New Discoveries -- Dirty Electrical Power Affects Cows

Condensed from "Relationship of Electric Power Quality to Milk Production of Dairy Herds," in Press
By Donald Hillman, Dave Stetzer. Martin Graham, Charles L. Goeke, Kurt Mathson, Harold H. VanHorn, and Charles J. Wilcox

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SUMMARY: Complaints that electricity was affecting behavior, health, and milk production of dairy cows when voltages were less than Public Utility Commission (PUC) standards were investigated on 12 farms located in Wisconsin, Michigan, and Minnesota. PUCs and utilities in some jurisdictions have adopted 0.5 volt or 1.0 milliampere at cow contact as actionable limits below which utilities would not respond to farmer complaints of stray voltage. Using power quality instruments common in the electrical industry, investigators found large numbers of transient electrical impulses, and higher than 60 Hertz frequency har-monics on power lines and in milking stalls. Milk production decreased as the number of transient events increased and as the sum of step potential voltages > 0.01 Volt (peak to peak) increased. Leg movements (steps) of the cow increased/minute as voltage differentials increased. Milk production decreased as the number of 3rd, 5th, 7th, 21st and 42nd harmonics increased in a multiple herd analysis. Transient voltages/currents were distorted, nonsinusoidal, impulses at various frequencies produced by nonlinear loads both on and off the farm. Nonlinear loads are produced by electronic devices used in computers, printers, variable speed drive motors, switching on and off, capacitor switching of lines to balance loads, trees brushing power lines, and faults on circuits.

INTRODUCTION

Uncontrolled electric current injected into the earth, commonly called "Stray Voltage" neutral-to-earth voltage (NEV), neutral-to-ground voltage (N-G), or tingle voltage has been the subject of controversy between dairy farmers, some swine and dog kennel operators, and electric utilities in North America since 1970. An Agricultural Engineer in the State of Washington found electrical currents on domestic water systems from primary neutral down-grounds, Jersey cows decreased in milk production, and cattle reduced water consumption when exposed to similar voltages on watering troughs [7,8].

Farmers have claimed that small electrical shocks from the electrical system adversely affect the behavior, health, reproduction, and decrease milk production of dairy cows. The problems stopped or were reduced when the sources of the shocks were mitigated.

Utilities that use a grounded wye distribution wiring system, and their experts, have claimed that the problems were all caused by poor wiring, worn insulation, faulty equipment, improper grounding on the farms, and poor management of livestock by the farmers.

Studies of voltages on farms by college agricultural engineers in Michigan, Minnesota, Nebraska, New York, Virginia, and Ontario (Canada) indicated that 30 to 81% of dairy farms had what was believed to be harmful amounts of voltage during the period 1980-83. A review of "Sources of Stray Voltage and Effect on Cow Health and Performance" by Appleman and Gustafson was published in 1985 [1].

In 1991 the opinions of experts, based on 60 Hertz alternating current (AC), sinusoidal voltage, were published in USDA-ARS Publication 696, ***Effects of Voltage/Current on Farm Animals***.

Publication 696 [18], 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 Volt or 1 milliampere of 60 Hertz, steady-state voltage at cow contact points contributed by the utility, must be present 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. The standards were based on cow "sensitivity" studies and short-term experiments, limited exposure to electrical treatments, and too few cows with too large variations between groups to find statistically significant differences in milk production if such differences did exist [2]. In one trial, milk production was 11 to 17% less than controls when cows were exposed to 5 milliampere intermittent shocks for 2 weeks [12]. 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. Voltages less than approximately 0.5 volt, or 1.0 milliampere current, were not measured when resistors were in the voltmeter circuit, and were not considered important. The lower impedance of cows subjected to high frequency impulses, (perhaps by-passing the hoof by electrical coupling of the short-circuit from body to ground) was not considered.

However, the Redbook contained no information about effects of transients (electrical surges) or harmonics generated within the power lines by transients, oscillating at frequencies higher than 60 cycles per second, on the power lines. Harmonics are often called electrical noise and produce the humming, buzzing sound, and 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." And "Dissemination of research results in particular case studies would be useful to inform farm personnel of new, different, or unusual problems with power system maintenance" [18, sec 6, pp. 2-4]. No reports of such studies have appeared in the agricultural literature during the intervening 10 years.

The Michigan Public Service Commission (MPSC) issued a Stray Voltage Task Report in 1993. It was a summary of articles

published in various research publications, but also contained investigative complaints from 31 Michigan farms. Commission employee, William O. English, P.E., Electrical Engineer found that on-farm wiring faults which allowed current to leak into the grounding system caused some of the stray voltage problems. In addition, he found that voltage and/or current from the power company's primary neutral-to-ground and possibly radiant energy by induction from power company 345 kV lines was also responsible for the voltage on some farms after the on-farm wiring faults were corrected.

In 1999, Dave Stetzer, Industrial Electrician, at Blair, Wisconsin, was asked by a milk company field man if he would "look into this stray voltage that dairy farmers claim is affecting their cows when the power company experts say, no stray voltage is there?" The electrician told him, I don't believe there is such a thing as "stray" voltage, because voltage follows the laws of physics, and the path of least resistance, but I will have a look!

While studying the electricity on over 100 farms with oscilloscope, and Fluke® Event Recorders for nearly a year without compensation, he observed that milk production went down as the number of transient voltage events per day went up. Statistical analysis of the data by dairy scientists at Michigan State University and The University of Florida using multi-herd multiple regression and SAS™ Inc. statistical procedures proved Stetzer's "eyeball" observation to be correct.

New Discoveries

Transients are unwanted, short-duration voltages, called spikes or surges, caused by the sudden release of stored energy on an electrical circuit. A transient voltage is produced from stored energy in the circuit inductance and capacitance. Oscillatory transients are commonly caused by turning OFF high inductive loads and by switching large utility power-factor correction capacitors. Nonlinear loads, such as electronic devices in computers, printers, microprocessors in appliances, EMR imaging in hospitals, battery charges, and variable speed motors**,** put transients on primary and secondary power line neutrals [11,16].

Fluke® Event Recorders VR101 plugged into 120-V outlets in the milkroom or milking parlor recorded transient events, transients, sags, and sag voltage (below specified), hot-to-neutral and neutral-to-ground voltages (Vp, peak-to-peak on the waveform), and phase angle degree of transients, swells (high voltage), outages and the time (h, min, sec) each occurred. Examples of EventView™ computer software printouts are in Figures 1 and 2.

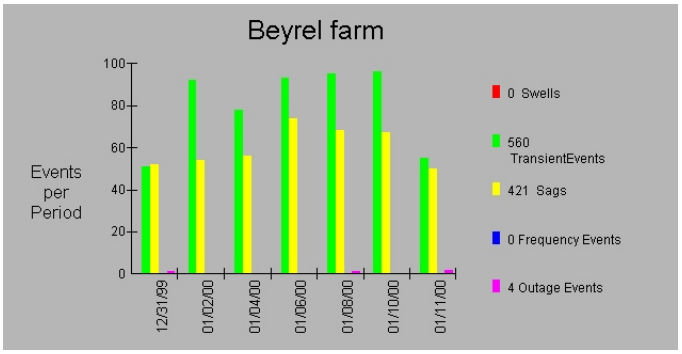

Figure 1. Measures of Power Quality Displayed from Fluke EventView™ Computer Software.

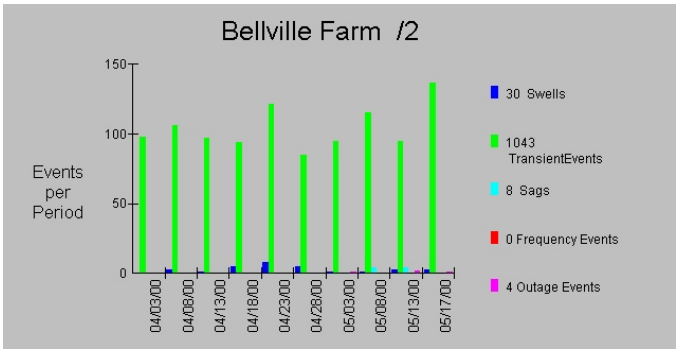

Figure 2. EventView Record of Transient Events. Event Recorder Thresholds H-N 100, N-G 50 Volts

Power Quality varied by Number of Transient Events from day to day and farm to farm. Event recorder threshold settings were 100-V hot-to-neutral and 50-V neutral-to-ground transients on circuits in 120-V wall outlets.

Transient Events averaged 20 ± 25.9 (standard deviation) and ranged from 0 to 122 per day on five farms, 515 data points (days) when the recorder was operating at least 23 hours per day as in Table 1.

	Trans. Events	Trans Oscilla-tions	H-N Trans. Events	H-N Vp	H-N ø Angle	N-G Trans. Events	N-G Vp	N-G ø Angle ° =>200°	Sags	Sags Vrms
Days / 515	515	515	385	385	389	191	191	144	261	261
Mean/day	19.6	182	11	-2367	166.2	8.7	-1793	26.3	25	2698
Std. Dev.	25.9	253	16.9	3349	61.7	16	1245	18.0	29	2636
Min	0	0	0	-21840	71	0	-7400	1	0	0
Max.	122	1939	89	1630	297	90	1170	90	166	18421
Ave./Tran.		9		-128	166.2		-79.9	73.7		108.3
Milk Coef.	-0.063									
P value Lin	0.025	0.025	0.03	0.21	0.001	0.27	0.27	0.10	0.02	0.02

Means = Average or sum per day for number days event occurred of possible 515.

Table 1. Event Recorder Measures of Power Quality for Five Herds Combined, 515 Data Points. Data Set 2.

Relationship of Transients to Milk Production. Milk tank weights were divided by the number of cows milked to determine milk per cow. Variations due to differences between farms, sequential dates, number of cows milked/day, transients and other known variables were included in multiple regression equations for determining effects of electrical measures on milk production.

Milk/cow per day decreased -0.063 lbs./Transient Event as the number of Transient Events increased per day, statistically significant (P<0.02). Thus 20 events x -0.063 lb. = -1.26 lb. average or -7.7 lbs./cow/day when the maximum 122 events/day occurred according to combined data of these five herds. Transient Events varied enormously from day to day and farm to farm.

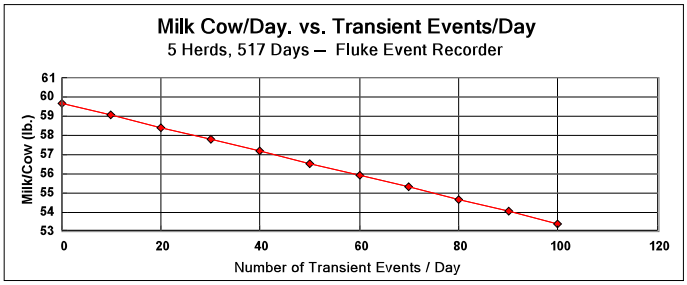

Figure 3. Relationship of Transient Events to Milk Production/Cow/Day, Five Farms, 517 Days.

Transients (the number of oscillations or spikes/day) averaged 182 ± 253 (SD) and ranged from 0 to 1939 per day. Eight electrical variables were found to be significantly related to milk production. They were: (1) number of transient events, (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 neutral ground transients, (6) total sum of N-G transients with phase degree angle => 200º, (7) number of sags (voltage <108), and (8) Sag Voltage rms.

Oscilloscope "Step Potential" Voltage from the Floor of Milking Stalls. Step Potential Voltages, above 0.010 Vp (10 millivolts) 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 in Wisconsin herds [17].

Milk per Cow/Day decreased as the number of impulse frequencies = >90 Hertz increased per day. Frequency and duration of exposure were often more important than voltage *per se*. The interaction of sum of voltage readings x sum of frequency readings greater than 90 Hz was negatively correlated with milk production, linear regression (P<0.008).

Harmonics

Harmonics are integer multiples of 60 Hz frequencies, i.e., 2nd harmonic = 120 Hz, 3rd harmonic = 180 Hz, etc. The oscilloscopes ordinarily recorded impulses up to 2520 Hz (ELF range), the 42nd harmonic, although some impulses were in the rf range (3,000 Hz to 30,000 megahertz).

Milk per Cow decreased as the number of 3rd, 5th, and 7th harmonics increased daily in a four-herd data set with 535 days (data points) (P<0.001) and **Milk decreased as number of 21st and 42nd harmonics increased** in a 3-herd data set, 165 days (P<0.03).

Milk decreased as the sum of triplen harmonics increased/day. Triplens are the 3rd harmonic and odd numbered multiples of the 3rd harmonic. Triplens are produced by nonlinear loads which draw current only during the peak of the voltage waveform. Triplen harmonics are additive and may increase the neutral load to173 percent of the rms phase current, causing heating of circuits, transformers, and telephone interference [11,16].

Specifically the 3rd, 9th, 15th, 27th, 33rd, and 39th harmonics were recorded in data set 3. As the average daily sum of triplen harmonics increased from 3,648 to maximum 30,388 per day, milk production decreased from average -0.27 to -2.28 lb./day attributable to triplen harmonics (P<0.003).

Electrical Pathways--In a wye distribution system, electricity flows from the utility primary neutral to the earth via down grounds at transformers and at least four times per mile. Also, primary neutral is connected to secondary (customer) neutral-bus at the service entrance panel and is redirected to secondary circuits, equipment down-grounds, water and drain pipes, soil, concrete, and livestock or humans throughout the premises. Current/voltage follows the path of least resistance, which varies from time to time, depending on moisture, frozen or thawed and other conditions of soil, wires, pipes, connections, etc. as described by Ludington et al. [14].

Electric Fields -- Electricity travels inside and outside of wires

Intensity of electric fields in milking stalls where the cows were standing was estimated by the methods of Chiba and Chen [6] using measured voltage and impedance (resistance) of cows from published values [1, 12], see Table 2.

Since voltage and frequency data were collected continuously for periods ranging from 54 to 204 days on the farms studied, the distribution of harmonics was calculated for each of the farms.

Electric-fields and Harmonic Distortion in Milking Stalls								
		Event (1) Ave.	Total	Different	E-Field	E-field	Voltage	
Farm	No.	Volts (Vp) / 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

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.

Table 2. Electric fields for average and maximum event Voltage (Vp), estimated from Chiba in Chen (5), and Total Harmonic Distortion (THD) percent of 1st harmonic voltage.

IEEE 519-1992 sets current limits on the utility side of the meter as THD, usually 5% of 1st harmonic voltage. Similarly, limits are set by the same publication for Total Distortion Demand (TDD) which is the limit for end-user amperage contribution to harmonic distortion on the utility line [10]. THD was outside these limits on the farms studied.

Health Effects

Increased incidence of disease, higher somatic cells in milk, low reproductive efficiency, and abnormally high mortality of cows and calves are common in herds exposed to excessive electricity. Cows exposed to 10 kV/m electric fields during 28-day experiments in Quebec, Canada, had significant changes in proteins and electrolytes of cerebrospinal fluid which bathes and provides nutrition for the brain and nerves of the spinal cord [3,4]. These findings are consistent with changes in the permeability of membranes and electro-chemistry of molecules and ions passing from blood to cells and tissues. A farm cow in the present study was videotaped dancing on two feet while a 0.165 volt, 625 Hertz transient shock was recorded on the oscilloscope three times during one milking. The estimated electric field created by that transient was 29.6 kV/m, approximately three times the E-field intensity applied to the cows in Canada. Reduced water consumption of cows exposed to electricity has been assumed to be caused by reluctance to touch metal water bowls, which may be true under some conditions. However, Marino [15] reported that mice exposed to E-fields and EMF reduced water consumption even though electrical exposure was from the air (over-head), and no current was attached to the water supply. Exposed mice gained less weight in 9 of 10 experiments and had depressed levels of cortisol in the blood after several weeks of exposure. In experiments with cows, blood cortisol increased when cows were exposed for short periods at or near milking time, which would be typical of an immediate reaction to stress. Stress causes immediate increases in cortisol (fight or flight reaction, Selye) but continuous stress causes adrenal fatigue, as in Addison's disease. Electrical effects on the brain, pineal and pituitary glands, and autonomic nervous system which controls heart rate, hormone secretions, immune responses, bone calcification, blood electrolytes, and general metabolism, suggest likely relationships between poor reproduction, poor health, and low milk production.

California Department of Health released a report prepared for the PUC, July 2001, concerning health risks from electric and magnetic fields from power lines in the home or workplace. They concluded more than 50% chance of a small increased risk of childhood leukemia, adult brain cancer, and amylotrophic lateral sclerosis (ALS -- Lou Gehrig's Disease), and more than 50% chance of 5-10% added miscarriages, 10-50% increased risk of male breast cancer, childhood brain cancer, suicide, Alzheimer's disease, or sudden cardiac death. Others warned about increased health risks [15], eryrthroleukemia [5], and disturbed sleep patterns and suicide [19].

CONCLUSIONS:

Step-potential voltage beginning at about 0.01 V (10 mV) was negatively correlated with milk production, and positively correlated with steps per minute. Milk production/cow decreased as the number of transient and harmonic impulses increased per day. Use of 500 ohm resistors in voltmeter circuits obscures higher frequency lower voltage that is harmful to cows. Effects of power quality, e.g., transient and harmonic impulses are not addressed in stray voltage literature. Power quality problems reported in this study were not due to stray voltage as described by stray voltage experts.

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