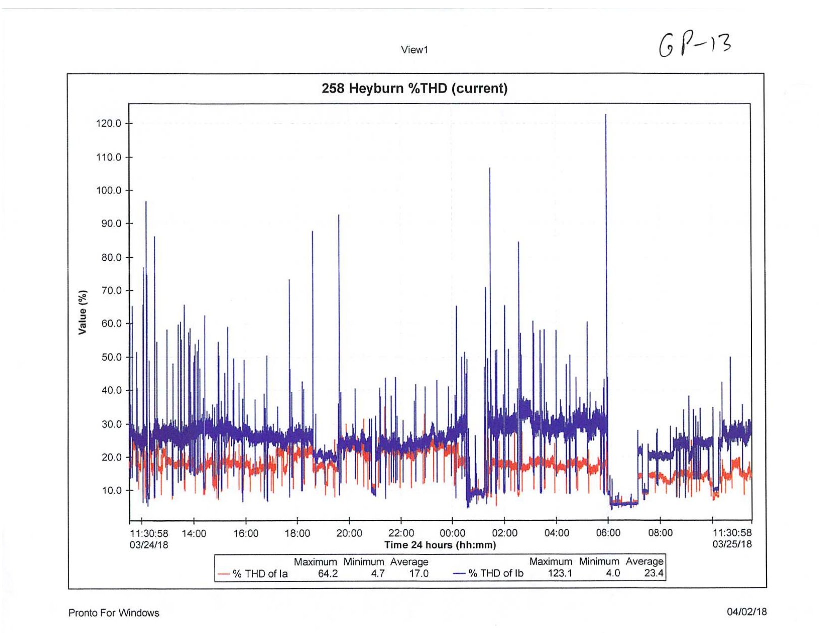
McKnight v. PECO Energy Company, Docket No: C-2017-2621057
Late Filing regarding Mr. Pritchard's New Exhibit GP-13

This document is a response to exhibit GP-13 presented in Mr. Glenn Pritchard's testimony on April 12, 2018. PECO did not file this exhibit on time, and we objected to it based on our inability to preview and prepare defense. Judge Heep did allow the exhibit, but allowed this late filing surrebuttal as defense.

PECO introduced GP 13 to indicate that the McKnight household has a very high amount of baseline 'dirty electricity' (harmonics and transients) with large spikes on the McKnight wiring, even without a smart meter installed. This is apparently in attempt to rebut Mr. Bathgate's testimony and graphs showing that the Aclara and L&G meters have a significant design problem where the switch mode power supply (SMPS) is not correctly filtered causing significant transients (more than 1200x out of FCC class B specifications). These transients were well in excess of the baselines he measured at the McKnight household. The high voltage transients generated by the SMPS were cited by Dr. Lawrence McKnight as one of 3 potential EMF transmission mechanisms for Alexia to have had the adverse effects she described caused by the AMI meter.



In court, we were not able to respond in full to this new exhibit in part because Mr. Pritchard himself was unable to explain it, or how it related to our case. We asked if this was a graph of transients or harmonics and he admitted he was not certain. We asked the specific device used and found it to be a Ranger PM 7000 power quality meter. We asked about the device characteristics such as the power supply and potential interference from an internal switch mode power supply based on Mr. Bathgates testimony that this was an important consideration. Mr. Prichard indicated he believed it had a battery, but was not sure. Mr. Prichard was unable to give other features or specifications of the device, and did not provide details of how it was installed, or other measurements that could have been obtained from the device.

There are several issues that invalidate the use of GP 13 as an indication that the McKnight household has a baseline problem with 'dirty electricity' even without a smart meter installed.

First, GP-13 does not have a comparison baseline to show the effect relative to other households or what effect a smart meter might have on this graph. Therefore GP-13 cannot stand on its own to mean that smart meter transients are lower than baseline house transients.

Next, and more importantly, GP-13 shows measurement of current, not voltage. The evidence presented by Mr. Bathgate specifically shows voltage transients. Thus, there is simply no way to compare GP 13 against Mr. Bathgate's analysis. Thus, it cannot be used as rebuttal.

Next, the literature showing biologic effects from dirty electricity does not cite effects using measurement of % THD (Total Harmonic Distortion) of Current flow (Amperage), and was not part of the McKnights' safety concern. We agree that the change in current flow created by AMI meter on a 200 amp circuit would likely be minimal, and it is unclear how that change might relate to any particular 15 amp circuit wiring in the house. Instead, the literature associated with biologic effects of 'dirty electricity' tend to show oscilloscope tracings of voltage with a 60 hz filter, as done by Mr. Bathgate. For example, Appendix A shows an example of how this was measured in cattle (see figure 6), for example, and Appendix B shows example of similar analysis in association with Cancer patients in California (see figure 1). Thus, there is no way to compare this graph to known biologic effects, or lack there of.

Finally, there are significant questions about the methodology and quality of this graph.

We know that PECO had the Ranger PM7000 in place for six days.

This recorder appeared under our transformer the afternoon of March 14 and was removed March 20. Mr. Ward Smith never responded to Alexia's email questioning the sudden appearance of this device:

> March 19, 2018, 4:43pm
>
> Dear Mr. Smith,
>
> I sent my letter to Judge Heep on Wednesday, Mar. 14 about bringing in some more necessary witnesses. Later that afternoon, a PECO bucket truck came and somebody hooked up a green bag to my lines under my transformer on Heyburn Rd. We are the only house served by that transformer now.   We did not request any service from PECO. Is that related to my case?
>
> 
>
> Thank you!
> Alexia

The green bag (recorder) was removed late morning on March 20, 2018 by Dennis Cronin, a PECO power quality technician:

March 20, 2018

Alexia asked Mr. Cronin what he was doing and he indicated that he was sent to “check voltage”. If PECO’s intent was to monitor our voltage for 6 days, it is quite suspicious why they did not present any voltage data, but instead submitted a 24 hour recording of current. It is also unclear why this needed to be a late filing during the hearing about a month later. PECO clearly had time to submit this ahead of the hearing, but chose not to do so.

To find out more about the Ranger PM7000, we sent GP-13 to our power quality witness, Mr. Russell Brocato. Mr. Brocato indicated this graph did not represent dirty electricity, but was a 24 hour graph of our electrical usage (amperage). He said that the recorder placed on our transformer had the capability for monitoring voltage and harmonics that would have had some relevance in assessing the dirty electricity at the house. He asked to see those graphs, however Mr. Pritchard did not present any of this other data to us to do that. We were only presented with that single 24 hour of current usage which was peculiarly graphed as % THD Current. Mr. Brocato also indicated that there should have been more than 24 hours shown. Given that the device was on for our house for 6 days, this begs the question why PECO did not submit other measurements that would have had some relevance and could have been obtained by this device.

Mr. Bathgate, another one of our witnesses, contacted the local company representative of that recorder in Michigan that sells the Ranger PM7000 and had a demo performed on the Bathgate house so he could determine what this GP-13 chart shows. He also learned how to hook this up and the features of the monitor.

Here is what the Ranger PM 7000 representative emailed back regarding the exhibit GP 13. (see appendix C).

> “I have to apologize. That graph is showing THD% of current A and THD% of current B. It would be very easy to have 120% THD on current if your current was very low for example. That’s why it should be displayed as a value. If your own whole home was steady at 1amp and you had 1amp of THD, that’s 100% THD. So again, it’s hard to paint a picture without seeing the rest of the recording from the utility.
>
> I thought after looking at the graph one of those was voltage and it’s not. Please let me know if you have any questions.”

The statement provided by the Ranger PM7000 representative is very disturbing, and suggests that PECO submitted this graph to distract the commission of what PECO is representing is false testimony to impugn the McKnights. Did PECO Engineers not know how to use the device, or did they choose to show something out of context to distract and confuse?

The explanation from the Ranger PM7000 representative also explains the seemingly excessive *readings displayed on the GP-13 graph. For example: If current usage is low and a lamp that* is not turned on and is turned on, the graph will show a 100% reading or spike because the usage suddenly changes. In other words, this is normal when measuring current. This graph is not at all reflective of harmonics or transients.

The Ranger PM 7000 representative showed Mr. Bathgate dozens of reports that could be obtained from the power quality monitor and if the intent of PECO was to demonstrate voltage harmonics and transients properly they should have included these additional reports from those 6 day recordings.

The Ranger PM7000 representative also confirmed Mr. Brocato's assessment that the reports need to be for a period of at least 3 days, but GP-13 only shows one 24 hour period. This again is suspicious that PECO introduced this exhibit as a cherry picked a 24 hr. window of an irrelevant measurement to distract the commission.

Mr. Bathgate confirmed that although the PM7000 does have a battery, it only lasts for 10 minutes (as a backup). The 6 days of recording could not have been using this, and instead relied on a SMPS which is another important source of error, even if the device was attempting to record transients.

Additionally, Mr. Bathgate contacted another party named Terry Stotyn of CRATUS CANDA to examine this same chart. Mr. Stotyn informed Mr. Bathgate that the PM7000 device was one of the least expensive power quality monitors on the market.

Mr. Stotyn further clarified that for a power quality reading there should be a report on the monitoring of the neutral wire since most devices in a home return the current from the primary *wire source to the neutral source and that would be able to directly indicate voltage harmonics* or transients. GP-13 does not include the neutral wire from the house in the report (only the A and B phase wires to the house) and is apparently indicative that the device may have been hooked up incorrectly.

In sum, GP-13 on its own is completely uninterpretable in our case, and certainly does not represent any rebuttal to Mr. Bathgate's assessment or assertions that AMI meters with SMPS create excessive conducted emissions far in excess of other household devices. It further does not rebut Dr. McKnights concern that conducted emissions from the AMI meter onto household wiring may have played an important role in contributing to Alexia's symptoms.

We affirm all above statements are true and correct to the best of our abilities.

Alexia McKnight 5/13/18 Lawrence McKnight 5/13/2018

Alexia McKnight and Larry McKnight

Appendix A

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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.

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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.

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,

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

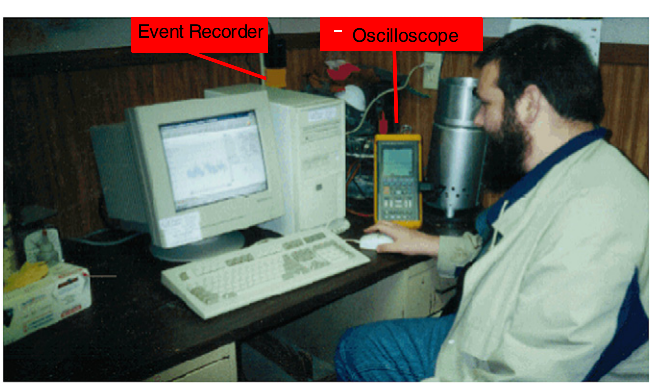

Fig. 1. Electrical instruments used to record power quality data. The event recorder is plugged into a 120-V outlet in the office and the oscilloscope is connected by twisted, shielded cable to metal plates grouted into the floor of milking stalls.

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, multiherd 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

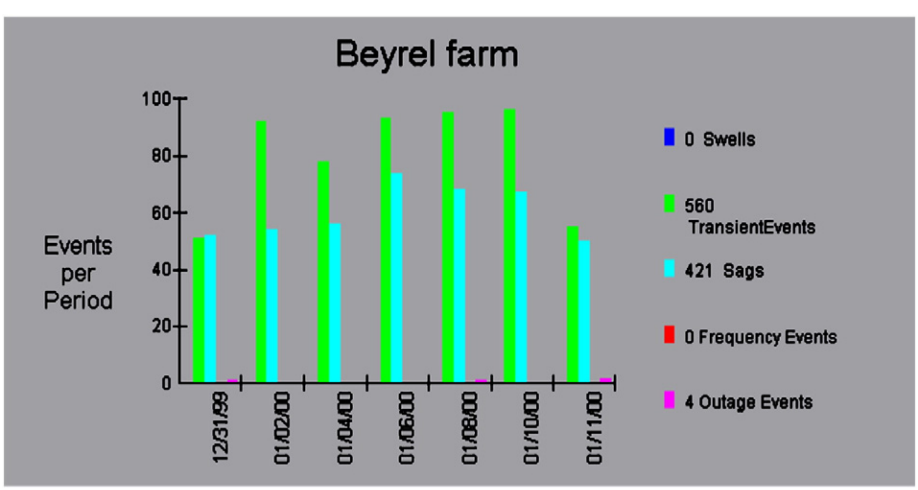

Fig. 2. Measures of power quality displayed from Fluke EventView™ Computer Software.

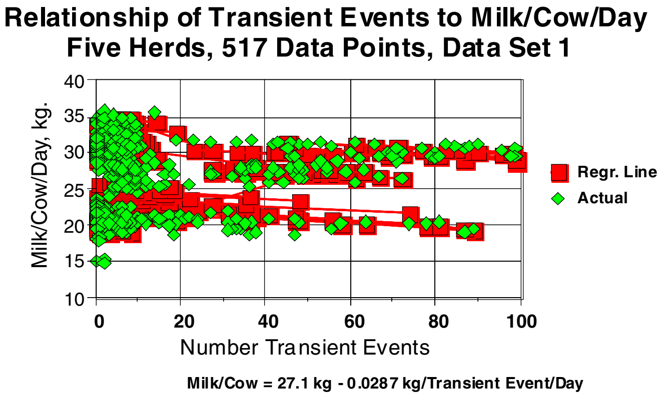

Fig. 3. Relationship of transient events to milk/cow/day, five farms, 517 days. The regression coefficient is −0.0287 kg milk per transient event (P<0.001).

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 field $= (V/R)/((5.4 * 10E^{-9} * H^2)/f60\ Hz)$, 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).

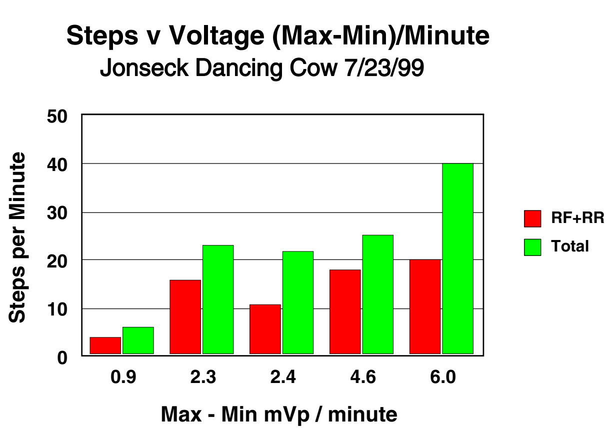

Fig. 4. Steps/minute increased as maximum minus minimum voltage increased/minute on the cow's leg. Voltages from the ground were recorded by oscilloscope attached to EKG (electrocardiogram) patches on right front and right rear legs.

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

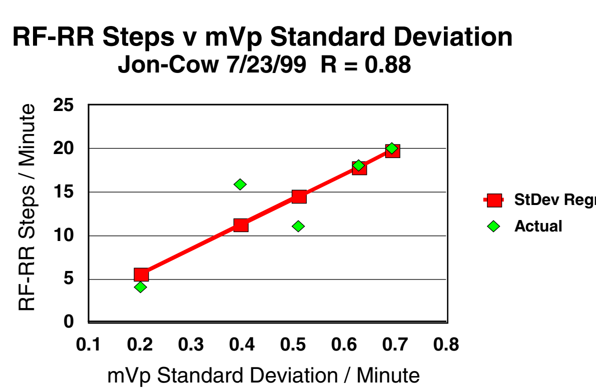

Fig. 5. Relationship of steps/minute to standard deviations of mVp/minute. (The standard deviation is a measure of voltage potential relative to average voltage).

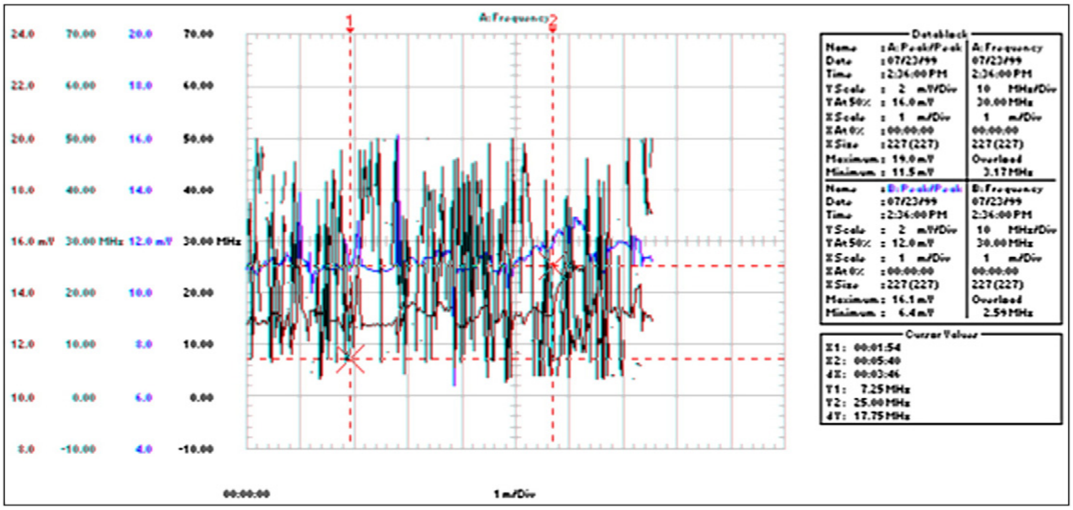

Fig. 6. Oscilloscope plot from EKG patches on leg of dancing cow from step voltage off the floor where the cow is standing. Voltage ranges from about 6.4 to 16.1 mVp, 7.25 to 25 MHz frequency in this oscilloscope snapshot, Jonseck Farm, 7/23/99.

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

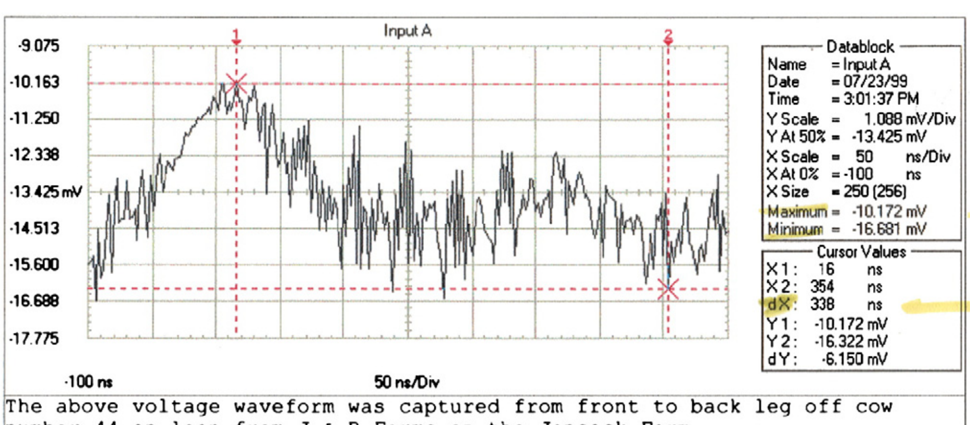

Fig. 7. Oscilloscope waveform showing the distorted notched non-sinusoidal transients carried on the 60-Hz waveform.

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_J 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.

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Appendix B

A New Electromagnetic Exposure Metric: High Frequency Voltage Transients Associated With Increased Cancer Incidence in Teachers in a California School

Samuel Milham, MD, MPH*,† **and L. Lloyd Morgan,** BS‡

Background *In 2003 the teachers at La Quinta, California middle school complained that they had more cancers than would be expected. A consultant for the school district denied that there was a problem.*
Objectives *To investigate the cancer incidence in the teachers, and its cause.*
Method *We conducted a retrospective study of cancer incidence in the teachers' cohort in relationship to the school's electrical environment.*
Results *Sixteen school teachers in a cohort of 137 teachers hired in 1988 through 2005 were diagnosed with 18 cancers. The observed to expected (O/E) risk ratio for all cancers was 2.78 ($P = 0.000098$), while the O/E risk ratio for malignant melanoma was 9.8 ($P = 0.0008$). Thyroid cancer had a risk ratio of 13.3 ($P = 0.0098$), and uterine cancer had a risk ratio of 9.2 ($P = 0.019$). Sixty Hertz magnetic fields showed no association with cancer incidence. A new exposure metric, high frequency voltage transients, did show a positive correlation to cancer incidence. A cohort cancer incidence analysis of the teacher population showed a positive trend ($P = 7.1 \times 10^{-10}$) of increasing cancer risk with increasing cumulative exposure to high frequency voltage transients on the classroom's electrical wiring measured with a Graham/Stetzer (G/S) meter. The attributable risk of cancer associated with this exposure was 64%. A single year of employment at this school increased a teacher's cancer risk by 21%.*
Conclusion *The cancer incidence in the teachers at this school is unusually high and is strongly associated with high frequency voltage transients, which may be a universal carcinogen, similar to ionizing radiation.* Am. J. Ind. Med. 2008. *© 2008 Wiley-Liss, Inc.*

KEY WORDS: high frequency voltage transients; electricity; dirty power; cancer; school teachers; carcinogen

BACKGROUND

Since the 1979 Wertheimer–Leeper study [Wertheimer and Leeper, 1979] there has been concern that exposure to power frequency (50/60 Hz) EMFs, especially magnetic fields, may contribute to adverse health effects including cancer. Until now, the most commonly used exposure metric has been the time-weighted average of the power-frequency magnetic field. However, the low risk ratios in most studies suggest that magnetic fields might be a surrogate for a more important metric. In this paper we present evidence that a

Abbreviations: EMF, electromagnetic fields; O, observed cases; E, expected cases; O/E, risk ratio; p, probability; Hz, Hertz or cycles per second; OSHA, Occupational Safety and Health Administration; OCMAP, occupational mortality analysis program; AM, amplitude modulation; GS units, Graham/Stetzer units; G/S meter, Graham/Stetzer meter; MS II, Microsurge II meter; mG, milligauss; EKG, electrocardiogram; LQMS, La Quinta Middle School.

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new exposure metric, high frequency voltage transients existing on electrical power wiring, is an important predictor of cancer incidence in an exposed population.

The new metric, GS units, used in this investigation is measured with a Graham/Stetzer meter (G/S meter) also known as a Microsurge II meter (MS II meter), which is plugged into electric outlets [Graham, 2005]. This meter displays the average rate of change of these high frequency voltage transients that exist everywhere on electric power wiring. High frequency voltage transients found on electrical wiring both inside and outside of buildings are caused by an interruption of electrical current flow. The electrical utility industry has referred to these transients as ‘‘dirty power.’’

There are many sources of ‘‘dirty power’’ in today’s electrical equipment. Examples of electrical equipment designed to operate with interrupted current flow are light dimmer switches that interrupt the current twice per cycle (120 times/s), power saving compact fluorescent lights that interrupt the current at least 20,000 times/s, halogen lamps, electronic transformers and most electronic equipment manufactured since the mid-1980s that use switching power supplies. Dirty power generated by electrical equipment in a building is distributed throughout the building on the electric wiring. Dirty power generated outside the building enters the building on electric wiring and through ground rods and conductive plumbing, while within buildings, it is usually the result of interrupted current generated by electrical appliances and equipment.

Each interruption of current flow results in a voltage spike described by the equation $V = L \times di/dt$, where V is the voltage, L is the inductance of the electrical wiring circuit and di/dt is the rate of change of the interrupted current. The voltage spike decays in an oscillatory manner. The oscillation frequency is the resonant frequency of the electrical circuit. The G/S meter measures the average magnitude of the rate of change of voltage as a function of time (dV/dT). This preferentially measures the higher frequency transients. The measurements of dV/dT read by the meter are defined as GS (Graham/Stetzer) units.

The bandwidth of the G/S meter is in the frequency range of these decaying oscillations. Figure 1 shows a two-channel oscilloscope display. One channel displays the 60 Hz voltage on an electrical outlet while the other channel with a 10 kHz hi-pass filter between the oscilloscope and the electrical outlet, displays the high frequency voltage transients on the same electrical outlet [Havas and Stetzer, 2004, reproduced with permission].

Although no other published studies have measured high frequency voltage transients and risk of cancer, one study of electric utility workers exposed to transients from pulsed

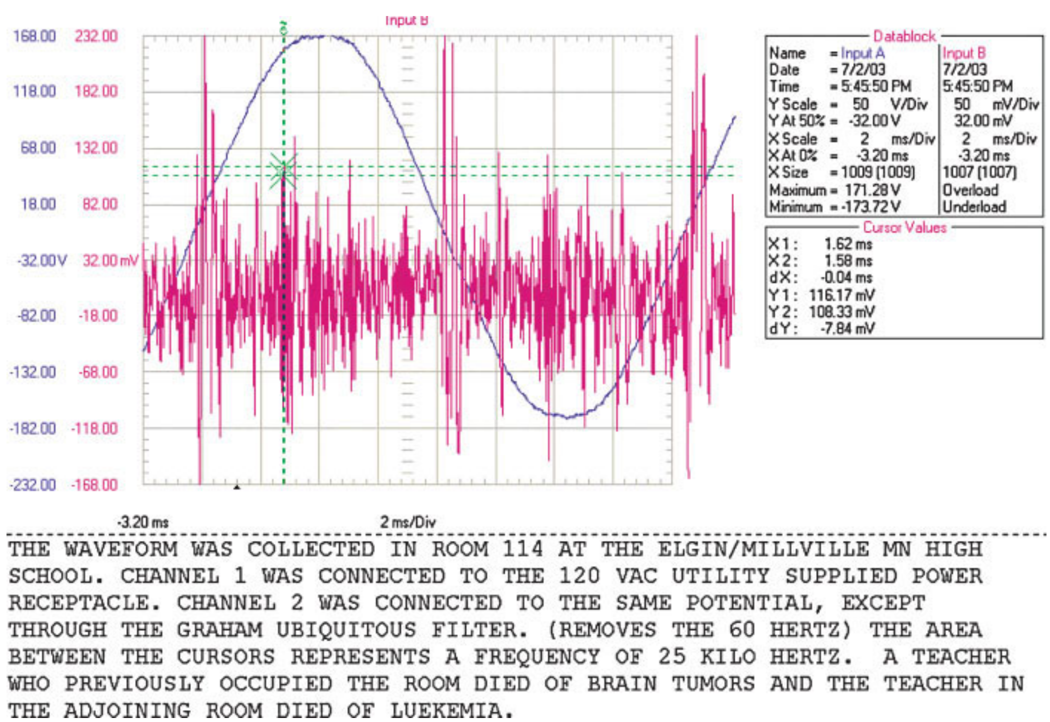

FIGURE 1. Oscilloscope display of dirty power: 60 Hz electrical power (channel 1) with concurrent high frequency voltage transients (channel 2). A 10 kHz hi-pass filter was used on channel 2 in order to filter out the 60 Hz voltage and its harmonics. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

electromagnetic fields found an increased incidence of lung cancer among exposed workers [Armstrong et al., 1994].

INTRODUCTION

In February 2004, a Palm Springs, California newspaper, The Desert Sun, printed an article titled, ''Specialist discounts cancer cluster at school,'' in which a local tumor registry epidemiologist claimed that there was no cancer cluster or increased cancer incidence at the school [Perrault, 2004]. An Internet search revealed that the teacher population at La Quinta Middle School (LQMS) was too small to generate the 11 teachers with cancer who were reported in the article. The school was opened in 1988 with 20 teachers hired that year. For the first 2 years, the school operated in three temporary buildings, one of which remains. In 1990, a newly constructed school opened. In 2003, the teachers complained to school district management that they believed that they had too many cancers. Repeated requests to the school administration for physical access to the school and for teachers' information were denied. We contacted the teachers, and with their help, the cancers in the group were characterized. One teacher suggested using yearbooks to develop population-at-risk counts for calculating expected cancers. We were anxious to assess the electrical environment at the school, since elevated power frequency magnetic field exposure with a positive correlation between duration of exposure and cancer incidence had been reported in first floor office workers who worked in strong magnetic fields above three basement-mounted 12,000 V transformers [Milham, 1996]. We also wanted to use a new electrical measurement tool, the Graham/Stetzer meter, which measures high frequency voltage transients.

The Graham/Stetzer Microsurge II meter measures the average rate of change of the transients in Graham/Stetzer units (GS units). Anecdotal reports had linked dirty power exposure with a number of illnesses [Havas and Stetzer, 2004]. We decided to investigate whether power frequency magnetic field exposure or dirty power exposure could explain the cancer increase in the school teachers.

METHODS

After the school administration (Desert Sands Unified School District) had refused a number of requests to assist in helping us evaluate the cancers reported by the teachers, we were invited by a teacher to visit the school after hours to make magnetic field and dirty power measurements. During that visit, we noted that, with the exception of one classroom near the electrical service room, the classroom magnetic field levels were uniformly low, but the dirty power levels were very high, giving many overload readings. When we reported this to Dr. Doris Wilson, then the superintendent of schools (retired December, 2007), one of us (SM) was threatened with prosecution for ''unlawful.. trespass,'' and the teacher who had invited us into the school received a letter of reprimand. The teachers then filed a California OSHA complaint which ultimately lead to a thorough measurement of magnetic fields and dirty power levels at the school by the California Department of Health Services which provided the exposure data for this study. They also provided comparison dirty power data from residences and an office building, and expedited tumor registry confirmation of cancer cases.

Classrooms were measured at different times using 3 meters: an FW Bell model 4080 tri-axial Gaussmeter, a Dexsil 310 Gaussmeter, and a Graham-Stetzer (G/S) meter. The Bell meter measures magnetic fields between 25 and 1,000 Hz. The Dexsil meter measures magnetic fields between 30 and 300 Hz. The G/S meter measures the average rate of change of the high frequency voltage transients between 4 and 150 KHz.

All measurements of high frequency voltage transients were made with the G/S meter. This meter was plugged into outlets, and a liquid crystal display was read. All measurements reported were in GS units. The average value was reported where more than one measurement was made in a classroom.

We measured seven classrooms in February 2005 using the Bell meter and the G/S meter. Later in 2005, the teachers measured 37 rooms using the same meters. On June 8, 2006, electrical consultants for the school district and the California Department of Health Services (Dr. Raymond Neutra) repeated the survey using the G/S meter and a Dexsil 320 Gaussmeter, measuring 51 rooms. We used results of this June 8, 2006 sampling in our exposure calculations, since all classrooms were sampled, multiple outlets per room were sampled, and an experienced team did the sampling. Additionally, GS readings were taken at Griffin Elementary school near Olympia, Washington, and Dr. Raymond Neutra provided GS readings for his Richmond California office building and 125 private California residences measured in another Northern California study.

All the cancer case information was developed by personal, telephone, and E-mail contact with the teachers or their families without any assistance from the school district. The local tumor registry verified all the cancer cases with the exception of one case diagnosed out of state and the two cases reported in 2007. The out-of state case was verified by pathologic information provided by the treating hospital. The teachers gathered population-at-risk information (age at hire, year of hire, vital status, date of diagnosis, date of death, and termination year) from yearbooks and from personal contact. The teachers also provided a history of classroom assignments for all teachers from annual classroom assignment rosters (academic years 1990–1991 to 2006–2007) generated by the school administration. The school administration provided a listing of school employees, including the teachers, to the regional tumor registry after the teachers involved the state health agency by submitting an OSHA complaint. The information we obtained anecdotally from the teachers, yearbooks, and classroom assignment rosters was nearly identical to that given to the tumor registry. None of the cancer cases were ascertained initially through the cancer registry search.

Published cancer incidence rates by age, sex, and race for all cancers, as well as for malignant melanoma, thyroid, uterine, breast, colon, ovarian cancers, and non-Hodgkin's lymphoma (NHL) were obtained from a California Cancer Registry publication [Kwong et al., 2001]. We estimated the expected cancer rate for each teacher by applying year, age, sex, and race-specific cancer incidence rates from hire date until June 2007, or until death. We then summed each teacher's expected cancer rate for the total cohort.

Using the California cancer incidence data, the school teacher data, and the GS exposure data, we calculated cancer incidence and risks. A replicate data set was sent to Dr. Gary Marsh and to Mike Cunningham at the University of Pittsburgh School of Public Health for independent analysis using OCMAP software. We calculated cancer risk ratios by duration of employment and by cumulative GS unit-years of exposure. We calculated an attributable risk percent using the frequencies of total observed and expected cancers, and performed trend tests [Breslow and Day, 1987] for cancer risk versus duration of employment and cumulative GS unit-years of exposure. Poisson *P* values were calculated using the Stat Trek website (Stat Trek, 2007). We also performed a linear regression of cancer risk by duration of employment in years and by time-weighted exposure in GS unit-years.

Since neither author had a current institutional affiliation, institutional review board approval was not possible. The teachers requested the study, and their participation in the study was both voluntary and complete. All the active teachers at the school signed the Cal OSHA request. The authors fully explained the nature of the study to study participants and offered no remuneration to the teachers for participation in the study. The authors maintained strict confidentiality of all medical and personal information provided to us by the teachers, and removed personal identifiers from the data set which was analyzed by the University of Pittsburgh. Possession of personal medical information was limited to the two authors. No patient-specific information was obtained from the tumor registry. With the individual's permission we provided the registry with case information for a teacher with malignant melanoma diagnosed out of state. The exposure information was provided by the California Department of Health Services. The basic findings of the study were presented to the Desert Sands Unified School District School Board and at a public meeting arranged by the teachers.

RESULTS

Electrical Measurements

In our seven-room survey of the school in 2005, magnetic field readings were as high as 177 mG in a classroom adjacent to the electrical service room. A number of outlets had overload readings with the G/S meter. Magnetic fields were not elevated (>3.0 mG) in the interior space of any of the classrooms except in the classroom adjacent to the electrical service room, and near classroom electrical appliances such as overhead transparency projectors. There was no association between the risk of cancer and 60 Hz magnetic field exposures in this cohort, since the classroom magnetic field exposures were the same for teachers with and without cancer (results not shown).

This school had very high GS readings and an association between high frequency voltage transient exposure in the teachers and risk of cancer. The G/S meter gives readings in the range from 0 to 1,999 GS units. The case school had 13 of 51 measured rooms with at least one electrical outlet measuring ''overload'' ($\geq$2,000 GS units). These readings were high compared to another school near Olympia Washington, a Richmond California office building, and private residences in Northern California (Table I). Altogether, 631 rooms were surveyed for this study. Only 17 (2.69%) of the 631 rooms had an ''overload'' (maximum, $\geq$2,000 GS units) reading. Applying this percentage to the 51 rooms surveyed at the case school, we would expect 1.4 rooms at the school to have overload GS readings ($0.0269 \times 51 = 1.37$). However, thirteen rooms (25%) measured at the case school had ''overload'' measurements above the highest value (1,999 GS units) that the G/S meter can

TABLE I. Graham/Stetzer Meter Readings: Median Values in Schools, Homes and an Office Building

Place	Homes	Office bldg	Olympia WA School	LQMS	Total
No. of rooms surveyed	500	39	41	51	531
Median GS units	159	210	160	750	<270[a]
Rooms with overload GS units ($\geq$2,000)	4	0	0	13*	17

[a]Excludes homes as specific room data was not available.
*$P = 3.14 \times 10^{-9}$.

TABLE II. Risk of Cancer by Type Among Teachers at La Quinta Middle School

Cancer	Observed	Expected	Risk ratio (O/E)	*P*-value
All cancers	18	6.51	2.78*	0.000098
Malignant melanoma	4	0.41	9.76*	0.0008
Thyroid cancer	2	0.15	13.3*	0.011
Uterus cancer	2	0.22	9.19*	0.019
Female breast cancer	2	1.5	1.34	0.24
All cancers less melanoma	14	6.10	2.30*	0.0025

*$P \leq 0.05$.

measure. This is a highly statistically significant excess over expectation (Poisson $P = 3.14 \times 10^{-9}$).

We noticed AM radio interference in the vicinity of the school. A teacher also reported similar radio interference in his classroom and in the field near his ground floor classroom. In May 2007, he reported that 11 of 15 outlets in his classroom overloaded the G/S meter. An AM radio tuned off station is a sensitive detector of dirty power, giving a loud buzzing noise in the presence of dirty power sources even though the AM band is beyond the bandwidth of the G/S meter.

Cancer Incidence

Three more teachers were diagnosed with cancer in 2005 after the first 11 cancer diagnoses were reported, and another former teacher (diagnosed out-of-state in 2000) was reported by a family member employed in the school system. One cancer was diagnosed in 2006 and two more in 2007. In the years 1988–2005, 137 teachers were employed at the school. The 18 cancers in the 16 teachers were: 4 malignant melanomas, 2 female breast cancers, 2 cancers of the thyroid, 2 uterine cancers and one each of Burkitt's lymphoma (a type of non-Hodgkins lymphoma), polycythemia vera, multiple myeloma, leiomyosarcoma and cancer of the colon, pancreas, ovary and larynx. Two teachers had two primary cancers each: malignant melanoma and multiple myeloma, and colon and pancreatic cancer. Four teachers had died of cancer through August 2007. There have been no non-cancer deaths to date.

The teachers' cohort accumulated 1,576 teacher-years of risk between September 1988 and June 2007 based on a 12-month academic year. Average age at hire was 36 years. In 2007, the average age of the cohort was 47.5 years.

When we applied total cancer and specific cancer incidence rates by year, age, sex, race, and adjusted for cohort ageing, we found an estimate of 6.5 expected cancers, 0.41 melanomas, 0.15 thyroid cancers, 0.22 uterine cancers, and 1.5 female breast cancers (Table II). For all cancers, the risk ratio (Observed/Expected = 18/6.5) was 2.78 ($P =$ 0.000098, Poisson test); for melanoma, (O/E = 4/0.41) was 9.8 ($P = 0.0008$, Poisson test); for thyroid cancer (O/E = 2/0.15) was 13.3 ($P = 0.0011$, Poisson test); for uterine cancer (O/E = 2/0.22), was 9.19 ($P = 0.019$, Poisson test).

Table III shows the cancer risk among the teachers by duration of employment. Half the teachers worked at the school for less than 3 years (average 1.52 years). The cancer risk increases with duration of employment, as is expected when there is exposure to an occupational carcinogen. The cancer risk ratio rose from 1.7 for less than 3 years, to 2.9 for 3–14 years, to 4.2 for 15+ years of employment. There was a positive trend of increasing cancer incidence with increasing duration of employment ($P = 4.6 \times 10^{-10}$). A single year of employment at this school increases a teacher's risk of cancer by 21%.

Using the June 8, 2006 survey data (Table IV), the cancer risk of a teacher having ever worked in a room with at least one outlet with an overload GS reading (≥2000 GS units) and employed for 10 years or more, was 7.1 ($P = 0.00007$, Poisson test). In this group, there were six teachers diagnosed

TABLE III. Cancer Risk by Duration of Employment

Time at school	Average time	Teachers	% of teachers	Cancer observed	Cancer expected	Risk ratio (O/E)	Poisson p
<3 years	1.52 years	68	49.6	4	2.34	1.72	0.12
3–14 years	7.48 years	56	40.9	9	3.14	2.87*	0.0037
15+ years	16.77 years	12	8.8	5	1.02	4.89*	0.0034
Total		137	100	18	6.51	2.78*	0.000098

Positive trend test (Chi square with one degree of freedom = 38.8, $P = 4.61 \times 10^{-10}$).
*$P \leq 0.05$.

TABLE IV. Cancer in Teachers Who Ever Taught in Classrooms With at Least One Overload GS Reading (≥2000 GS Units) by Duration of Employment

Ever in a room >2,000 GS units	Employed 10 + years	Total teachers	Cancers observed	Cancers expected	Risk ratio (O/E)	Poisson p
Yes	Yes	10	7[a]	0.988	7.1*	0.00007
Yes	No	30	3[a]	0.939	3.2	0.054
Total		40	10	1.93	5.1*	0.00003
No	Yes	19	2	1.28	1.6	0.23
No	No	78	6	3.25	1.8	0.063
Total		97	8	4.56	1.8*	0.047
Grand total		137	18	6.49	2.8*	0.000098

[a]One teacher had two primary cancers.
*$P < 0.05$.

with a total of seven cancers, and four teachers without a cancer diagnosis, who were employed for 10 or more years and who ever worked in one of these rooms. Five teachers had one primary cancer and one teacher had two primary cancers. These teachers made up 7.3% of the teachers' population (10/137) but had 7 cancers or 39% (7/18) of the total cancers. The 10 teachers who worked in an overload classroom for 10 years or more had 7 cancers when 0.99 would have been expected ($P = 6.8 \times 10^{-5}$ Poisson test). The risk ratio for the 8 teachers with cancer and 32 teachers without cancer, who ever worked in a room with an overload GS reading, regardless of the time at the school, was 5.1 ($P = 0.00003$, Poisson test). The risk ratio for 8 teachers with cancer and 89 teachers without cancer who never worked in a room with an overload G-S reading was 1.8 ($P = 0.047$, Poisson test). Teachers who never worked in an overload classroom also had a statistically significantly increased risk of cancer.

A positive dose-response was seen between the risk of cancer and the cumulative GS exposure (Table V). Three categories of cumulative GS unit-years of exposure were selected: <5,000, 5,000 to 10,000, and more than 10,000 cumulative GS unit-years. We found elevated risk ratios of 2.0, 5.0, and 4.2, respectively, all statistically significant, for each category. There was a positive trend of increasing cancer incidence with increasing cumulative GS unit-years of exposure ($P = 7.1 \times 10^{-10}$). An exposure of 1,000 GS unit-years increased a teacher's cancer risk by 13%. Working in a room with a GS overload (≥2,000 GS units) for 1 year increased cancer risk by 26%.

An attributable risk percentage was calculated: (observed cancers-expected cancers)/observed cancers = (18−6.51)/18 = 63.8%.

The fact that these cancer incidence findings were generated by a single day of G/S meter readings made on June 8, 2006 suggests that the readings were fairly constant over time since the school was built in 1990. For example, if the 13 classrooms which overloaded the meter on June 8, 2006 were not the same since the start of the study and constant throughout, the cancer risk of teachers who ever worked in the overload rooms would have been the same as the teachers who never worked in an overload room.

Although teachers with melanoma and cancers of the thyroid, and uterus, had very high, statistically significant risk ratios, there was nothing exceptional about their age at hire, duration of employment, or cumulative GS exposure. However, thyroid cancer and melanoma had relatively short latency times compared to the average latency time for all 18 cancers. The average latency time between start of

TABLE V. Observed and Expected Cancers by Cumulative GS Exposure (GS Unit-Years)

Exposure group	<5,000 GS unit-years	5,000 to 10,000	>10,000 GS unit-years	Total
Average GS unit-years	914	7,007	15,483	
Cancers obs.	9	4	5	18
Cancers exp.	4.507	0.799	1.20	6.49
Risk ratio (O/E)	2.01*	5.00*	4.17*	2.78*
Poisson p	0.0229	0.0076	0.0062	0.000098

Positive trend test (Chi square with one degree of freedom = 38.0, $P = 7.1 \times 10^{-10}$).
*$P < 0.05$.

employment at the school and diagnosis for all cancers was 9.7 years. The average latency time for thyroid cancer was 3.0 years and for melanoma it was 7.3 years (with three of the four cases diagnosed at 2, 5, and 5 years).

An independent analysis of this data set by the University of Pittsburgh School of Public Health using OCMAP software supported our findings.

DISCUSSION

Because of access denial, we have no information about the source, or characterization of the high frequency voltage transients. We can assume, because the school uses metal conduit to contain the electrical wiring, that any resultant radiated electric fields from these high frequency voltage transients would radiate mainly from the power cords and from electrical equipment using the power cords within a classroom.

The school's GS readings of high frequency voltage transients are much higher than in other tested places (Table I). Also, teachers in the case school who were employed for over 10 years and who had ever worked in a room with an overload GS reading had a much higher rate of cancer. They made up 7.3% of the cohort but experienced 39% of all cancers.

The relatively short latency time of melanoma and thyroid cancers suggests that these cancers may be more sensitive to the effects of high frequency voltage transients than the other cancers seen in this population.

In occupational cohort studies, it is very unusual to have a number of different cancers with an increased risk. An exception to this is that cohorts exposed to ionizing radiation show an increased incidence of a number of different cancers. The three cancers in this cohort with significantly elevated incidence, malignant melanoma, thyroid cancer and uterine cancer, also have significantly elevated incidence in the large California school employees cohort [Reynolds et al., 1999].

These cancer risk estimates are probably low because 23 of the 137 members of the cohort remain untraced. Since exposure was calculated based on 7 days a week for a year, this will overstate the actual teachers' exposure of 5 days a week for 9 months a year.

We could not study field exposures in the classrooms since we were denied access to the school. We postulate that the dirty power in the classroom wiring exerted its effect by capacitive coupling which induced electrical currents in the

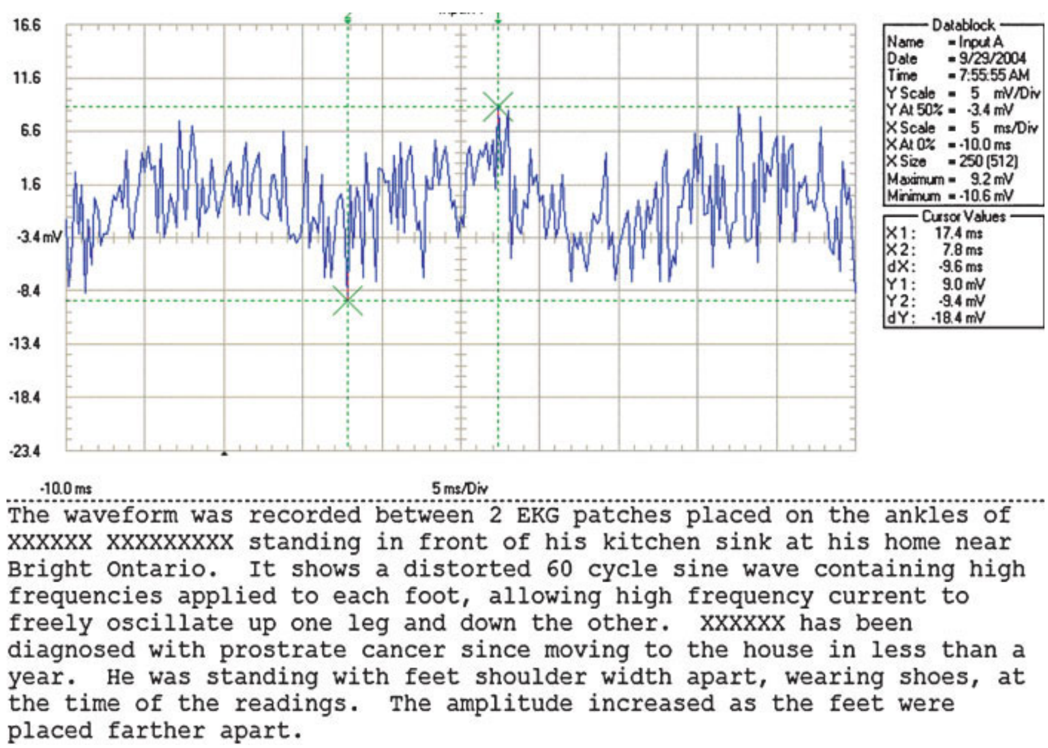

FIGURE 2. Oscilliscope display of 60 Hz current distorted with high frequencies taken between EKG patches applied to the ankles of a man standing with shoes on at a kitchen sink. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

teachers' bodies. The energy that is capacitively coupled to the teachers' bodies is proportional to the frequency. It is this characteristic that highlights the usefulness of the G/S meter. High frequency dirty power travels along the electrical distribution system in and between buildings and through the ground. Humans and conducting objects in contact with the ground become part of the circuit. Figure 2 [Havas and Stetzer, 2004, reproduced with permission] shows an oscilloscope tracing taken between EKG patches on the ankles of a man wearing shoes, standing at a kitchen sink. The 60 Hz sine wave is distorted by high frequencies, which allows high frequency currents to oscillate up one leg and down the other between the EKG patches.

Although not demonstrated in this data set, dirty power levels are usually higher in environments with high levels of 60 Hz magnetic fields. Many of the electronic devices which generate magnetic fields also inject dirty power into the utility wiring. Magnetic fields may, therefore, be a surrogate for dirty power exposures. In future studies of the EMF-cancer association, dirty power levels should be studied along with magnetic fields.

The question of cancer incidence in students who attended La Quinta Middle School for 3 years has not been addressed.

CONCLUSION

The cancer incidence in the teachers at this school is unusually high and is strongly associated with exposure to high frequency voltage transients. In the 28 years since electromagnetic fields (EMFs) were first associated with cancer, a number of exposure metrics have been suggested. If our findings are substantiated, high frequency voltage transients are a new and important exposure metric and a possible universal human carcinogen similar to ionizing radiation.

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Appendix C

From: **Alexia McKnight** alexia@mcknightinsight.com
Subject: Fwd: Ranger PM7000 Quote
Date: April 25, 2018 at 11:36 AM
To: Husband McKnight lawrence.mcknight@gmail.com

That's exactly what Russell told me, too—our current usage, nothing to do with DE. Now that makes 2 of them saying the same thing.

---------- Forwarded message ----------
From: "**Brett**" <bkauten@synergy-mi.com>
Date: Tue, Apr 24, 2018 at 2:13 PM -0400
Subject: Re: Ranger PM7000 Quote
To: "Bill Bathgate" <bill.bathgate@defiltersllc.com>

Bill,

I have to apologize. That graph is showing THD% of current A and THD% of current B. It would be very easy to have 120% THD on current if your current was very low for example. That's why it should be displayed as a value. If your own whole was steady at 1amp and you had 1amp of THD, that's 100% THD. So again, it's hard to paint a picture without seeing the rest of the recording from the utility.

I thought after looking at the graph one of those was voltage and it's not. Please let me know if you have any questions.

Brett Kauten

Synergy Systems Inc

4101 Pierce Dr.

Shelby Twp., MI 48316

Office: 248-656-2727

Cell: 248-505-2674

Email: bkauten@synergy-mi.com

From: Bill Bathgate <bill.bathgate@defiltersllc.com>
Date: Tuesday, April 24, 2018 at 1:44 PM
To: Brett <bkauten@synergy-mi.com>
Subject: RE: Ranger PM7000 Quote

Brett,

Based on the chart called GP13, would you say the chart does not provide adequate data to provide a conclusion?

A simple yes or no answer is sufficent.

Sincerely yours,

William S. Bathgate

DE Filters LLC

10909 Monticello Road

Pinckney, MI 48169

256-570-5434

www.defiltersllc.com

From: Brett [mailto:bkauten@synergy-mi.com]
Sent: Tuesday, April 24, 2018 12:15 PM
To: Bill Bathgate <bill.bathgate@defiltersllc.com>
Subject: Ranger PM7000 Quote

Bill,

Attached is the quote for the PM7000 you saw yesterday. I also attached screenshots of your THD percentages and voltages from our short recordings yesterday. It's not a ton of data, but shows you what your house looks like.

As far as answering your question about the graph you were given by the utility. There's too many variables and it's hard to say what they were recording and where they were recording. Doing your own recording might be the only way to really see what's going on and control what you see.

I'm looking into the switching power supply now and will let you know.

Brett Kauten

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