency (ELF), below 1,000 Hz; and the lower range (kilohertz [kHz] to megahertz [MHz]) of the radio frequency radiation (RFR) band. Electromagnetic waves can enter homes by various paths: through the air, along wires, through the ground, and via plumbing and other metal structures. Electromagnetic waves travelling across the ground contribute to ground current.

Intensity is measured by the amplitude of the wave and, for sound, is measured in decibels (dB). Vibrations with the same frequency but different amplitude will sound the same, but one will be louder than the other. The decibel scale is logarithmic. A quiet bedroom is at 25 dB, conversation is around 60 dB, a rock group is at 110 dB, and the human threshold of pain is at 140 dB.

The intensity of electromagnetic waves is measured in various ways: electric field, magnetic field, voltage, current, and power density. The biological effects of electromagnetic energy are a function of frequency, intensity, and both the manner and the duration of exposure.

Pressure Waves: Noise

Most people who live near wind turbines and complain of ill effects blame the effects on the noise generated by the turbines (Frey & Hadden, 2007).

> Everything changed . . . when the wind turbines arrived . . . approximately 700 metres away from our property . . . Within days of the windfarm coming into operation we began to hear a terrible noise . . . The noise drove us mad. Gave us headaches. Kept us awake at night. Prevented us from having windows and doors open in hot weather, and was extremely disturbing.
>
> This noise is like a washing machine that's gone wrong. It's whooshing, drumming, constant drumming, noise. It is agitating. It is frustrating. It is annoying. It wears you down. You can't sleep at night and you can't concentrate during the day . . . It just goes on and on . . . It's torture . . . [4 years later] You just don't get a full night's sleep and when you drop off it is always disturbed and only like "cat napping." You then get up, tired, agitated and depressed and it makes you short-tempered . . . Our lives are hell.

The French National Academy of Medicine (Chouard, 2006) issued a report that concludes,

> People living near the towers, the heights of which vary from 10 to 100 meters, sometimes complain of functional disturbances similar to those observed in syndromes of chronic sound trauma . . .
>
> The sounds emitted by the blades being low frequency, which therefore travel easily and vary according to the wind . . . constitute a permanent risk for the people exposed to them . . .
>
> . . . sound levels 1 km from an installation occasionally exceeded allowable limits.
>
> . . . the Academy recommends halting wind turbine construction closer than 1.5 km from residences. (Translated from French)

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Noise, especially at night, has been associated with an increase in stress hormones leading to hypertension, stroke, heart failure, and immune problems. It is discussed in greater detail elsewhere in this journal.

Pressure Waves: Infrasound

Repetitive noise can be disturbing, especially at night, when sound seems amplified. However, pressure waves at levels outside the range of human hearing can also have unpleasant side effects.

In Nova Scotia, one family was unable to remain in their home and blamed their loss of sleep and headaches on vibrations from 17 turbines (Keller, 2006).

> The d'Entremont family complained of noise and low frequency vibrations in their house after the wind turbines began operation in May 2005. The inaudible noise deprived his family of sleep, gave his children and wife headaches, and "made it impossible for them to concentrate." They now live nearby; if they return to their home, the symptoms return.
>
> Natural Resources Canada, which oversees funding for wind farm projects, found no problems with low-frequency noise or infrasound. The government report concludes that the measurements:
>
> indicate sound at infrasonic frequencies below typical thresholds of perception; infrasound is not an issue. (cited in Frey & Hadden, 2007)

Gordon Whitehead, a retired audiologist with 20 years of experience at Dalhousie University in Halifax, conducted tests and found similar results but came up with a different conclusion:

> They're [Natural Resources Canada] viewing it from the standpoint of an engineer; I'm viewing it from the standpoint of an audiologist who works with ears . . . The report should read that (the sound) is well below the auditory threshold for perception. In other words, it's quiet enough that people would not be able to hear it. But that doesn't mean that people would not be able to perceive it.
>
> " . . . low-frequency noise can affect the balance system of the ear, leading to a range of symptoms including nausea, dizziness and vision problems. It's not perceptible to the ear but it is perceptible. It's perceptible to people with very sensitive balance mechanisms and that's generally people who get very easily seasick.

Resonance may explain why infrasound is harmful at low intensities. Different parts of the human body have different resonance frequencies. When the external frequency generated by a wind turbine approaches the resonance frequency of a part of the human body, that body part will preferentially absorb the energy and begin to vibrate. For example, frequencies that affect the inner ear (between 0.5 and 10 Hz) can interfere with balance, cause dizziness or vertigo, contribute to nausea, and be experienced as tinnitus or ringing in the ears. According to the International Standards Organization (ISO Standards 2631), frequencies for the eye are between 20 and 90 Hz, head 20 and 30 Hz, chest wall 50 and 100 Hz, abdomen 4 and 8 Hz, and spinal column 10 and 12 Hz. Some of the symptoms documented at infrasonic frequencies (between 4 and 20 Hz) include general feeling of discomfort, problems with breathing, abdominal and chest pain, urge to urinate, lump in throat, effect on speech, and head symptoms (Frey & Hadden, 2007).

According to a report by the U.S. Air Force, Institute for National Security Studies, acoustic infrasound can have dramatic and serious effects on human physiology (Bunker, 1997).

> Acoustic, infrasound: very low frequency sound which can travel long distances and easily penetrate most buildings and vehicles. Transmission of long wavelength sound creates biophysical effects, nausea, loss of bowels, disorientation, vomiting, potential organ damage or death may occur. Superior to ultrasound because it is "inband," meaning it does not lose its properties when it changes mediums such as air to tissue. By 1972 an infrasound generator had been built in France, which generated waves at 7Hz. When activated it made the people in range sick for hours.

In a paper known as "The Darmstadt Manifesto," published in September 1998 by the German Academic Initiative Group and endorsed by more than 100 university professors in Germany, the German experience with wind turbines is described as follows (cited in Frey & Hadden, 2007):

> More and more people are describing their lives as unbearable when they are directly exposed to the acoustic and optical effects of wind farms. There are reports of people being signed off sick and unfit for work, there is a growing number of complaints about symptoms such as pulse irregularities and states of anxiety, which are known to be from the effects of infrasound [sound frequencies below the normal audible limit].

Infrasound is influenced by topography, distance, and wind direction (Rogers, Manwell, & Wright, 2006) and differs from home to home and room to room because each room is a distinct cavity with its own resonant frequency. Whether a door is open or closed can alter the effect.

The biological effects of low-frequency noise (20-100 Hz) and infrasound (less than 20 Hz) are a function of intensity, frequency, duration of exposure, and direction of the vibration.

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Wind Turbine Syndrome and Vibroacoustic Disease

Exposure to low-frequency noise and infrasound may produce a set of symptoms that include depression, irritability, aggressiveness, cognitive dysfunction, sleep disorder, fatigue, chest pain/pressure, headaches, joint pain, nausea, dizziness, vertigo, tinnitus, stress, heart palpitations, and other symptoms. Not everyone has the same sensitivity. Those who experience motion sickness (car, boat, plane), get dizzy or nauseous on carnival rides, have migraine headaches, or have eye or ear problems may be particularly susceptible to low-frequency vibrations.

Two different "diseases" have been associated with low-frequency noise exposure and infrasound. They are wind turbine syndrome—coined by Pierpont (2009) in her book by the same name—and vibroacoustic disease (VAD). VAD is a whole-body, systemic pathology characterized by the abnormal proliferation of extracellular matrices and caused by excessive exposure to low-frequency noise (Castelo Branco & Alves-Pereira, 2004). These two "diseases" differ as described by Pierpont (2009).

> Wind Turbine Syndrome, I propose, is mediated by the vestibular system—by disturbed sensory input to eyes, inner ears, and stretch and pressure receptors in a variety of body locations. These feed back neurologically onto a person's sense of position and motion in space, which is in turn connected in multiple ways to brain functions as disparate as spatial memory and anxiety. Several lines of evidence suggest that the amplitude (power or intensity) of low frequency noise and vibration needed to create these effects may be even lower than the auditory threshold at the same low frequencies.
>
> Vibroacoustic Disease, on the other hand, is hypothesized to be caused by direct tissue damage to a variety of organs, creating thickening of supporting structures and other pathological changes. The suspected agent is high amplitude (high power or intensity) low frequency noise. (p. 13)

VAD seems to be dose dependent, with symptoms becoming progressively worse with continued exposure. Three stages have been identified based on 70 aircraft technicians who, presumably, were exposed to much higher intensities of low-frequency noise than those who live near wind turbines (Castelo Branco, 1999, Castelo Branco & Alves-Pereira, 2004).

Stage 1: Mild, 1 to 4 years, slight mood swings, indigestion, heartburn, mouth/throat infections, bronchitis

Stage 2: Moderate, 4 to 10 years, depression, aggressiveness, pericardial thickening, light to moderate hearing impairment, chest pain, definite mood swings, back pain, fatigue, skin infections (fungal, viral, parasitic), inflammation of stomach lining, pain during urination, blood in urine, conjunctivitis, allergies

Stage 3: Severe, more than 10 years, myocardial infarction, stroke, malignancy, epilepsy, psychiatric disturbances, hemorrhages (nasal, digestive, conjunctive mucosa), varicose veins, hemorrhoids, duodenal ulcers, colitis, decrease in visual acuity, headaches, severe joint pain, intense muscular pain, neurological disturbances

Whatever name is given to the symptoms, the symptoms are real and can be caused by low-frequency sound waves and infrasound.

Electromagnetic Waves

One undesirable consequence of wind-generated electricity is poor power quality due to variable weather conditions, mechanical construction of the towers, and the electronic equipment used (Lobos, Rezmer, Sikorski, & Waclawek, 2008). Electricity in North America has a frequency of 60 Hz and is a sine wave when viewed on an oscilloscope (Figure 1). When a wind turbine generates electricity, the frequency must be converted to 60 Hz by power converters; that conversion generates a large spectrum of current and voltage oscillations leading to poor power quality (Lobos et al., 2008). Wind turbines can generate a wide range of frequencies—from less than 1 Hz (Lobos et al., 2008), with the majority of the frequencies in the kHz range associated with power conversion.

Dirty Electricity

High-frequency transient spikes that contribute to poor power quality, also known as dirty electricity, can flow along wires, damage sensitive electronic equipment, and adversely affect human and animal health.

After wind turbines were activated in Ripley, Ontario, several of the residents complained of ill health. Residents suffered from headaches, poor sleep, elevated blood pressure (requiring medication), heart palpitations, itching, ringing and pain in the ears, watering eyes, and pressure on the chest causing difficulty breathing. These symptoms disappear when the residents leave the area. Some residents were forced to move out of their homes because the symptoms were so severe. Locals complain of headaches and poor radio reception when they drive near these power lines.

One of the authors (DC) measured the power quality near several residences where people were unwell. The primary neutral-to-earth voltage (PNEV) is the electrical potential difference between the earth and the neutral wire on the primary distribution line, as shown in Figure 2. Measurements taken before wind turbines were installed and after they were installed and operating (Figure 3) clearly show the distortion (spikes on the waveform) generated by the wind turbines.

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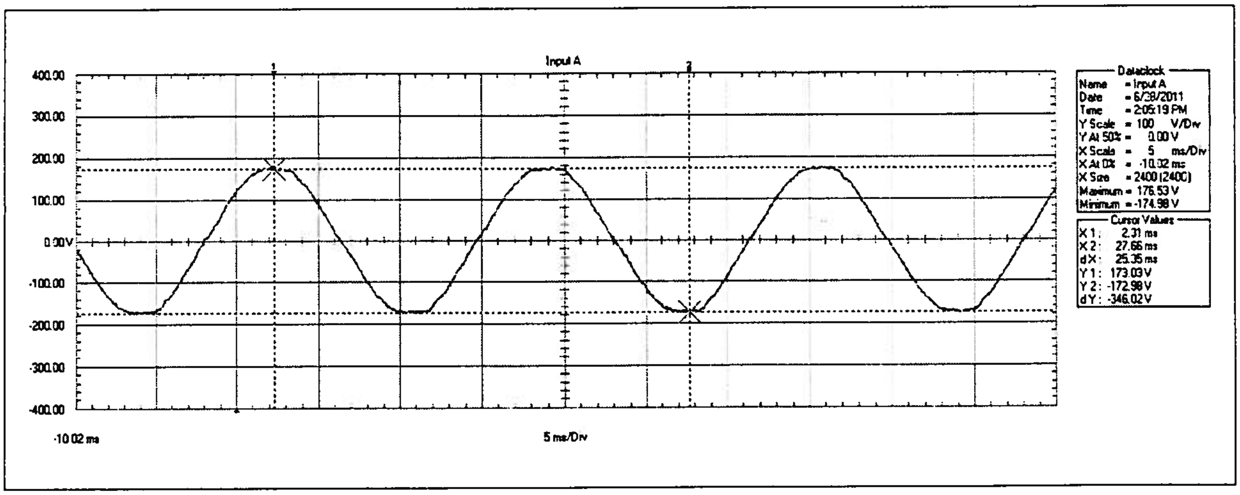

Figure 1. Good power quality exemplified by the 60-Hz sine wave

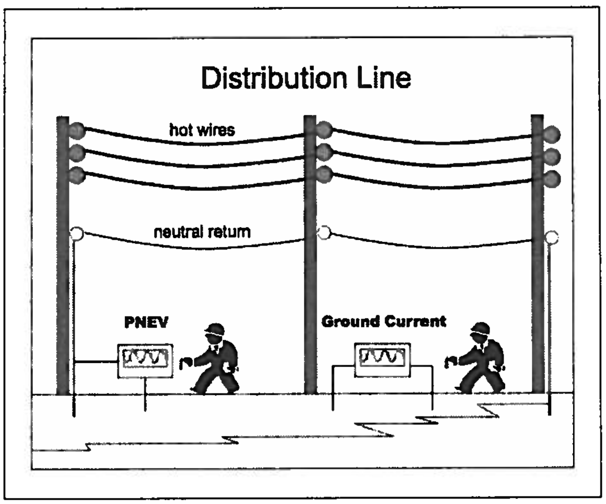

Figure 2. Diagram demonstrating how primary neutral-to-earth voltage (PNEV) and ground voltage measurements are taken

In this area, wind turbines are variable speed and are interconnected. The collection lines connecting the wind turbines to the substation are attached to the same utility pole as the home owners' lines.

According to one of the authors (DC; September 30, 2008),

> We had four families move out of their homes and now if I spend too much time in these homes I get the same symptoms, which is ear aches, ringing in the ears and pressure in the ears. [name removed] eventually buried a portion of the line but have only isolated the lines by insulators so it is better, however there is still some high frequency coming into the houses. The three families that now have buried lines are back in their homes, but things are far from ideal.

Dirty electricity in the kHz range affects human health; this has been shown in schools and homes in both Canada and the United States. Power quality can be improved both on electrical wires by using power line filters (Ontario Hydro, 1998) and inside buildings by using special surge suppressors or power filters that dampen the voltage spikes (http://www.stetzerelectric.com).

In one Wisconsin School that had "sick building syndrome," once power quality was improved, the health of both teachers' and students' improved. According to the school nurse, both staff and students have more energy, fewer allergies, and fewer migraine headaches, and asthmatics rely less on their inhalers (Havas, 2006a).

In a Toronto School, improvements in power quality were accompanied by improvements in teachers' health and students' behavior. Teachers were less tired, less frustrated, less irritable; they had better health and more energy; they had a greater sense of satisfaction and accomplishment; they were more focused and experienced less pain. Students' behavior also improved especially in the elementary grades (Havas, Illiatovitch, & Proctor, 2004). Similar results were reported in a placebo-blinded study in three Minnesota schools (Havas & Olstad, 2008).

Dirty electricity has been associated with increased risk of various types of cancers among teachers in a California school (Milham & Morgan, 2008), with higher blood sugar levels among diabetics, and with exacerbation of tremors and difficulty walking among those with multiple sclerosis (Havas, 2006b). People who are adversely affected by dirty electricity are classified as electrically hypersensitive.

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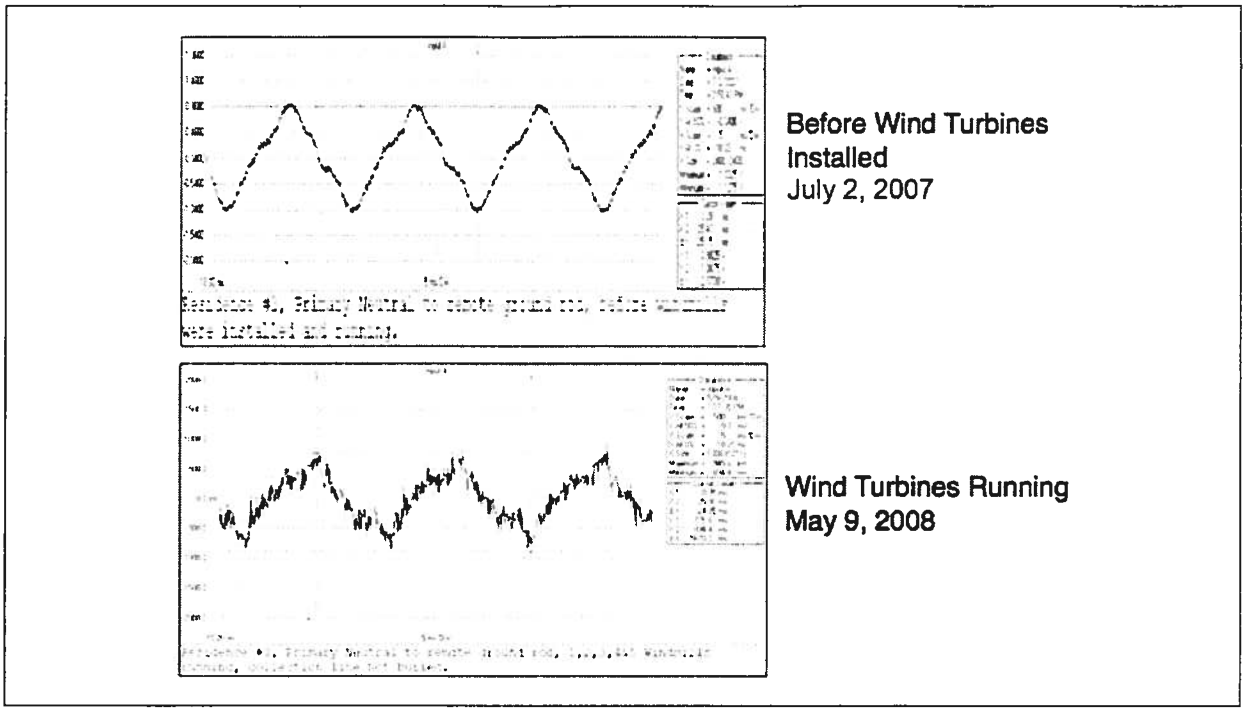

Figure 3. Primary neutral-to-earth voltage (PNEV) at Residence No. 3 in Ripley, Ontario, before wind turbines were installed (July 2, 2007) and when five wind turbines were operating (May 9, 2008)
Note. Collection line was not buried.

Ground Current

Just as dirty electricity can flow along wires, it can also flow along the ground resulting in ground current. Ground current (often measured as voltage and called stray voltage or tingle voltage) is a serious problem in certain locations and has been shown to adversely affect the health of farm families and the health and productivity of farm animals, especially dairy cattle.

The Ontario Federation of Agriculture (2007) provides information on symptoms experienced by farm animals, pets, and people who are exposed to tingle voltage as follows:

> Farmers and their families who suffer from immune disorders such as allergies or rheumatoid arthritis find their symptoms worsen or go into remission in close coordination with livestock symptoms. Periods of fatigue increase. Sleep disorders may increase.
>
> Cats leave the farm, become ill, cease to bear litters or have small, unhealthy litters, or die; coats are usually dull and shaggy and eyes are runny.
>
> Horses may paw the ground and shy away from watering or feeding troughs; behaviour and handling becomes more difficult.
>
> Pigs often take to ear and tail biting; mastitis and baby pig scours are common; piglet mortality may increase.
>
> Cattle lap water from the trough or bowl; feed in the bottom of the manger is not cleaned up; milk out is slow and uneven; cows are reluctant to enter the milk parlour and quick to leave; slow growth in calves and heifers; somatic cell counts are high; unexplained spontaneous abortions of calves; bulls become markedly more irritable.

According to the *National Electrical Safety Code (NESC) Handbook* (Clapp, 1997),

> When the earth returns were used in some rural areas prior to the 1960's, they became notorious offenders in dairy areas because circulating currents often cause both step and touch potentials.
>
> In some cases, they have adversely affected milking operations by shocking the cattle when they were connected to the milking machines, and have affected feeding. (p. 152)

According to Lefcourt (1991) in the U.S. Department of Agriculture book titled *Effects of Electrical Voltage/Current on Farm Animals: How to Detect and Remedy Problems*:

> The effect of a transient voltage superimposed on the regular power voltage (dc or ac) is to cause a momentary

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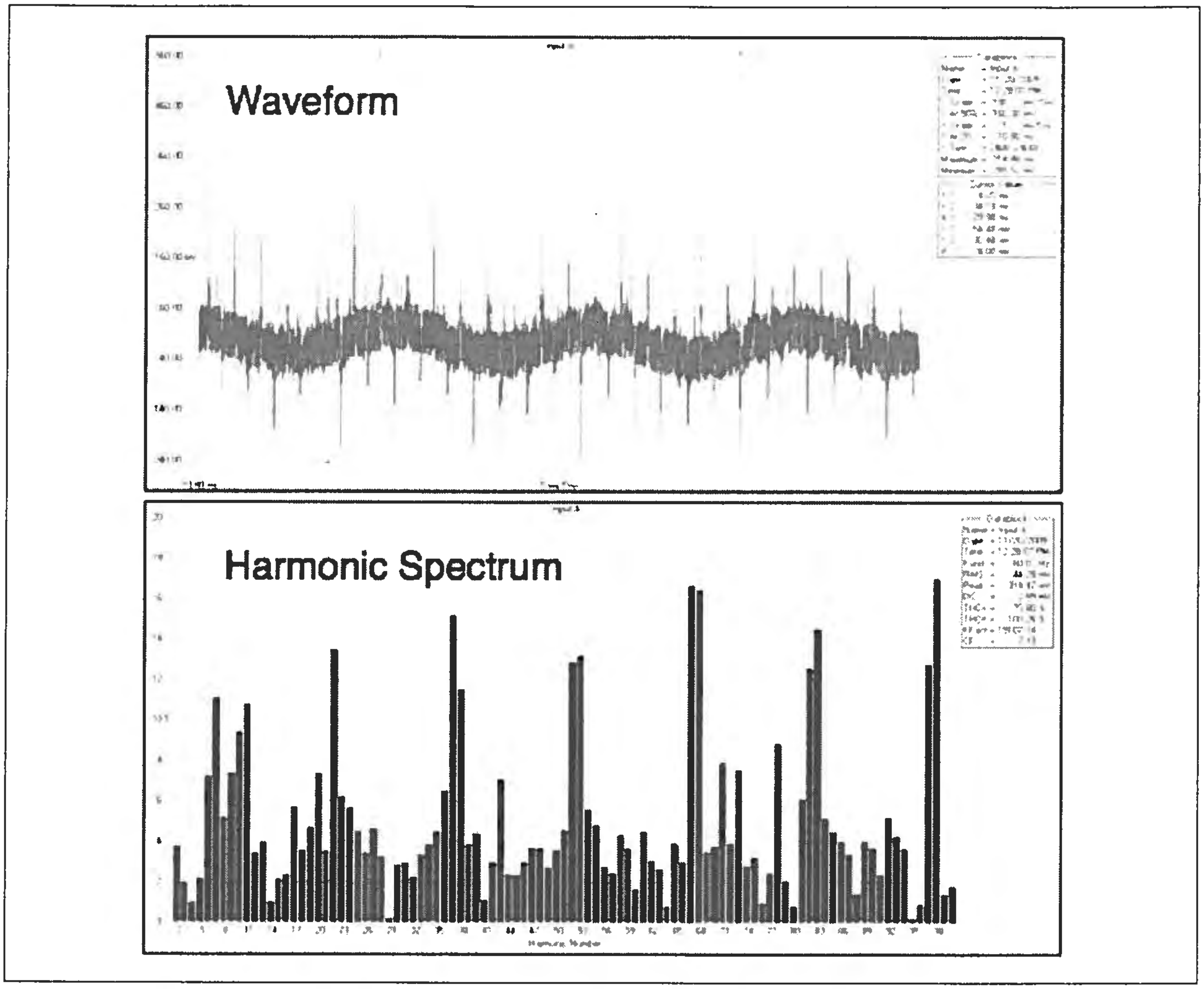

Figure 4. Ground voltage measured at the Palm Springs wind farm in California using 50 feet of copper wire attached to two metal rods in the earth
Note. The top graph shows the distorted 60-Hz waveform, and the bottom graph shows the harmonic frequencies. Data courtesy of Dr. Sam Milham.

> change in the waveform. When the transient causes the momentary voltage to be greater than normal, it may cause a transient current to flow in an animal. If the transient waveform has sufficient energy (magnitude and duration), there may be an animal response. (p. 63-64)

Indeed, dirty electricity flowing along the ground may be more harmful to farm animals than the 60-Hz ground current (Hillman et al., 2003):

> Cows were sensitive to harmonic distortions of step-potential voltage, suggesting that utility compliance with IEEE standards on dairy farms may need to be addressed.
>
> Power quality varied greatly from farm to farm and day to day. Milk production responses to changes in power quality varied inversely with the number of transient events recorded with event recorders, oscilloscope, and power quality meters. Harmonics often gave better estimates of electrical effects on milk production than voltage *per se.* (p. 19)

Do wind turbines generate ground current? They can if proper safeguards are not taken. Generally, this is a problem with power distribution once the energy leaves the turbine.

Figure 4 shows the waveform of ground voltage near an industrial wind farm in Palm Springs, California (as shown in Figure 5 photographs). The waveform distortion in Figure 3 and 4 are considerable when compared with Figure 1.

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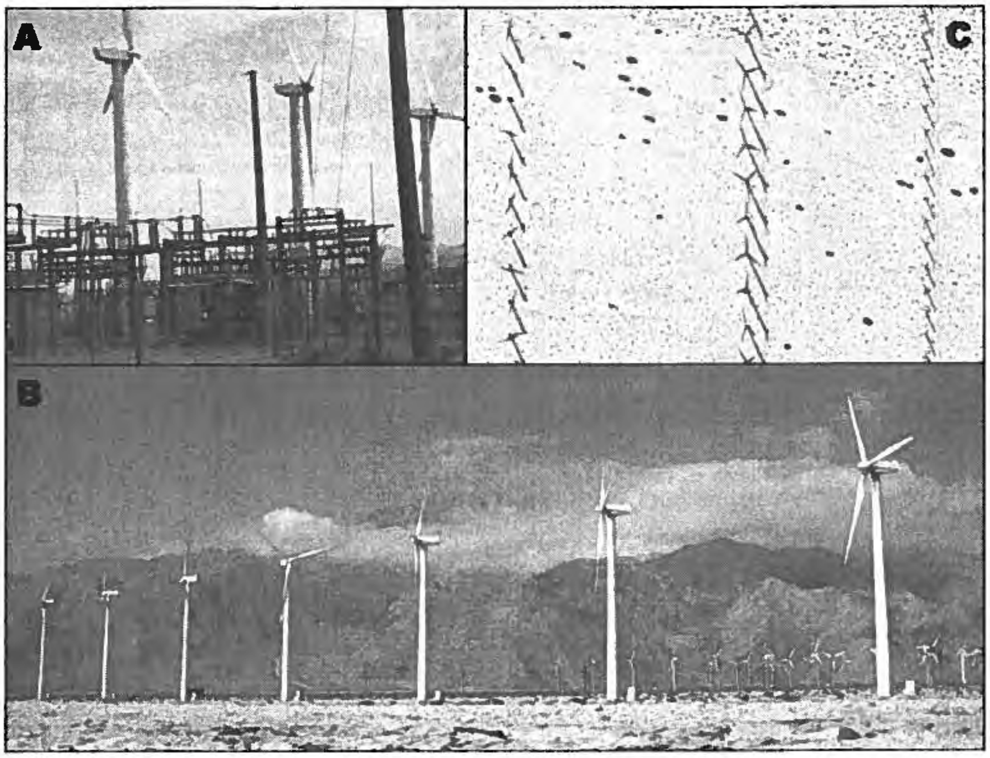

Figure 5. Wind farm in Palm Springs, California, showing (A) location of ground voltage readings; (B), view of wind turbines from the ground; and (C) view of wind turbines from the air
Note. Photograph A from Dr. Sam Milham. Photographs B and C from Google maps.

Burying the collection line may not eliminate the ground voltage but can improve power quality, as shown in Figure 6.

Just as animals are adversely affected by dirty ground current, so are people. If ground current enters a home via the plumbing, touching any part of the plumbing (e.g., faucet) induces a current in the body, known as contact current.

In one Ripley home, the frequency fingerprint (relative intensities of various frequencies) on the plumbing (sink to floor measurement) was similar to the PNEV, indicating that the source of the ground voltage was the wind turbines' collection line (Figure 7). In this home, the sink to floor contact current was calculated to be 400 microamperes (peak to peak based on 200 millivolts and 500 ohms), and this value is 22 times higher than levels associated with cancer according to Kavet, Zaffanella, Daigle, and Ebi (2000).

> "The absolute (as well as modest) level of contact current modeled (18 micro Amps) produces average electric fields in tissue along its path that exceed 1 mV/m. At and above this level, the NIEHS Working Group [1998] accepts that biological effects relevant to cancer have been reported in "numerous well-programmed studies." (p. 547)

Wertheimer, Savitz, and Leeper (1995) documented the link between ground current and cancer in Denver, Colorado. They found that leukemia risk increased by 300% among children exposed to elevated magnetic field from ground current that enters the home through conductive plumbing.

Electrohypersensitivity (EHS)

Why do some people who live near wind turbines become sick while others feel no ill effects?

Exposure to both pressure waves and electromagnetic waves is highly variable—spatially and temporally—as is sensitivity to these vibrations. Not everyone in the same home is going to have the same exposure or the same sensitivity. People who have balance problems, experience motion sickness, or have ear or eye problems are more likely to react to low-frequency sound vibrations. Those who are electrically hypersensitive are more likely to suffer from dirty electricity

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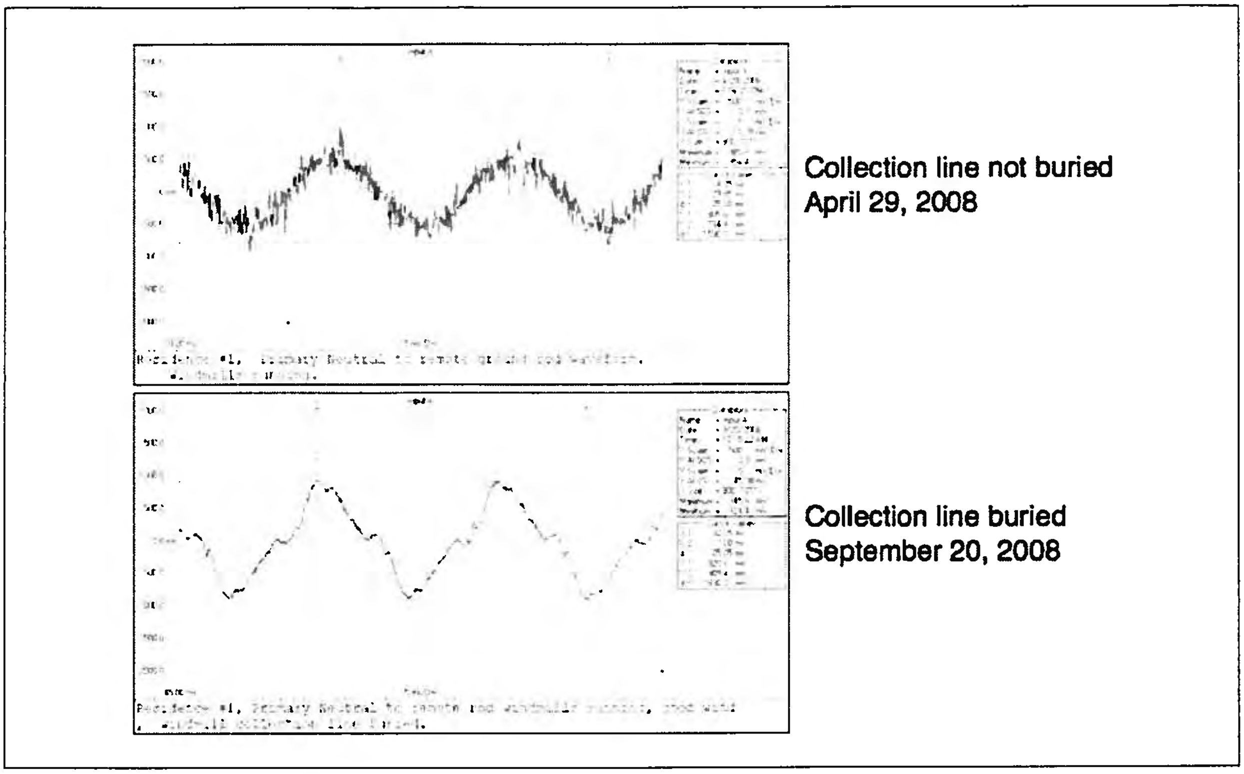

Figure 6. Primary neutral-to-earth voltage (PNEV) at Residence 1 in Ripley, Ontario, when wind turbines were operating
Note. Collection line from wind turbines was buried on September 20, 2008 (bottom graph), but not on April 29, 2008 (top graph).

and contact current. As a result, people living in the same home may have very different sensitivities and may respond differently to these vibrations.

At the Working Group meeting on EMF Hypersensitivity in Prague, the World Health Organization (2004) described electrosensitivity as

> a phenomenon where individuals experience adverse health effects while using or being in the vicinity of devices emanating electric, magnetic, or electromagnetic fields (EMFs).
>
> Whatever its cause, EHS is a real and sometimes a debilitating problem for the affected persons, while the level of EMF in their neighborhood is no greater than is encountered in normal living environments. Their exposures are generally several orders of magnitude under the limits in internationally accepted standards.

Symptoms include cognitive dysfunction (memory, concentration, problem solving); fatigue and poor sleep; body aches and headaches; mood disorders (depression, anxiety, irritability, frustration, temper); nausea; problems with balance, dizziness, and vertigo; facial flushing, skin irritations, and skin rashes; chest pressure, rapid heart rate, and altered blood pressure; ringing in the ear (tinnitus); and nosebleeds. A comprehensive list of the symptoms is provided in Table 1.

In Sweden, EHS is recognized as a functional impairment (not as a disease). Between 230,000 and 290,000 Swedes (about 3% of the Swedish population) may be electrohypersensitive (Johansson, 2006). The number of people complaining of EHS seems to be increasing as is the medication sold to deal with the symptoms of insomnia, pain, fatigue, depression, and anxiety. By 2017, as many as 50% of the population may experience these symptoms (Hallberg & Oberfeld, 2006).

Some individuals may have a predisposition to EHS. Those who have experienced physical trauma to their nervous system (whiplash), electrical trauma in the form of multiple shocks or several severe shocks, and/or chemical exposure to mercury or pesticides are likely to be more electrically sensitive. Children, the elderly, and those with impaired immune systems are also likely to be more electrically sensitive.

It is not possible to determine which factors are contributing to ill health until appropriate monitoring is conducted and steps are taken to reduce exposure to the offending agents. Monitoring of both electromagnetic waves and pressure waves in homes where people report ill health is highly recommended as are the mitigation techniques mentioned below

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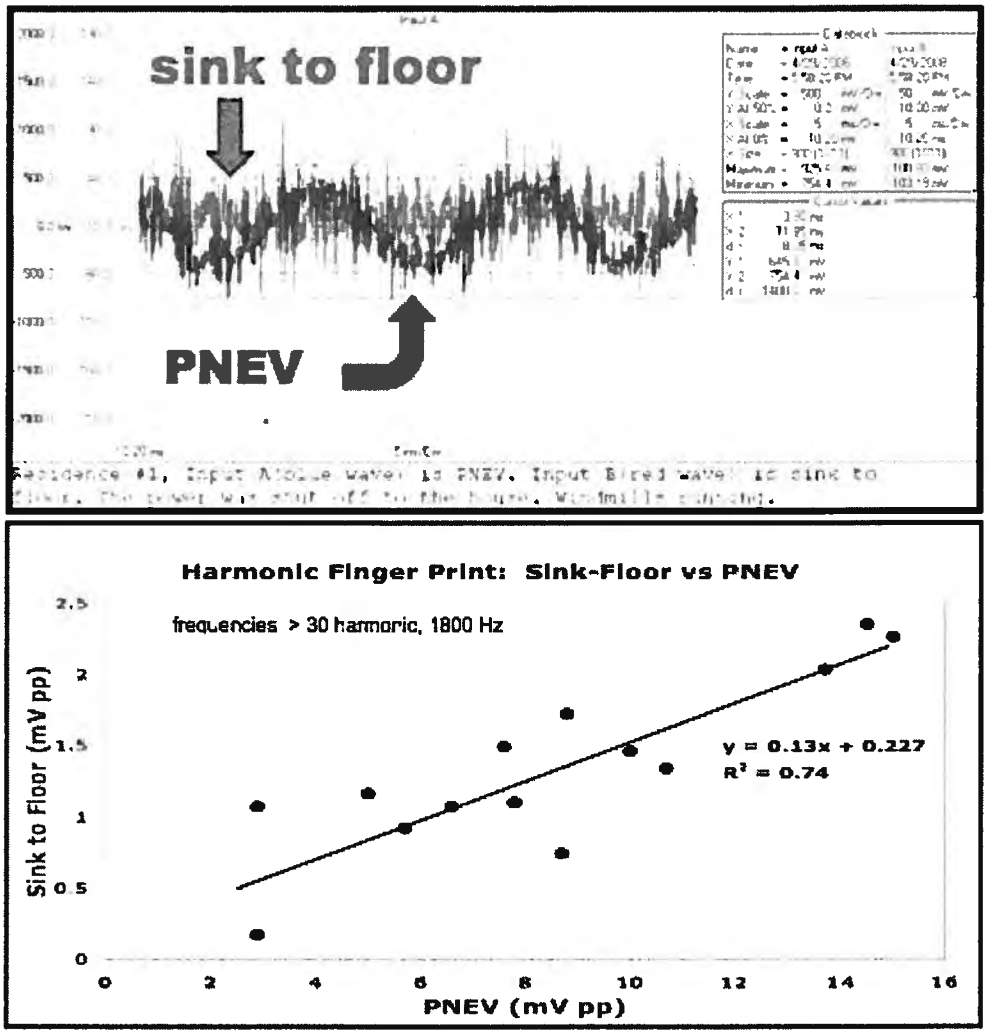

Figure 7. The primary neutral-to-earth voltage (PNEV) and the sink-to-floor voltage for Residence 1 in Ripley, Ontario (top graph), and the harmonic figure print for these voltages (bottom graph).

Recommendations

What can be done to minimize adverse biological and health effects for those living near wind turbines?

One obvious step is to eliminate or reduce exposure to the agent(s) causing the illness.

1. To minimize noise and exposure to infrasound, the following steps should be taken:
   a. Wind turbines should be placed as far away as possible from residential areas. The French National Academy of Medicine (Chouard, 2006) recommends 1.5 km from residential areas.
   b. Buffers can be constructed to disrupt pressure waves and to absorb or deflect sound waves in areas where turbines are closer to homes or where problems have been documented,
2. To improve power quality, the following steps should be taken:
   a. The electricity should be "filtered" at all inverters before it leaves the wind turbine. Ontario Hydro (1998) provides information on power line filters and other ways to improve power quality.
   b. The collector lines from the wind turbines should be attached to utility poles that do not provide power to homes.
   c. Power from the substation supplied by the wind turbines should be filtered before it is distributed to customers.

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Table 1. Comprehensive List of Electrohypersensitivity (EHS) Symptoms (Bevington, 2010)

Auditory	**Dermatological**	**Musculoskeletal**	**Ophthalmologic**
earaches,	brown 'sun spots',	aches / numbness	eyelid tremors/'tics',
imbalance,	crawling sensations,	pain / prickling	impaired vision,
lowered auditory	dry skin,	sensations in:	irritating sensation,
threshold,	facial flushing,	bones, joints &	pain / 'gritty' feeling,
tinnitus	growths & lumps,	muscles in:	pressure behind eyes,
	insect bites & stings,	ankles, arms, feet	shiny eyes,
Cardiovascular	severe acne,	legs, neck,	smarting, dry eyes
altered heart rate,	skin irritation,	shoulders, wrists,	
chest pains,	skin rashes,	elbows, pelvis,	**Other**
cold extremities	skin tingling,	hips, lower back,	**Physiological**
especially hands	swelling of face/neck	cramp / tension in:	abnormal
& feet,		arms, legs, toes,	menstruation,
heart arrhythmias,	**Emotional**	muscle spasms,	brittle nails,
internal bleeding,	anger,	muscular paralysis,	hair loss,
lowered/raised	anxiety attacks,	muscular weakness,	itchy scalp,
blood pressure,	crying,	pain in lips, jaws,	metal redistribution,
nosebleeds,	depression,	teeth with amalgam	thirst / dryness of
shortness of breath,	feeling out of control,	fillings,	lips, tongue, eyes
thrombosis effects	irritability,	restless legs,	
	logorrhoea,	tremor & shaking	**Respiratory**
Cognitive	mood swings,		asthma,
confusion,		**Neurological**	bronchitis,
difficulty in learning	**Gastrointestinal**	faintness, dizziness,	cough /throat irritation,
new things,	altered appetite,	'flu-like symptoms,	pneumonia,
lack of concentration,	digestive problems,	headaches,	sinusitis
short / long-term	flatulence,	hyperactivity,	
memory impairment,	food intolerances	nausea,	**Sensitisation**
spatial disorientation		numbness,	allergies,
	Genito-urinary	sleep problems,	chemical sensitivity,
	smelly sweat / urine,	tiredness	light sensitivity,
	urinary urgency,		noise sensitivity,
	bowel urgency		smell sensitivity

   d. Wind power electrical substations that require power from an external source (electrical distribution network) must ensure that the power quality of this eternal source is not affected as this can result in power quality problems for customers, connected to the same external power source.
   e. Nearby home owners may need to install power line filters in their homes if levels of dirty electricity remain high.
3. To reduce ground current/voltage, the following steps should be taken:
   a A proper neutral system (possibly a five-wire system) should be installed to handle the high-frequency return current in overhead lines (Electric Power Research Institute, 1995).
   b. Insulators can be placed between the neutral line and the grounding grid for the wind turbine.
   c. The collection lines from the wind turbine to the substation should be buried if the other techniques to minimize dirty ground current are ineffective.
   d. Local home owners may need to install stray voltage isolators near their transformers until the electric utility can resolve the problem (Hydro One, 2007).

If these steps are taken, improved quality of life and a feeling of wellness may return to some of the people adversely affected by nearby wind turbines.

Conclusions

A subset of the population living near wind turbines is experiencing symptoms of ill health. These symptoms are likely caused by a combination of noise, infrasound, dirty electricity, ground current, and shadow flicker. These frequencies can be highly viable spatially and temporally and are affected by distance; terrain; wind speed and direction; shape, size, and type of dwelling; type of power converters used; state of the electrical distribution line; type and number of grounding systems; and even the type of plumbing in homes. Furthermore, not everyone has the same sensitivity to sound and electromagnetic radiation nor do they have the

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same symptoms. The following symptoms seem to be quite common: sleeplessness, fatigue, pain, dizziness, nausea, mood disorders, cognitive difficulties, skin irritations, and tinnitus. To help alleviate symptoms in areas where wind turbines have been erected, remediation is necessary to reduce or eliminate both sound waves and electromagnetic waves. More research is required to help us better understand the relative importance of the various factors contributing to poor health. This type of information will enable a healthy coexistence between wind turbines and the people living nearby.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

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Bios

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David Colling has applied his electrical engineering studies at Ryerson Polytechnical Institute and his specialized training in electrical pollution to conduct electrical pollution testing for Bio-Ag on farms, homes, and office buildings. Some of the homes tested are located in the environs of industrial wind turbines.

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This is Exhibit "C" referred to in the Affidavit of STEPHEN MCAULEY sworn before me on this 27th day of March, 2013.

____

A Commissioner, etc.

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A COMMISSIONER, ETC.
IN THE COUNTY OF HURON

Science of the Total Environment 447 (2013) 500–514

Contents lists available at SciVerse ScienceDirect

Science of the Total Environment

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Relationship of electric power quality to milk production of dairy herds — Field study with literature review ☆

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HIGHLIGHTS

- ► Dairy cows were sensitive to earth currents from neutral-to-ground circuit outlets.
- ► Clamp-on ammeters on grounded-Y down grounds give quick current readings.
- ► Harmonic distorted voltage affects cows' behavior, health, and milk production.
- ► Peak-to-peak current must be measured for full impact of current on production.
- ► IEEE standards should include harmonic current effects on human and animal health.

ARTICLE INFO

Article history:
Received 8 November 2012
Received in revised form 21 December 2012
Accepted 22 December 2012
Available online xxxx

Keywords:
Transients
Harmonics
EMF voltage p-p
Power quality
Milk production
Dairy farms

ABSTRACT

Public Utility Commissions (PUC) in several states adopted 0.5 volt rms (root mean squared) or 1.0 milliampere as the actionable limit for utilities to respond to complaints of uncontrolled voltage. This study clearly shows that the actionable level should be reduced to 10 mV p-p (peak-to-peak), which is 140 times less than the current standard. Dairy farmer complaints that animal behavior and milk production were affected by electrical shocks below adopted standards were investigated on 12 farms in Wisconsin, Michigan, and Minnesota. Milk production per cow was determined from daily tank-weight pickup and number of cows milked. Number of transient events, transients, voltage p-p, waveform phase angle degree, sags, and sag-Vrms were measured from event recorders plugged into milk house wall outlets. Data from 1705 cows and 939 data points were analyzed by multiherd least-squares multiple regression and SAS-ANOVA statistical programs. In five herds for 517 days, milk/cow/day decreased −0.0281 kg/transient event as transient events increased from 0 to 122/day ($P<0.02$). Negative effects on milk/cow/day from event recorder measurements were significant for eight independent electrical variables. Step-potential voltage and frequency of earth currents were measured by oscilloscope from metal plates grouted into the floor of milking stalls. Milk decreased as number of 3rd, 5th, 7th, 21st, 28th, and 42nd harmonics and the sum of triplen harmonics (3rd, 9th, 15th, 21st, 27th, 33rd, and 39th) increased/day ($P<0.003$). Event recorder transient events were positively correlated with oscilloscope average V p-p event readings. Steps/min counted from videotapes of a dancing cow with no contact to metal in the barnyard were correlated with non-sinusoidal 8.1 to 14.6 mV p-p impulses recorded by oscilloscope for 5 min from EKG patches on legs. PUC standards and use of 500-Ohm resistors in test circuits underestimate effects of non-sinusoidal, higher frequency voltage/current common on rural power lines.
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1. Introduction

Uncontrolled electric current injected into the earth in a Grounded-Wye Distribution System (commonly called "Stray Voltage"), NEV (neutral-to-earth voltage), N-GV (neutral-to-ground voltage), or tingle voltage has been the subject of controversy between dairy farmers,

☆ There are no conflicts of interest. No funding has been received for any part of this work.

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http://dx.doi.org/10.1016/j.scitotenv.2012.12.089

some swine and dog kennel operators (Marks et al., 1995), and electric utilities in North America since 1970. Craine (1969, 1982) and Craine et al. (1970) found electrical currents on domestic water systems from primary neutral down-grounds. Jersey cows decreased in milk production, and cattle decreased water consumption when exposed to similar voltages on watering troughs. Some 1300 herd owners filed complaints of electrical interference to the MPSC and Attorneys General of Michigan prior to initiation of AG v Consumers Energy MPSC Case No. 11684 in 1998.

A Review of the Problems Associated with Stray Voltage on Dairy Farms was published in the Bovine Practitioner (Zdrojewski and Davidson, 1981) and a review of "Sources of Stray Voltage and Effect on Cow Health and Performance" was published in the Journal of Dairy Science (Appleman and Gustafson, 1985). The opinions of "stray voltage experts," based on limited studies of 60-Hz (Hertz) AC (alternating current), sinusoidal voltage, were published in USDA-ARS Publication 696 (1991), Effects of Electrical Voltage/Current on Farm Animals: How to Detect and Remedy Problems.

USDA-ARS Publication 696 (1991), called the Redbook, became the standard for cow-contact stray voltage adopted by public utility commissions and utilities in several states. The standard usually accepted was a minimum of 0.5 Vrms (volt root mean squared) or 1 mA (milliampere) of 60-Hz, steady-state voltage, contributed by the utility, an amount that must be present at cow-contact points for the utility to be responsible for correcting an electrical problem. Cow contact was defined as touching metal water bowls, pipelines, stanchions, stall dividers, and feeding equipment. Power company stray voltage experts use a 500-Ohm resistor in the voltmeter circuit. The theory was that a voltage must be strong enough for the current to pass through the resistor to affect cows; and if cows do not exhibit physical signs of electric shock, electricity has no harmful effect. Voltages less than approximately 0.5 V, or 1.0 mA current, were considered "not significant" when resistors were in the voltmeter circuit and Wisconsin or Michigan PSC protocol were followed. However, the Redbook contained no information about effects of transients (electrical surges) or harmonics, integer (whole number) multiples of 60 Hz in North America and 50 Hz in Europe and Asia, generated within circuits and power lines by transients, oscillating at frequencies other than 60 cycles per second on power lines. Harmonics, often called electrical noise, may produce humming, buzzing, and rf (radio frequency) radio noise heard near electrical power lines.

Professor Lloyd B. Craine, co-author of the Redbook, acknowledged, "...When consumer equipment consisted primarily of lights, motors, and tube-type electronic equipment, and electrical loads were relatively small, neutral-to-earth voltages and transients were not great problems, due to low neutral currents and the tolerance of the equipment. With increasing use of low-signal-level solid-state computers and microprocessors, increasing electrification and automation of farms, and increased loads on distribution lines, the issue of power quality and tolerable neutral-to-earth voltage is increasingly important." Craine recommended, "Transient-effects research is necessary to fully evaluate power system effects on animals" (USDA, 1991, sec 6, pp. 2–4). The purpose of this investigation was to determine if electric power quality and stray voltage were related to changes in milk production of dairy cows.

A dairy company farm-service agent asked a local industrial electrician to "look into" farmers' complaints that their cows were affected by stray voltage when utility stray voltage experts said no voltage was present and the problems were all caused by poor farm wiring and management. Tests were conducted on more than 100 farms in Wisconsin, Michigan, and Minnesota. Power quality was measured in terms of compliance with defined voltage, frequency, phase generation and current phase delivery efficiency, number and magnitude of transients, harmonics, sags, surges, and outages. Inferior quality power is known as "dirty electricity" in the electrical industry (Kennedy, 2000; Mazur, 1999). Effects of transients and harmonics in stray voltage on dairy cattle and other farm animals were not previously reported in animal science literature in our search of the journals. However, electrical interference, assumed to be 50–60 Hz "Stray Voltage," was in the Redbook and ASAE Symposia 1984 and 2003.

2. Materials and methods

Milk and electrical measurements were studied on 11 farms, and leg movements and electrical data from a 12th farm (Table 1). These farms were selected because of suspected electrical problems that farmers believed may have influenced animal behavior and performance.

2.1. Data recording

Data recording equipment were located in the office or milk-room adjacent to the milking barn or parlor as in Fig. 1.

Transient information was recorded with a FLUKE® Voltage Event Recorder VR101 employing EventView™ Software. The event recorder was plugged into an electrical outlet in the milk house or in the milking parlor. Time (day, h, min, s), number of H-N (Hot-to-Neutral) and N-G (Neutral-to-Ground) transient events, total number transient oscillations per event, V p-p (voltage peak-to-peak), H-N sags Vrms (voltage root mean square), H-N swells, and wave angle degrees were recorded by the event recorder. The event recorder accumulated 4000 events before it was full and had to be downloaded to computer.

Step-potential voltage and frequency (Hz) were measured from metal plates (10×15 cm), 1.5 m apart, grouted into the concrete floor of milking stalls as recommended by science advisors (Hoben et al., 1998). Plates were connected via twisted shielded cable, twisted pair, or THHN building wire leads to a FLUKE® 105B Scopemeter Series II (100 MHz recording oscilloscope) employing FlukeView™ Software SW90W on a Dell® Inspiron 7000 (laptop computer). Cattle movements were recorded simultaneously with a Sony® Handycam Vision CCD-TRV43 videoHi8 (portable video recorder) for part of the period. Computer output was converted to a video signal via Focus Enhancements Tview™ Gold Card (pc-card adapter and software) and mixed with the video signal of the cattle by way of a Videonics MXPro Digital Video Mixer model MX-3000 (audio/video mixer) and recorded on a Sony Hi8 Video Cassette Recorder EV-C200 (Hi-8 VCR). Electrical impulses and cow movements were recorded simultaneously on videotape by Stetzer Electric, Inc., and analyzed by Essential Regression© ver. 2.218, 1998, with macros incorporated into Excel by Microsoft®. Composite multi-herd data were analyzed as described in Section 2.3.

A BK Precision 4040 20-MHz sweep/function generator was used to calibrate the remote monitoring oscilloscope by first injecting a 42-Hz square wave 2.3-V signal into a battery powered Tektronix 720P scopemeter at the plates, and then injecting the same signal into the wires that would be connected to the plates for monitoring purposes. The signal was then verified to be the same on the Fluke oscilloscope in the remote monitoring location as the Tektronix 720P at the plates.

Milk production was from daily milk tank weights determined by the milk-hauler and from milk-check statements. Milk (kilograms = 2.2046 pounds) were divided by the total number of cows that contributed to the tank load. Cows that were too fresh to enter their milk in the tank or were receiving medical treatment were not part of the milk herd. In two herds where milk was picked up on alternate days, weights were handled accordingly to determine average milk per cow per day corresponding to electrical measurements for the 2-day period and were analyzed separately.

Cow leg movements (lifting feet, stepping, kicking) of a cow, tied only by a rope in the barnyard of herd number 12 (Table 1) located near a large substation, were recorded on videotape while electrical activity on the cow's legs was recorded by oscilloscope. Channel A leads were attached to EKG patches (electrocardiogram electrodes, 3M Red Dot™) placed on shaved skin over the right front (RF, metacarpal) and right rear (RR, metatarsal, or cannons) and were held in

Table 1
Data source: Farm records, Fluke® Event Recorder Transient Deviation Thresholds, oscilloscope, RPM, distribution system, and connections.

Herd I.D.	Monitor dates	Description	Cows milked avg. no./day	Milk per cow average kg/day	Data points weight periods no.	Recorder transient threshold Vp-p H-N & N-G
1. Kru WI	7/15/99–3/22/00	Event recorder in 110-V outlet in milk room.	110	22.50	243	100 & 50
2. H-M WI	1/30/00–4/04/00	Tie stall barn, event recorder in milk room.	87	30.49	43	100 & 50
3. Eri WI	8/1/99–12/20/99	Free stalls, double-12 parlor, event recorder in parlor. Ground currents from plates imbedded in concrete in milking parlor recorded by oscilloscope.	366	32.80	136 74	200 &100 and 100 &50
4. Bey WI	12/17/99–1/19/00	Free stall barn, some tie-stalls. Milking parlor. Event recorder in 110-V outlet in milk room. Oscilloscope.	80	27.50	34 52	150 & 50 100 & 50
5. Pla MN	2/6/00–4/10/00	Free stall barn, double-4 parlor. Event recorder and oscilloscope. Farm located in return path between sub-station and nonlinear loads. Earth primary neutral return conductor.	56	29.50	135	100 & 50
6. Ram MI	6/26/99–7/22/99	Freestalls, double-8 parlor; event recorder; 2-day pickup. Loss of milk production, 56 cows died in previous 2 years, herd dispersed.	110	22.70	13	200 & 100
7. Bel MI	3/5/00–8/01/00	Freestalls, double-6 parlor. Event recorder and oscilloscope; 2-day pickup, data for subperiods of time. Loss of milk, cows, displaced abomasums, herd dispersed.	96	31.40	37	100 & 100
8. Wal MI	4/22/00–12/31/00	Oscilloscope, free stall, 2-12 parlor. Some event meter data. Milk loss, cow health. System changed to 3-phase after investigation.	325	31.66	204	100 & 100
9. Gut WI	8/04/00–9/04/00	RPM—Split single-phase primary neutral.	68	27.71	32	NA
10. Mic WI	6/10/00–9/04/00	RPM—3-Phase Wye primary neutral.	374	27.94	60	NA
11. Mut WI	5/19/00–3/23/00	RPM—3-Phase Delta (floating and grounded) Primary neutral-to-ground.	40	25.26	73	NA
12. Jon MI	7/23/99	Oscilloscope and video camera, substation <200 M., transmission lines near farmstead. Loss of milk, cows and herd.				
Average			154	28.13	105	
Sum			1705		939	

place by wrapping athletic bandages. Channel B leads were placed on shaved skin over left-rear (LR) and right-rear (RR) cannons of the cow's legs. Leg movements or steps per minute were counted from the videotape and regressed on V per minute (V p-p) simultaneously recorded (once/s) for five minutes by oscilloscope. Movement of cows while in the milking stall, and shimmering of skin and muscles of cows, heifers in the feedlot, and horses at pasture were recorded on videotape by Stetzer while corresponding electrical impulses recorded from the step-potential electrodes appeared on the oscilloscope and television screen (Stetzer, 1999).

Time (day, h, min, s), peak-to-peak voltage plots, frequency plots, waveform capture (snapshot of waveform required for harmonic spectrum analysis), and harmonic spectrum analysis (fundamental frequency, total harmonic distortion) were monitored by oscilloscope, recorded once per second, and evaluated on FlukeView™.

The oscilloscope recorded once per second (86,400 observations per day), generating a large amount of data for processing into

Fig. 1. Electrical instruments used to record power quality data. The event recorder is plugged into a 120-V outlet in the office and the oscilloscope is connected by twisted, shielded cable to metal plates grouted into the floor of milking stalls.

meaningful values. A computer software program was devised to expedite summarizing event meter and oscilloscope recordings to daily numbers for analyses.

The Reliable Power Meter, Multi-port Permanent RPM Recorder, Model 1942, and similar RPM recorders were used to monitor power quality in a trial test at three dairy farms in Wisconsin. The meter was installed at the interface of the primary and secondary circuits at the service entrance PCC (point of common coupling) according to manufacturer's instructions (Reliable Power Meters, 400 Blossom Hill Road, Los Gatos, CA). Milk per cow was determined from daily tank weights and number of cows milked as described above. Milk/cow/day was regressed on number of transients per day, described by codes of events, recorded by the RPM in a combined three-herd data set.

Measures of step potential were recorded by battery-powered oscilloscope while the primary power supply was completely disconnected from each farm. During this period there were no detectable changes in spikes on waveforms indicating the inferior power was from off-farm sources.

2.2. Data sets

Several data sets were constructed to obtain as many farms and days as possible that included the same measured observations. *Data Set 1* consisted of five herds (Table 1, ID 1, 2, 3, 4, 5) that included 517 observations of milk production and the number of transient events per day. Transient events were composed of mixed H-N transient threshold settings at 100, 150, and 200 V in three herds, with corresponding N-G thresholds set at 50, 50, and 100 V, respectively, while in the other two herds thresholds were 100 V H-N and 50 V N-G.

Data Set 2 was a five-herd data set that included transient event observations for 515 days. Independent variables include the same herds as in Data Set 1, but with Fluke® Event Recorder threshold setting in all herds, H-N 100 V and N-G 50 V p-p and included only days when the recorder operated at least 23 h. Independent variables from

EventView™ software were added to the database. They included: number of transient events, number of H-N and N-G transient events and corresponding voltages (V p-p), number of transients (oscillations/event), waveform degree angle of the transient event, number of sags (5% below nominal voltage), sag voltage rms (root mean square as in 60 Hz), and number of surges/day.

Data Set 3 contains milk production for four herds (Table 1, I.D. 3, 4, 5, 8), 535 data points, and corresponding step-potential voltage and frequencies (Hz) obtained by oscilloscope from the floor of milking stalls. *Data Set 4* contains milk production from three herds, 165 data points, and corresponding step-potential event recorder and oscilloscope data. In *Data Set 5*, milk production/cow/day of three herds, 165 data points, was regressed on the number of transient events measured by the RPM at the point of common coupling (PCC) as electrical power entered the farm.

2.3. Statistical analysis

Statistical analysis of Data Set 1 was by multiple regression, multi-herd least squares analysis of data with unequal subclass numbers (Harvey, 1990). Dependent variable, average daily milk yield, was adjusted for Farm (class variable), Date (cubic), Farm × Date Interaction, Number of Transient Events (continuous independent variable), and Farm × Number of Transient Events.

For Data Sets 2, 3 and 4, a series of preliminary statistical analyses were performed to develop the final mathematical model. The computer program utilized was SAS, Inc. (SAS, 1985). Data first were screened by visual observation and by use of SAS PROC CORR. Several potential independent variables were perfectly correlated because they were derived from one or more other variables, e.g., some totals of the number of events or voltages were perfectly or very highly correlated with averages. These were deleted from further consideration. In least squares ANOVA, farm, date on experiment, and their interactions were found to have significant effects ($P = .05$) on milk yield. To reduce the set of up to 77 recorded or derived electrical measures to a manageable number, SAS PROC REG (selection = backward) was performed on the residuals resulting from the least squares ANOVA (SAS PROC GLM) which included farm, days on experiment (to the cubic order of regression), and their interactions. To be included in the final analysis, a probability level of $P < 0.10$ was required arbitrarily. The final mathematical model was analyzed with SAS PROC GLM and included farm, date on experiment (cubic), their interactions, a set of electrical variables selected from PROC REG and their interactions with farm. All effects were considered to be fixed, except residual, considered to be random.

3. Results

Power quality measures were recorded by Fluke® Event Recorder downloaded to computer for processing and displayed using EventView™ software as in Fig. 2.

3.1. Transient/harmonic effects on milk production

The number of transient events averaged 14.3 ± 21.7 (range 0 to 99 events/day) in Data Set 1. Milk production of cows in five herds in Data Set 1 averaged 27.08 ± 5.1 kg/cow/day for 517 days (data points), and ranged from minimum 14.7 to maximum 35.8 kg for individual farms. Number of cows averaged 165.7 ± 123, ranging from 49 to 394 cows milked per day per farm. Difference between farms was the most significant factor in the mathematical model that was associated with variation in daily milk production. Date (cubic) and transient threshold settings of the event recorder were also significant. Milk/cow/day was negatively related to number of transient events per day (TEV), regression coefficient = −0.0281 kg milk/transient event, significantly linear ($P = 0.02$).

3.2. Transient/harmonic effects on milk production using different independent variables

In a second model with milk/cow/day as the dependent variable and farm, sequential dates, threshold settings, and number of transient events as independent variables, the regression coefficient was −0.0287 kg milk/cow/transient event/day, linear ($P < 0.001$) using Essential Regression© ver. 2.218, 1998, on Microsoft® Excel software. Transient events accounted for average -0.41 ± 0.62 kg to −2.87 kg milk/cow/day from average 14 ± 22 and maximum 99 transient events/day respectively, as measured by event recorder in Data Set 1 and illustrated in Fig. 3. Transients are unwanted, short-duration voltages, called spikes or surges, caused by the sudden release of stored energy on an electrical circuit.

3.3. Transient/harmonic events v milk/cow on five farms

In Data Set 2, transient events averaged 20 ± 25.9 (standard deviation) and ranged from 0 to 122/day on five farms, 515 data points (days), when the recorder was operating at least 23 h per day and threshold settings were 100 V H-N and 50 V N-G. Eight electrical variables were found to be significantly related to milk production as in Table 2. They were (1) total number of transients, (2) total transient degree angle/100, (3) number of hot-to-neutral transient events, (4) total H-N waveform phase degree angle/100, (5) total sum of

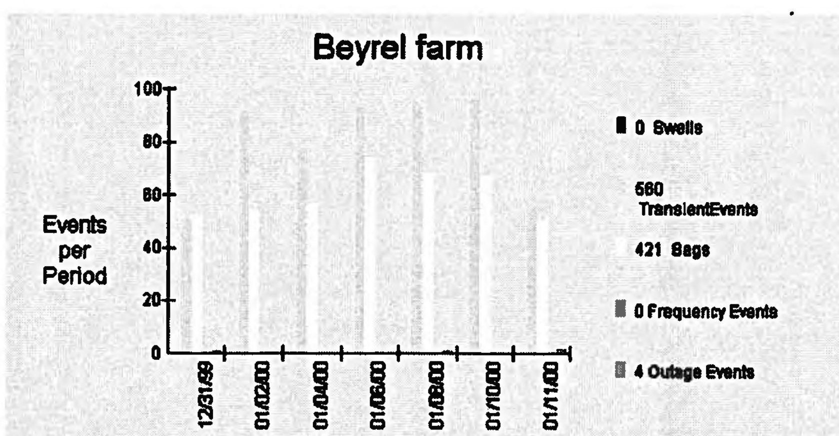

Fig. 2. Measures of power quality displayed from Fluke EventView™ Computer Software.

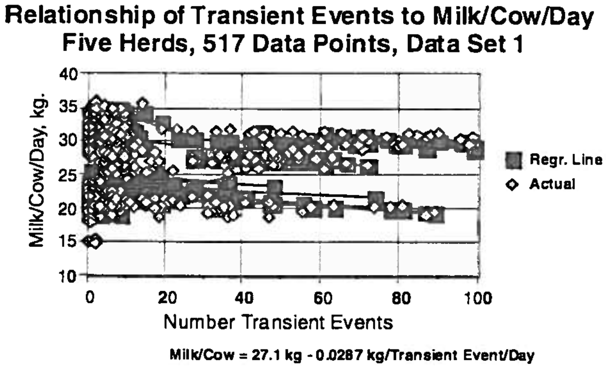

Fig. 3. Relationship of transient events to milk/cow/day, five farms, 517 days. The regression coefficient is −0.0287 kg milk per transient event ($P<0.001$).

N-G transients, (6) total sum of N-G transients with phase degree angle = > 200°, (7) number of sags (voltage < 108), and (8) Sag Voltage rms.

Transient events and number of transients varied enormously from day to day and farm to farm. Transient degree angle refers to electric degrees on a 360° waveform scale, where voltage peaking between 0 and 180° is positive and between 180 and 360° is negative. The normal 60-Hz sinusoidal waveform peaks are at +90° and −270°. The waveforms recorded were distorted and non-sinusoidal. They did not conform to the 60-Hz waveform as from the generator. Such distortion causes a shift in time of one voltage waveform relative to other voltage waveforms delivered to the point of service and may reduce operating efficiency of equipment.

3.4. Oscilloscope "step potential" voltage from the floor of milking stalls

Sixty-nine electrical variables were utilized in statistical analyses. The data were divided into four data sets to be able to manage the data and, within each set, the number of variables were reduced by backward stepwise regression to determine those significant at $P<0.10$. There were 13 variables found to be significant in the separated data sets. These 13 variables were then combined and reduced in number by backward stepwise regression, yielding seven that were significant ($P<0.10$) with one included variable highly correlated with one other (0.998). After removing one of the two most highly correlated variables, including the remaining 6 electrical variables (linear) in the model that included farm and date (cubic); farm x date reduced variation 8.5%. Those six variables were as in Table 3: (1) number of V p-p Readings, (2) Number V p-p Events, (3) Number Vp-p Event Readings, (4) Number of 3rd Harmonics (NH3), (5) Number of 5th Harmonics (NH5), and (6) Number 7th Harmonics (NH7).

3.5. Third, fifth, and seventh harmonic events, and V p-p decreased milk production

Variation of harmonic voltage included: (1) number of V p-p readings (No. V p-p Rd), (2) number V p-p events (No. V p-p Events), (3) number V p-p event readings (No. V p-p Ev Rd), (4) number of 3rd harmonics (N3H), (5) number of 5th harmonics (N5H), and (6) number 7th harmonics (N7H). The most potent single variable in the set of six, and the one that reduced residual variation from the base model the most (2.8%), was NH5. Using the linear regression coefficient −0.000165 with mean NH5 of 536 ± 980 harmonics/day suggests milk yield was reduced −0.15 ± 0.28 kg/cow/day at mean NH5. However, maximum NH5 was 6244 impulses per day × −0.000165 = −1.75 kg milk/cow/day maximum accounted for by the 5th harmonic regression coefficient in this data set. The 5th and 7th harmonics combined averaged 753 ± 1348 impulses with maximum of 12,065 × −0.000365 kg milk/harmonic, thus decreasing milk average −0.27 to −4.4 kg maximum milk/cow/day. Similarly, milk production decreased as the number of triplen harmonics increased per day. As the sum of triplen harmonics increased from average of 3648 impulses to maximum 30,288 × −0.000034 kg milk/triplen, milk decreased −0.123 to −1.02 kg/cow/day ($P<0.003$). Triplen harmonics are the 3rd harmonic and odd numbered multiples of the 3rd harmonic. The 3rd, 9th, 15th, 21st, 27th, 33rd, and 39th were recorded in this data set with significantly negative effect on milk production/cow/day.

The number of 1st harmonics, 60 ± 30 Hz/day (26,852 ± 30,289/day) was not correlated with changes in milk production/cow in data set 3, apparently because of the large standard deviation in this data set.

3.6. 42nd Harmonic decreased milk production

Data Set 4 consisted of milk production, event recorder and oscilloscope data, both recording at least 23 h/day, for three herds (Table 1, ID 3, 4, 5), 165 data points. Seventy-seven variables were reduced to six significant variables as in Table 4. Including these six variables (linear) in the basic model that included farm and date (cubic), farm × date reduced residual variation 16.3%. The most potent single variable based on the analysis including all six variables was number of 42nd harmonic (NH42 = 2520 Hz). Selecting NH42 and including it as a single variable in base model reduced residual 4.2%. With linear regression coefficient of −0.007 kg milk/42nd harmonic and mean NH42 of 16 ± 56, apparent reduction in milk yield at average NH42 was −0.122 ± 0.39 kg milk/cow/day with a maximum of 294 voltage impulses/day at 2520-Hz frequency accounting for −2.06 kg milk/day. All harmonics were recorded by the oscilloscope as step-potential voltage and frequencies from metal plates in the floor of the milking stall.

Since transients are not produced by the generator, but rather from switching and electronic devices, the non-sinusoidal distortions of the waveform are related to the H-N and N-G voltages recorded

Table 2
Event recorder measures of power quality for five herds combined, 515 data points, Data Set 2.

	Total transients (oscillations) no./day	H-N Trans-sients (oscillations) no./day	Total H-N trans degr. angle	Total trans. degr. angle	N-G trans. events	Total N-G trans. no./day	Sum N-G Angle = > 200° total/day	Sags no./day	Sags Vrms
Days – 515	515	385	385	515	191	191	144	261	261
Mean/day	182	11	−2367	3419	8.7	79.1	−309	25	2698
Std. dev.	253	17	3349	4618	16	163	660	29	2636
Min.	0	0	−21840	0	0	0	−3310	0	0
Max.	1939	89	1630	20,480	90	1024	980	166	18421
Ave./trans.			−128	297		9.1	−73.7		108.3
Yield milk f X, least squares analysis of variance (17) and essential regression by Microsoft									
Milk, kg Coef, f X	−0.0025	−0.086	−0.014	0.0003	−0.062	−0.0014	−0.0012	−0.03	−.0003
P Linear>0	<0.001	0.031	0.0018	<0.10	<0.001	<0.001	<0.001	0.02	0.024

Means = average or sum/day for number days event occurred per possible 515.

Table 3
Oscilloscope measures of step potential electrical variables affecting milk production, (P<0.05), four herds, 535 days, Data Set 3.

	No. VpRd	No. V p-p events	No. V p-p EvRd	Ave. V p-p Ev. Rd.	No. 3rd harmonic	No. 5th harmonic	No. 7th harmonic
Mean/day	86,280	3441	41,987	0.0628	2082	536	217
Std. dev.	410	2574	33,220	0.0398	4246	980	511
Min	82,809	0	4736	0.0268	0	0	0
Max	86,400	10,678	83,268	0.1516	30,288	6244	9503
Milk, kg. Coef.*X	−0.000286	−0.00007	−0.000095	Reference	−0.000136	−0.0002	−0.00033
P-value	<0.01	<0.008	<0.001	Voltage	<0.001	<0.005	<0.001

Oscilloscope events were 3 standard deviations from the mean of non-event readings after the last previous event.

by the event recorder. N-G impulses averaged −75.7 ± 37.6 V p-p (range 0 to −190) corresponded to H-N impulses, which averaged −113.4 ± 104 V p-p (range +203 to −307 V p-p).

Oscilloscope event average step voltage, 0.040 ± 0.0116 V p-p, increased linearly as the number of event recorder transient events increased daily (P<0.001). Step-potential voltages above 0.010 V p-p (10 mV p-p), measured from the floor of milking stalls and in barnyards, affected behavior and milk production of dairy cows in four herds for 535 days. This concurs with findings of Polk (2001) in Wisconsin herds, working with data collected by science advisors to the Minnesota PUC (1998).

3.7. RPM (Reliable Power Meter), transient events, and milk production

Numbers of transient events recorded by the RPM are in Table 5. Milk/cow/day averaged 26.8 ± 1.75 kg in three herds (Table 1, ID 9, 10, 11); 167 cows was the average number milked/day; 165 data points (days). Herds averaged 40, 68, and 374 cows milked/day. Milk/cow/day was regressed on primary neutral transient events (Table 5) recorded from the point of common coupling between primary and secondary circuits. Herd number, sequential dates and number of cows milked/farm/day were significant and included as independent variables. Number of cows reduced residual variance 6%, and transient events (Code 30-2) reduced residual variance 9% from the basic model residual. Milk production decreased −0.029 kg milk/cow/code 30-2 transient event/day, (P<0.001), and similarly for other primary neutral event codes. The average number of primary phase transient events was similar for phases 0, 1, and 2, but only phase 2 waveform events were related to changes in milk/cow/day in this RPM data set. Milk/cow/day decreased as total phase transient events (total of 3 phases) increased/day, regression coefficient −0.001 kg milk/transient/cow/day (P<0.03). Correlation coefficients for primary neutral transient events and phase-2 transient events ranged from r = 0.47 to 0.86. Results obtained with the RPM were comparable to results with Event Recorders and oscilloscopes at different locations. Large variations in number of events were recorded from day to day and farm to farm.

3.8. Relation of leg movements to 60-Hz electricity

Leg or foot movements (steps/min) and oscilloscope measures of voltage from EKG patches attached to shaved cannons of a cow were recorded and reported in ADSA Presentation Paper No. 03-3116 (Hillman et al., 2003b). RF (Right front) to RR (right rear) voltages were recorded on Channel A and averaged 13.2 ± 0.49 mV p-p and ranged 8.1 to 14.6 mV p-p. RF movements averaged 3.6 ± 2.7 steps/min (range 1 to 8), while RR averaged 10.4 ± 5.7 steps/min. The RR leg was a common ground for both channels. Regression coefficients for RF + RR and total steps as a function of maximum–minimum mV p-p were positive and significant (P<0.04). Leg movements were significantly correlated (r = +0.89) with step-potential 60-Hz voltage. The procedure was presented in ASAE Presentation Paper No. 03-3116 in Las Vegas, NV; in CSAE-CSGR Presentation No. 03-505 in Montreal, Quebec, Ca; in a presentation at ADSA in Phoenix, AZ, in 2003, and at the 12th International Conference on production diseases in farm animals at Michigan State University (Hillman et al., 2003a, 2003b, 2003c, 2004).

Fig. 4 indicates the critical value was 0.9 mV p-p differential between Maximum and Minimum mV p-p during the corresponding minute at which leg movements accelerated significantly with voltage on Channel A. Standard deviations for Channel A mV p-p per minute (5 min = 300 observations) were also correlated with RF + RR and Total Steps per corresponding minute, r = 0.88, (P<0.05), in Fig. 5. Apparently, measures of dispersion or differences in potential voltage were more important than average voltage since neither averages nor sums were related to the number of steps per minute on either channel.

Voltages recorded from LR (left rear) to RR leg on Channel B averaged 12.04 mVp-p (range 5.6 to 12.4 mVp-p). LR steps averaged 9.8 ± 5.7 (range 1 to 20) and RR steps averaged 10.4 ± 6.9 (range 2 to 18) steps per minute. Steps were not significantly correlated with voltage on Channel B (P = 0.12). Total number of leg movements averaged 20 ± 8.7 (range 6 to 40) movements per minute. RR steps were correlated with Channel A Max–Min mVp-p (P<0.07). The LR Steps was correlated with RR steps, r = 0.99, (P<0.008). Perhaps Channel A voltages were reflected in LR voltages through the RR leg common ground.

During the 22 min the videotape was recording, the Jonseck cow stepped with her RF foot 3.4 times per minute, RR foot 7.2 times, and LR foot 7.0 times per minute. RF was attached to Channel A, LR to Channel B and RR was a common ground for both A and B. The cow lifted rear feet twice as many times as front feet. The video camera was inadvertently shut off for about 1½ min (2:48 and 2:49); thus limiting the leg count for that period while the oscilloscope operated for 429 s recording once per second continuously.

Step-potential voltage from the ground during the period ranged from 18.8 to 22 mV p-p. A voltage drop of 38 to 42% occurred between ground surface and leg skin. This finding is within the 25 to 45% of voltage from cow contact (stall divider) to floor plates noted by Ludington et al. (1987).

Table 4
Event recorder and oscilloscope measures of transient and harmonic electrical impulses affecting milk production in three dairy herds, 165 data points. Data Set 4.

	Ave. qty NG trans Ø >200°	NG trans Ø>200° V p-p	Minimum sag V rms	Number 21st harmonic	Number 42nd harmonic	Step volt event rd V p-p
Days	122/165	66/165	96/165	17/165	17/65	165
Ave./day	3.75	−75.7	102.6	467	164	0.040
Std. dev.	4.5	37.6	51.7	154	56	0.010
Min.	0	−190	84	0	0	0
Max.	26	0	107	805	294	0.071
Milk, coef. kg × X	−0.027	−0.0017	−0.0042	−0.0664	−0.0041	−14.7
P-value	0.004	0.10	0.01	0.07	0.03	0.02

Table 5
Transient events recorded by the Reliable Power Meter® in three herds.

	Code 25-2 trans. events	Code 26-2 trans events	Code 30-2 trans events	Phase A = 0 trans events	Phase B = 1 trans events	Phase C = 2 trans events
Average/day	12.4	5.5	14.0	33.6	32.6	32.5
S.D.	22.8	28.0	18.4	87.2	107.8	63.4
Minimum	0	0	0	0	0	0
Maximum	257	315	139	1051	1357	681
Milk, kg/trans event	−0.025	−0.020	−0.029	0.0	−0.0008	−0.003
P value linear > 0	0.018	0.015	<0.001	Not sig.	Not sig.	0.07

Code 25 – RMS voltage/current event.
Code 26 – voltage/current waveform event.
Code 30 – voltage/current transition waveform event.
Phases 0, 1, 2 – Primary phase voltage/current waveform event, equivalent to Phases A, B, and C.

Frequency of voltage during recording with oscilloscope ranged from 2.7 MHz to overload at 30 MHz while the Jonseck cow was dancing to avoid electrical shocks. Oscilloscope snapshots of the waveform indicate the distorted voltage as in Figs. 6 and 7.

3.9. Electric fields – Electricity travels inside and outside of wires

Electric fields were estimated from step-potential voltage (V p-p) recorded by the oscilloscope in milking stalls at each farm, using impedance (resistance) reported for cows (Aneshansley et al., 1995; Appleman and Gustafson, 1985; Craine, 1969; Norell et al., 1983). Intensity of electric fields (E-field V/m) was estimated from human models of the amperage short circuit (Isc), frequencies from 60 Hz to 1 MHz using Chiba's formula with known short-circuit current, frequencies, and height of the object as: $Isc = 5.4 * 10^{-9} * H^2 * E * f/60$. Therefore, $E \text{ field} = (V/R)/((5.4 * 10E^{-9} * H^2)/f60 \text{ Hz})$, and $Isc = V/R$, where V = step potential V p-p, H = Height of Cow (1.4 m), R = Cow Resistance, f/60 = frequency normalized, and $5.4^* \ 10^{-9}$ = Constant from Chen et al. (1986). Chen et al. found the formula, $Isc = 0.108 * h^2_m * E_0 * f_{MHz}$, provided reliable results for predicting short-circuit currents induced by high frequency (>1 MHz) electric fields in a human body.

Estimated E-fields ranged from average, 1.29 kV/m on one farm for 54 days to maximum 5.55 kV/m on another farm for 204 days as in Table 7. The actual exposure time (days, months, or years) of farm herds was unknown. The highest E-field observed was 29.6 kV/m causing a cow to dance in the milking stall while 0.165 V p-p, 625-Hz electric shocks were recorded on oscilloscope three times during one milking. That was three times the 10 kV/m exposure of cows to 60-Hz E-fields in 28-day trials by Burchard et al. (1998, 1999, 2003).

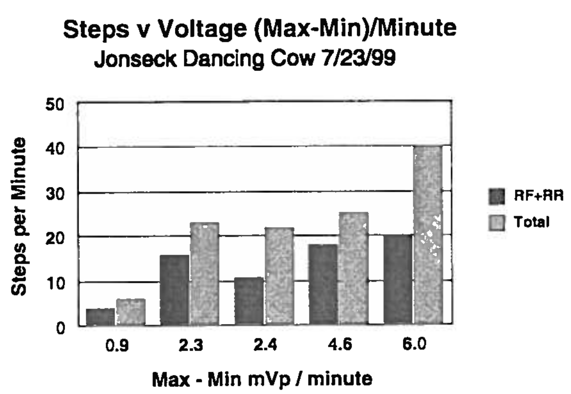

Fig. 4. Steps/minute increased as maximum minus minimum voltage increased/minute on the cow's leg. Voltages from the ground were recorded by oscilloscope attached to EKG (electrocardiogram) patches on right front and right rear legs.

THD (Total Harmonic Distortion) is a measure of the percentage of harmonic voltage > 60 Hz relative to the fundamental first harmonic voltage (Kennedy, 2000). The Institute of Electrical and Electronic Engineers in publication IEEE 519-1992 (1993) sets current limits on the utility side of the meter THD as 5% of the fundamental harmonic. THD was outside these limits on the five farms studied as in Table 6. THD on phase wires also exceeded IEEE 519 limits in power quality studies conducted by utilities in Indiana (Tran et al., 1996) and Kansas (Li et al., 1990). Similarly, limits for TDD (Total Distortion Demand) which is the end-user contribution to distortion on the utility line are also recorded in IEEE 519 (1993).

4. Discussion

4.1. Sources of neutral-to-earth voltages and consequences

Electric current flows through conductors, including the earth, the air, water, metal equipment, animals, and man in its return path to its original source as well as on wires. In a grounded-neutral wye distribution system, 65–75% of residual current returns to the earth since the neutral wire is inadequate to return the current to the substation. In addition electric and magnetic fields radiate from the conductors.

The finding that milk production decreased as event recorder neutral-to-ground voltages increased from an outlet in a milk-room corresponds to other reports. Neutral-to-ground voltages during transient events averaged −137.9 V p-p (range 20 to −160) in milk-room outlets of five farms in this study.

4.2. Step-potential voltage

The pathways, the step-potential voltages from the floor of milking-stalls, and the transient events from nonlinear loads in the present study were comparable to unbalanced loads (from primary

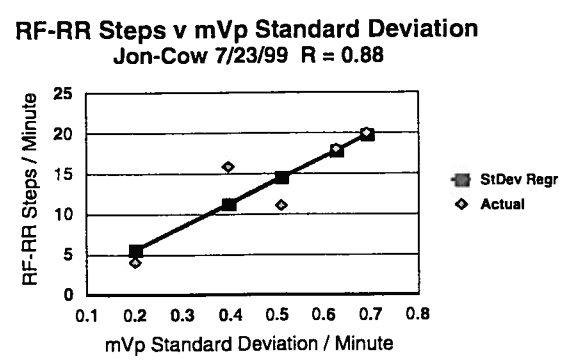

Fig. 5. Relationship of steps/minute to standard deviations of mVp/minute. (The standard deviation is a measure of voltage potential relative to average voltage).

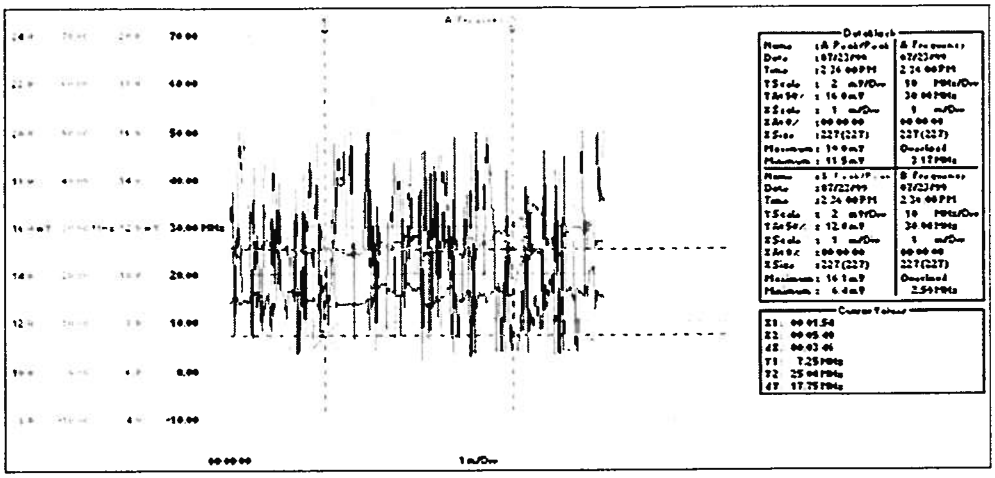

Fig. 6. Oscilloscope plot from EKG patches on leg of dancing cow from step voltage off the floor where the cow is standing. Voltage ranges from about 6.4 to 16.1 mVp, 7.25 to 25 MHz frequency in this oscilloscope snapshot, Jonseck Farm, 7/23/99.

or secondary circuits) as described by Ludington et al. (1987). "Bonding allows current to flow to metal water pipes, lightning protection, and branch circuit equipment ground wires. The amount of current flowing in each path will depend on the impedance of the path." Impedance of cows decreases as frequency of voltage/current increases, thus cows receive higher energy (amperage) from higher frequency harmonics than from 60-Hz sinusoidal electrical impulses (Aneshansley et al., 1995; Aneshansley and Czarniecki, 1990); and cows may not feel the higher rf charges as most humans do not hear or feel (perceive) rf waves unless aided by a radio receiver at proper Hz (frequency). An AM radio produces static (audible noise) in the presence of electrical disturbances in the environment or near power lines and can be used as a simple test instrument. Further, Ludington noted "the service panel is a divider of neutral voltage. [And] the animal would almost always be a current path in series with, and in parallel to, other resistances." In addition, "The stray voltages, as measured with a 500-Ohm resistor, are fractions (ca 10%) of the applied voltages," according to the data (Ludington et al., 1987).

4.3. Transient voltage

Transient voltage is a temporary unwanted voltage, caused by the sudden release of stored energy in an electrical circuit. A transient voltage is produced from stored energy contained in the circuit inductance and capacitance. Oscillatory transient voltages are commonly caused by turning OFF high inductive loads and by switching large utility power-factor correction capacitors. A phase shift occurs between alternating voltage and current in an inductive circuit. The greater the inductance the larger the phase shift, in which current lags voltage. Because a change in frequency changes inductance reactance of a circuit, any change in frequency delivered to the load has an effect. Because non-linear loads produce harmonics, harmonics have an effect on the power distribution system and loads (Kennedy, 2000, p. 34). The trend of increasing harmonics on power lines (Najdawi et al., 1999) and adverse effects of inferior quality power on customers' equipment have been reported (De Andrea, 1999; Kennedy, 2000; Mazur, 1999).

4.4. Harmonic distortion

Harmonic distortion is caused by non-linear loads in electronic circuits such as variable speed motor drives (speed depends on frequency), electronic ballast used in lighting circuits, switch-mode power supplies in personal computers, printers, and medical test equipment such as MRI (magnetic radiation imaging) and cellular-telephone relay station transmitter neutral wires. Harmonics are especially a problem where there are large numbers of computers and other nonlinear loads that draw current in short impulses. Triplens result from single-phase nonlinear loads that draw current only during the peak of the voltage waveform. These loads combined in a

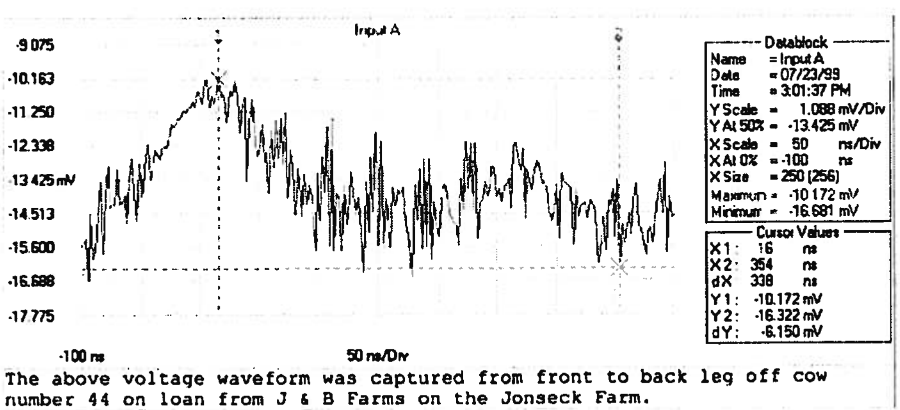

Fig. 7. Oscilloscope waveform showing the distorted notched non-sinusoidal transients carried on the 60-Hz waveform.

Table 6
Steps per minute and mV p-p from shaved skin at cannons of dancing cow. Maximum (-) minimum mV p-p during the corresponding minutes was correlated with steps R = 0.89 ($P<0.05$).

Time	Leg/foot moves per minute				Channel A: Voltage measured Shaved skin on leg					
Minute	LR Steps	RF Steps	RF + RR Steps	All Legs Steps	mV p-p Ave	MV p-p Sum	mV p-p St. dev.	MV p-p Min	mV p-p Max	Max mV p-p Min mV p-p
2:44	10	4	16	26	13.21	806	0.4011	12.3	14.6	2.3
2:45	11	1	11	22	13.20	792	0.5150	11.9	14.3	2.4
2:46	1	3	5	6	13.32	799	0.2045	12.9	13.8	0.9
2:47	7	8	18	25	13.03	782	0.6293	10.0	14.6	4.6
2:50	20	2	20	40	13.16	790	0.6963	8.1	14.1	6.0
Sum:	49	18	70	119	65.9	3969	2.4462	55.2	71.4	16.2
Ave	10	3.6	14	24	13.18	793.7	0.4892	11.04	14.28	3.24
St dev	6.9	2.7	6	12.1	0.095	8.27	0.1743	1.76	0.3059	1.818
Min	1	1	5	6	13.02	781.7	0.2045	8.1	13.8	0.9
Max	20	8	20	40	13.32	805.8	0.6963	12.9	14.6	6.0

three-phase circuit produce triplen harmonics. Triplens do not cancel one another but are additive and return exclusively through the neutral conductor. The resulting magnitude of the neutral current may exceed the capacity of the neutral conductor, and since there are no circuit breakers in the neutral, overheating of circuits occurs and may cause fires (Kennedy, 2000; Mazur, 1999).

Nonlinear loads include all types of electronic equipment that use switched-mode power supplies, e.g., rectifiers converting ac to dc, inverters converting dc to ac, arc welders, battery chargers, and switch-mode AC–DC power supplies that run radio stations and cellular telephone relay stations. All these devices change a smooth sinusoidal wave into irregular distorted wave shapes (Kennedy, 2000, p. 51; Mazur, p. 89) as were captured by oscilloscope at all farms in the present study (Figs. 6 and 7).

Excessive leg/foot movements, stepping and shifting weight represent abnormal behavior that can be disturbing during milking. These movements correspond to the same magnitude of voltage that caused decreases of milk production in the present study and do not conflict with other research. Norell et al. (1983) observed that cows picked up a front foot twenty-two percent of the time under no shock conditions and considered these random foot movement. However, the lowest treatment current in their experiments were 1.0 mA, equivalent to 0.36 V, considering 360-Ohm mouth to front hooves resistance, determined in the experiment to cause cows to raise a front foot. Lower uncontrolled voltages were not measured. Similarly, Brennan and Gustafson (1986) found "an unexpected level of response to control (0 cycles of 60 cycle AC treatment)." Controls gave escape responses (opening the mouth) 26 times per 30-second test period compared to treatment cows receiving 1, 3, 8, 15 cycles responding 56 to 58 times and cows receiving 30 cycles responding 75 times per 30 s.

In the present study, uncontrolled impulses of various frequencies (Figs. 6 and 7) were recorded by the oscilloscope as the cow was dancing. Cow resistance to current decreases as frequency increases (Aneshansley et al., 1995), thus the high-frequency, non-sinusoidal impulses from rural power lines recorded at the farms studied apparently produce different responses than 60-Hz, steady-state, sinusoidal currents used in experiment station trials reported in journal articles.

The present observation of leg movements in relation to voltage differential was similar to the conclusion by Norell et al that 13.8% of cows that were trained to perform an avoidance response, responded to 1.0 mA 60 Hz AC from mouth to rear hooves (Appleman and Gustafson, 1985; Norell et al., 1983). Milk production was not reported for cows responding to various voltages/currents in the sensitivity experiments (Appleman and Gustafson, 1985; Norell et al., 1983; Stray Voltage Symposium, 1984; USDA, 1991). The assumption that sensitivity or perception of electricity by cows equates to effect on milk production and animal health has not been tested sufficiently to permit a valid conclusion.

Milk production decreased 11 to 17% compared to controls when cows were exposed to 5.0 mA intermittent 60-Hz, steady-state electric shock (Lefcourt et al., 1982). Reliable laboratory experiments determining effects of electrical power quality on milk production and health of dairy cattle comparable to those found on rural utility lines have not been reported. All of the previously reported experiments have been conducted with 60-Hz, steady-state sinusoidal currents. In general, stray voltage experiments (Stray Voltage Symposium, 1984; USDA, 1991) have jeopardized the probability of finding statistically significant effects of electricity on milk production because number of cows/treatment were inadequate, sources of variance within and between groups were too large and often not considered, electrical exposure time of cows too limited, and turnover of cows too excessive to provide reliable data and valid conclusions (Behr, 1997). Those laboratory exercises have very little in common with farm experiences

Table 7
Electric fields for average and maximum event voltage (Vp), estimated from Chiba in Chen et al. (2000), and THD (total harmonic distortion) percent of 1st harmonic voltage.

Electric-fields and harmonic distortion in milking stalls								
	Recorded days	Event (1) ave. ± std. deviation	Total harmonic impulses	Different harmonics 1st–42nd	E-field ave.	E-field max	Voltage harmonic distortion %	
Farm	No.	Volts (Vp-p)/day	No./day	Number	kV/m ave.	KV/m max	THD ave. %	THD max. %
Eri	115	0.056 ± 0.01	39,805 ± 23695	16	2.678	3.740	67.8	132.1
Bey	76	0.050 ± 0.01	34,593 ± 10411	7	3.585	4.301	19.3	70.9
Pla	108	0.032 ± 0.01	9,746 ± 9403	11	2.150	4.482	29.9	79.6
Bel	54	0.039 ± 0.01	21,553 ± 26442	29	1.293	3.430	22.7	75.0
Wal	204	0.063 ± 0.04	44,084 ± 33,201	25	2.298	5.551	90.3	23.6

(1) Event on the oscilloscope was ±3.0 standard deviations from the mean of voltages following the last event.
Voltage = average recorded during events for the period.

where exposure may be lifetime, constant, variable in magnitude and frequency, and sunken resources are limited.

Increases of primary neutral current flow into the grounded neutral network (I_{PA}) by primary neutral current from a neighboring farm and primary neutral current from on-farm loads was described by Gustafson and Cloud (1982). Secondary neutral current due to unbalanced on-farm loads, interconnection of equipment and circuit neutral conductors, wiring faults, poor connectors, improper use of neutral conductors, and tree branches brushing power distribution lines may each contribute to increased neutral-to-earth transient and harmonic currents in the livestock environment.

Results of the present study confirm a 1980 report that low-level neutral-to-ground voltages and transients are a significant problem in some milking areas. And, jumpiness, kicking, refusal of some cows to enter the milking parlor, and reduced milk production are some manifestations of the problem (Gruesenmeyer, 1980).

Polk (2001), one of the science advisors to the Minnesota Public Utilities Commission, using the science advisor's data (Hoben et al., 1998) shows considerable scatter of milk/cow/day when step voltage was less than 0.01 V (10 mV), but a linear relationship between milk/cow/day and step voltage above 9 mV. He noted that when one considers only the V-lu (voltage at low electric use) above 9 mV the correlation coefficient between milk/cow/day and V-lu becomes +0.994. However, because of the small number of farms, 3 over 9 mV, the *P*-value becomes 0.069. Also, on three farms where step voltage was 9 mV or larger, the value of milk/cow/day decreased linearly with soil resistivity to current. Results of the present study, when number of transients, frequency of impulses, and the number of harmonics per day are considered, support the position of Polk that 10 mV peak to peak is a critical voltage level on some farms.

Exposure of cows under controlled laboratory conditions to a 10 kV/m, 60-Hz electric field and a uniform horizontal magnetic field of 30 μT (microtesla) for 28 days, has shown physiological effects that are potentially adverse (Burchard et al., 1998, 1999). Burchard et al. (1998) found a significant increase in quinolinic acid and a trend towards an increase in tryptophan in cerebrospinal fluid consistent with a weakening of the blood-brain barrier due to exposure to the electric and magnetic fields. Burchard et al. (1999) also found decreased concentrations of magnesium and increased concentrations of calcium and phosphorus in blood plasma and decreased concentrations of iron and manganese in cerebrospinal fluid of dairy cows and heifers exposed to 60 Hz, 10 kV/m electric fields, and 30 μT magnetic fields. Milk decreased 5.97%, fat-corrected milk decreased 13.78%, milk fat yield decreased 16.39%, while feed dry matter intake increased 4.75% during 28-day reversal trials with 16 mid-lactation cows at McGill University, Quebec, Ca (Burchard et al., 1996). Groups were alternated: 1st period current Off-On-Off, 2nd period On-Off-On for each 28-day period so cows were exposed for 84 days, total. Results were different than a previous trial during which milk fat was higher from exposed cows compared to unexposed. The large difference in fat secreted in milk by exposed cows has not been explained (Burchard et al., 1996). However, fat secretion in milk from electrically charged cows was lower than from unexposed controls in four of five experiment-station reports of effects of electricity on dairy cows (Gorewit et al., 1992; Aneshansley et al., 1992).

Observations in the present study indicate that step-potential cow-contact current in milking stalls was sufficient to cause cattle to lift their feet to avoid electric shock from the floor or ground, and to decrease milk production without contacting metal, e.g., water bowls, feeders, or stall pipes. Thus, the assumption that cows are affected by electricity because they are repelled from shocks on water bowls and metal feeders, etc., may be true. But, the present data also reveals that ground currents that were conducted, or coupled, through feet and legs without touching any metal objects affected behavior (stepping) and milk production. This concurs with reports that rats exposed to 150 V/cm electric fields reduced water consumption, gained less weight, and had lower levels of cortisol in blood in 9 of 10 trials, although exposure was through the air, and water was not connected to electric circuits (Marino et al., 1977).

In contrast, blood cortisol of cows increased temporarily upon exposure for a few minutes during or near milking (Stray Voltage Symposium, 1984; USDA, 1991). Effects on changes in blood adrenal steroids over long periods of exposure and a wide range of frequencies as found on farms have not been reported but may cause pituitary-adrenal fatigue as in Addison's disease or other impairment of health.

Recent discovery of the effect of external electric fields on membrane harmonic oscillations, caused by ions whose collisions with the membrane surface influence properties of a single lipid chain may be key to understanding electrical effects on cattle (Wojczak and Romanowski, 1996). Cows depend on microbial fermentation of ingested feeds to supply acetic, propionic, and butyric acids for energy and for formation of milk fat. Electrochemical effects of modulated VHF fields on the central nervous system (Bawin et al., 1975) may help explain the significance of cerebrospinal fluid protein and electrolyte (calcium ion) modifications by electric fields in dairy cows (Burchard et al., 1998, 1999). Autonomic nervous system response, such as epinephrine reducing blood flow through the udder of cattle under stress (Appleman and Gustafson, 1985; Lefcourt and Akers, 1982; Stray Voltage Symposium, 1984) could explain reduced milk production but has not been adequately investigated in relation to electrical shock (Hillman, 2002).

A review by California Health Services Department prepared for the PUC, reveals human health risks from electric and magnetic fields from power lines in the home or workplace (Neutra et al., 2001). Chen et al. (2000) reported that ELF (extremely low frequency, 60 Hz) inhibition of differentiation of Friend erythroleukemia cells was dose dependent on electromagnetic exposure; and because ELF inhibits the same enzyme in-vitro as phorbal esters, phenobarbital and dioxin, it falls in the same class of carcinogens that proliferate but do not cause cancer. Human colon cancer cells increased six-fold during exposure to electromagnetic fields in-vitro (Phillips et al., 1986). Electrical exposure disturbed melatonin secretion patterns in blood by the pineal gland (Burch et al., 2000), increased brain cancer and leukemia among electrical workers (Loomis and Savitz, 1990; Thomas et al., 1987), increased leukemia in children (Loomis and Savitz, 1990), and decreased T lymphocytes in power plant workers (Nakata et al., 2000) indicating a wide range of physiological pathological conditions have been related to EMF exposure. A higher rate of suicide among utility electricians and linemen than utility workers not employed in those jobs, suggests increased risk of mental depression and disturbed sleep patterns upon chronic exposure to low frequency electromagnetic fields (Van Wijngaarden et al., 2000), and further suggests electric field or electromagnetic field involvement with central nervous system functions (Bawin et al., 1975).

4.5. Power quality test meter with true RMS volt peak-peak

Power quality problems such as harmonics, sags, or swells involve distortion of the sine wave. The correct measurement tool for a power quality problem must accurately measure the characteristics of a total distorted sine wave (Graham, 2002, 2003, 2006).

In 1994, the Wisconsin SVAT (Stray Voltage Analysis Team), made the choice that a SVAT investigation would include only V p (not V p-p) readings (Dasho et al., 1994); and this decision was adopted by the WI Public Service Commission as well as by Minnesota and Michigan's Public Service Commissions. All three states' utility commissions measure with instruments such as the SVM-10 and Waverider, adjusted to read only peak (not peak to peak) values, thus missing half of the distorted wave form, giving a false reading. Since the Midwest USA utilities' voltmeters do not read peak-peak values, they use "average peak" readings, missing the distorted waveforms, and report 25 to 50% below True RMS readings as published in Power Quality

Primer (Kennedy, 2000, pp. 180–184). A FLUKE® 105B Scopemeter Series II instrument was used in our 12-farm study; and it recorded voltage, amperage, and frequencies of the complete sine wave. According to Aneshansley, "The combination of equal amounts of 60 and 180 Hz with different phase shifts and their lack of sensitivity to DC bias indicates that cows are sensitive to peak-to-peak voltages and not peak or rms" (Reinemann et al., 1999).

Many "stray voltage experts" including Public Service Commissions, government officials, and utilities may need to update their measurement techniques and knowledge of measuring tools. Use of a True RMS clamp-on ammeter to measure AC and DC current on the PN-E (primary neutral-to-earth) down-ground at the transformer pole is a simple method to determine the source and magnitude of the grounded-Y (Wye) utility's contribution to primary and secondary neutrals of the electrical system.

Use of a 500-Ohm resistor in the volt meter test circuit for power quality effectively eliminates from consideration the electrical power line harmonics, radiofrequency, and microwave measures that were found to be harmful in this study and may give misleading or unreliable information to investigators and herd owners. Studies of the effects of various electrical frequencies and harmonics on animals and humans and the physiological processes affecting behavior, health, reproduction, and productivity deserve further attention.

Resistance on a circuit can be measured with an Ohm meter and need not depend on inaccurate hypothetical 500-Ohm resistance. Appleman and Gustafson (1985) reported that 94.6% of cows were sensitive to 4 mA or less current. Norell et al. (1983) demonstrated that for a mouth-to-all-hooves pathway, 10% of cows had a resistance R = 244 Ω (Ohm) and 90% had Resistance = 525 Ω. "In this case, 10% of the cattle exposed to 1.0 V mouth-to-all-hooves shock would receive a 4.0 mA or greater shock; whereas 90% of cattle would receive a 1.9 mA or greater shock." Norell reported that specific avoidance responses were exhibited 13.8% of the time at 1.0 mA of current. Significant increases of response rates occurred for each 1.0 mA increment comparison up to 4.0 v 5.0 mA paired test, namely: 2.0 mA = 30% response; 3.0 mA = 69.2%; 4 mA = 92.3% response, and 5.0 mA = 98.4% response (Appleman and Gustafson, 1985, p 1558).

4.6. Subsequent research and related studies

4.6.1. Water drinking reluctance behavior

Dairy heifers decreased water consumption 32% when the water trough was charged with 3.0 volts and reduced water consumption 52% when the troughs were charged with 6.0-V, 60-Hz power line current compared to no current (Craine, 1969; Craine et al., 1970).

Cows were reluctant to drink water at all the farms we tested. They exhibited "lapping with the tongue," a sign of testing the water and reluctance to drink. Since water consumption is mandatory for milk production and good health in animals, it most probably contributed to the demise of many herds.

The observation that cows were reluctant to drink water on farms reporting stray voltage and decreased milk production led to our measuring current (20–40 mA p-p) in the water on farms reporting stray voltage in Michigan. We found that milk production decreased as transient, harmonic, and rf (radiofrequency) currents increased, and as step-potential voltage increased daily. We were not able to find any North American agricultural literature reporting the relevance of rf and MW (microwave frequency) currents to dairy cow behavior, health, and milk production prior to our study (Hillman, 2008, 2012; Hillman et al., 2011a, 2011b) and believe more research on this topic is necessary.

Scientists have observed that the fundamental physical composition of water can be changed by weak alternating magnetic fields at the cyclotron frequency combined with a weak, static dc field (Zhadin, 2010; Del Giudice and Giuliani, 2010). Similar findings were reported by Abraham R. Liboff, while working at the U.S. Naval Medical Research Center in Bethesda, MD, and later as a physics professor at Oakland University Rochester, MI (Liboff, 1985; McLeod et al., 1987) and Carl Blackman, at the U.S. Environmental Protection Agency (EPA), Washington D.C. (Blackman et al., 1985). Liboff reported that the inorganic nutrients: calcium, potassium, and magnesium became immobile in the water in experiments with mice.

Cows that are genetically capable of producing over 100 lb (50 + kg) milk daily require about 70–100 grams or more of calcium secreted in milk daily. If ingested calcium, potassium, and magnesium are immobile in the metabolic system during electromagnetic exposure, Liboff's theory may explain periparturient hypocalcemia (so-called milk fever), rumen stasis, displaced abomasums, and impaired uterine recovery from infections permitting failed reproduction and mastitis post-calving, as well as decreased water consumption and milk production.

4.6.2. Water lines frequently carry EMF into homes as well as barns

In 2004, the Lansing Board of Water and Light, Lansing, MI, found high levels of electric current entering the Hillman home and installed a dielectric coupling on the waterline to stop the electromagnetic fields from entering the home (Hillman, 2007).

Similar reports of EMF on water lines have been reported by Wertheimer et al. in studies from 1979 to 1995 (Lanera et al., 1997) and by Stetzer (2001) in his video, Beyond Coincidence – The Perils of Electrical Pollution.

4.6.3. Harmonic distortion on farm power lines and on substations

Our observations that harmonic frequencies generate elevated levels of current on the neutral wire of a grounded-wye distribution system concur with reports of harmonics on utility substations and farm power lines. Tran et al. (1996), an Engineer of PSI Energy, Inc., Plainfield, IN, et al., reported that "Triplen harmonics, particularly the 3rd, add in the neutral and have little diversity between loads. The higher neutral currents may cause significant problems. Neutral to earth voltages will increase near the substations which could increase stray voltage complaints. ... This paper provides fundamental understanding of triplen harmonic influence on stray voltage and EMF related to multi-grounded wye electric distribution systems." Tran made reference to USDA Publication 696 for stray voltage problems on animal farms; but USDA Pub. 696 contains no information about harmonics nor frequencies other than 60 Hz.

Similar to Tran's findings, Kansas engineers, measured electric power harmonics, 2nd through 63rd, on five rural substations and seven farms in Kansas, where maximum THD_I ranged from 8.2 to 34.2% on farms (Li et al., 1990). Gustafson et al. (1979) in response to farmer's complaints, recorded 83 harmonics near a DC transmission line in Minnesota.

4.6.4. Radio-frequency interference on power lines

The coupling of external electromagnetic fields to transmission lines was described by Albert A. Smith, Jr., a Senior Engineer for IBM Corporation. The effect of induced currents can range from noise on communication lines and errors in digital circuits to equipment damage and even personnel hazards. Some of the more well-known sources of electromagnetic fields include nearby lightning strikes, AM, TV and FM broadcast stations; radars; industrial, scientific and medical (ISM) equipment; automobile ignitions; personnel electrostatic discharge; the esoteric nuclear electromagnetic pulse (NEMP); and power supply noise and switching transients inside electronic equipment (Smith, 1989). Smith's book illustrates causes and consequences of shielding circuits, spacing of transmission cables, and IEEE references to research.

4.6.5. Health and reproduction impaired by EMF exposure

Cows and other animals exposed to electrical stress over long periods of time develop an analgesic effect, docile, unresponsive to stress, and may not exhibit a physical reaction to electrical charges. This opioid effect results from accumulation of dopamine in certain sections of the brain. It is excreted in the urine and has been used as a marker for electrical stress when other sources of stress are controlled (Brown et al., 1991; Buchner and Eger, 2011; Milham and Stetzer, in press).

Failed reproduction was a common impediment of dairy herds afflicted with extraneous electricity. Induction of lymphopenia, a common result of electropathic stress, caused luteal dysfunction in cattle (Alila and Hansel, 1984). Retained CL (corpus luteum) on ovaries is a common cause of failed estrus in dairy cows (Kristula et al., 1992). Failed conception of experimental cows subjected to electricity was often overcome by administration of prostaglandins F2 alpha (Lutalyse) to cows not pregnant by 50-days post-partum in complete lactation electrical exposure experiments (Gorewit et al., 1992). Lutalyse, which removes the CL, causes estrus within 120 hours, and may have biased experimental effects of voltage on evidence of estrus and reproduction in some experiments (Shaw and Britt, 2000).

Displaced abomasums and rumenitis associated with poor muscle tone in cattle were common on farms with uncontrolled voltage and is comparable to the ulcers and gastro-intestinal pain as recognized symptoms of electropathic stress in humans and other animals (Selye, 1950, 1951; Rea et al., 1991; Dahmen et al., 2009).

Exposure to weak EMF resulted in deformed embryos and offspring in laboratory animals (Delgado et al., 1982; Moh'd-Ali et al., 2001) and abnormal chick embryos (Juutilainen et al., 1987). Mutations of salmonella microbes exposed to weak 100-Hz fields could account for the more common outbreaks of uncommon diseases and also raises questions about the effect of EMF on the health of ruminant microbial populations. Exposure of cows to low-level EMF resulted in alteration of circadian rhythms and some leukocyte differentiation antigens compared to unexposed cows (Stelletta et al., 2007).

Dairy cows on farms and dogs in commercial breeding-for-research kennels failed to conceive when induced current from near power lines was found on the metal cages near Kalamazoo, Michigan (Marks et al., 1995). Exposure to induced current increased length of estrus and progesterone content of blood in cows during 28-day exposure periods (Burchard et al., 2003). Repeated acute stress caused a luteinizing hormone surge to be missing during the follicular phase of ovulation in dairy heifers (Stoebel and Moberg, 1982). Induction of lymphopenia caused luteal dysfunction in cattle (Alila and Hansel, 1984). Prolonged stress affects estrous cycles and prolactin secretion in sheep (Przekop et al., 1984).

Likewise, early pregnancy loss and miscarriage of women and poor quality sperm in men were associated with exposure to magnetic fields (Juutilainen et al., 1987; Li et al., 2002, 2010). Chromosomal abnormalities were in lymphocytes of humans exposed to power frequencies (Nordenson et al., 1984). Genetic defects occurred in offspring of power frequency workers (Nordstrom et al., 1983).

Electrical charge and EMF have been shown to proliferate and exacerbate neuroendocrine stress and cortical hormones in blood of cows (Gorewit et al., 1984a,1984b), in sheep (Przekop et al., 1984), and in humans (Buchner and Eger, 2011; Eskander et al., 2011).

Decreased fibrinogen in blood of cows after three weeks exposure to ground currents was a significant discovery in a Minnesota farm herd (Hartsell et al., 1994). The "low fibrinogen" corresponds to reports of DNA SSB (single-strand breaks) and DNA DSB (double strand breaks) in human fibroblast cells of persons exposed to EMF, using the comet assay for DNA (Ivancsits et al., 2002, 2003). Nonthermal DNA breakage by mobile phone radiation (1800 MHz) in human fibroblast cells and in transformed GFSH-R17 rat granulosa cells *in vitro* indicates serious deleterious effects of RF-MF radiation (Diem et al., 2005).

"The International Agency for Research on Cancer (IARC) has classified ELF EMF as 'possibly carcinogenic,' a classification which necessarily implies that the epidemiological link (e.g., EMF and leukemia) may be causal and that directly or indirectly, weak ELF magnetic fields may promote DNA damage; that is, they are genotoxic" (Crumpton and Collins, 2004). Report of DNA damage by exposure to low-level EMF corresponds to the blood chemistry reports from cows (Hartsell et al., 1994). In addition, Hartsell et al reported increased lymphocyte count, decrease of white blood cells, decrease in segmented neutrophils, decrease in monocyte count, and increased SCC (somatic cell counts) in milk after cows were exposed to ground current for 17 days.

A relationship of childhood leukemia to 3rd, 5th, and 7th harmonic (180–420 Hz) current in the living environment of children was reported (Kaune et al., 2002; Wertheimer & Leeper, 1979, 1982). Also, childhood leukemia was 4.3 times higher among children whose bedrooms registered 4 mG, (0.4 μT-microTesla) or higher, the threshold breakpoint chosen, compared to those with 1.0 mG (0.1 μT) or less in their bedrooms in Japan (Kabuto et al., 2006).

Maisch (2010, 2012) has explained the Procrustean Approach used by standards-setting committees and has described irrefutable experiences of customers suffering from excessive exposure to electromagnetic fields, including radiation through the wall from Smart Meters in Victoria, Australia. Michigan's Public Service Commission is involved in two smart meter cases (MPSC E-Docket Case # U-16129, 2011, MPSC E-Docket Case # U-17000, 2012).

Since EMF interferes with the autonomic nervous system, control of the neuro-endocrine system which controls essentially all functions of the body toward homeostasis, logically a long list of chronic symptoms are possible, and not necessarily the same in every person, but largely dependent on the individual DNA tolerance or range for the function or dysfunction of a particular organ, tissue, or cell (Berne et al., 1998).

Rea et al. (1991) tested over 100 patients who believed they were sensitive to electrical exposure by challenging them to respond to 2900 nT at the floor, 350 nT at the level of the chair seat, of frequencies ranging from 0.1 Hz to 5 kHz. He found that 16% of the patients responded to 100 percent of the test signals which were repeated randomly 3 times.

Many signs and symptoms of such human common complaints as chronic fatigue syndrome, fibromyalgia, and myofascial pain syndrome may be caused by toxicities such as electrohypersensitivity (Genuis and Lipp, 2011). Electrical exposure often proliferates and exacerbates multiple chemical sensitivities (Scarfi, 2008).

The Electropathic Stress Syndrome is a manifestation of the General Adaptation Syndrome developed by Dr. Hans Selye, M.D. In every aspect of stress studied the uniform systems were (1) enlargement of the adrenal cortex with histological signs of hyperactivity, (2) thymic and lymphatic involution with changes in the blood picture, and (3) gastrointestinal ulcers, usually accompanied by other manifestations of shock (Selye, 1950, 1951; Turner, 1955). Selye and colleagues at the University of Montreal, Quebec, Canada, published some 1500 reports and 27 books describing a lifetime of research defining the effects of stress on animals and man.

EMF proliferates and exacerbates: allergies, asthma, Alzheimer's disease, brain tumors, strokes, CNS cancer, leukemia, breast, ovarian, prostate and testicular cancer; heart arrhythmia–atrial fibrillation. EMF interrupts communication between cells, enzyme action, ATP energy transfer, and neuroendocrine control of the autonomic nervous system, homeostasis; interrupts immune defense, reproduction, neuroendocrine response of adrenals, thyroids, gonads, and other glands as noted above and in the references (Genuis and Lipp, 2011; Johansson, 2006, 2007; Havas, 2006; Havas and Olstad, 2008; Rea et al., 1991; Marino and Ray, 1986; Cherry, 2001; Taylor, 2009; Hillman, 2009a, 2009b; Milham, 2010; Sage and Carpenter, 2012; Li et al., 2011).

5. Conclusions

Dairy cows were sensitive to earth currents associated with transients recorded in neutral-to-ground circuit outlets, from the floor in milking stalls, and in barn yards of twelve farms studied. Ground voltage as low as 10 mV p-p adversely affected milk production. Step potential voltages recorded by oscilloscope from metal plates in the floor of cow-stalls and in watering tanks were non-sinusoidal distortions of the 60-Hz waveform having frequencies ranging from the 1st through the 42nd harmonic, and up to 30 MHz with numerous impulses in overload, exceeding the capacity of the oscilloscope. The quality of electric power on farms and power lines affecting cattle was inferior to the 60-Hz steady-state sinusoidal current described in "stray voltage" laboratory reports (Appleman and Gustafson, 1985; Lefcourt and Akers, 1982; Stray Voltage Symposium, 1984; USDA, 1991).

Cow's behavior, health, and milk production were negatively responsive to harmonic distortions of step-potential voltage, suggesting that utility compliance with IEEE standards on dairy farms needs to be addressed. Measures of step potential were recorded by battery-powered oscilloscope while the primary power supply was completely disconnected from each farm. During this period there were no detectable changes in spikes on waveforms indicating the inferior power was from off-farm sources transferred on the neutral wire, uninterrupted in a grounded-Wye distribution system.

Power quality varied greatly from farm to farm and day to day. Milk production responses to changes in power quality varied inversely with the number of transient events recorded with event recorders, oscilloscope, and power quality meters. Harmonics often gave better estimates of electrical effects on milk production than voltage *per se*.

Peak-to-peak values were correlated with changes in milk production which permitted measuring the partial effects of independent variables of electrical currents on milk production using multiple regression analysis in the present research.

Use of a 500-Ohm resistor in the volt meter test circuit, for power quality, effectively eliminates from consideration the electrical measures that were found to be harmful in this study and may give misleading or unreliable information to investigators and herd owners. Studies of the effects of various electrical frequencies and harmonics on animals and humans and the physiological processes affecting behavior, health, reproduction and productivity deserve further attention.

Because power company employees and public service commissions are unable to find transients and harmonics in stray voltage, it would be advisable for all of them as well as professors of electricity to read Barry Kennedy's Power Quality Primer (Kennedy, 2000).

IEEE-SA, Standards Association Marketing Manager Shuang Yu announced, 25 April 2011, that the IEEE Standards Board approved new projects that will limit the injection of harmonic frequencies into the public electric transmission system. The release said further: "Harmonic pollution is a growing problem caused by the widespread use of power supplies and other non-linear loads. It can result in power loss and equipment damage and it may also be related to environmental safety issues. Both standards will address harmonic injection in 60-Hz and 120-V/240-V systems such as those in use in the United States, Canada, and other regions of the world. Both standards will also use the IEC SC77A and IEC 61000-3-12 standards as seed documents." The IEEE Standards Association should include harmonic current effects on human and animal health as well as effects on electrical equipment.

Acknowledgments

Special appreciation is expressed to Jeff Goeke-Smith, Network Planner and Security Engineer, Michigan State University, who assisted his father, Charles Goeke, and Dave Stetzer in recording and analyzing data, and to Dr. Edward Rothwell and Dr. Kun Mu Chen, Professors and Electrical Engineers, Michigan State University, for their helpful suggestions and for confirming electrical measurements in East Lansing, MI, homes. Also, Mary Hillman, for preparing and editing the manuscript, and all the farm families who shared their technical, financial, and personal information for the benefit of neighbors and advancement of public knowledge.

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