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

Donald Hillman [a,*], Dave Stetzer [b], Martin Graham [c], Charles L. Goeke [d], Kurt E. Mathson [e], Harold H. VanHorn [f], Charles J. Wilcox [g]

[a] Department of Animal Science, Michigan State University, East Lansing, MI 48824, United States
[b] Stetzer Electric, Inc., Blair, WI 54616, United States
[c] Department of Computer Science and Electrical Engineering, University of California, Berkeley, CA 94720-1770, United States
[d] Goeke Enterprises, Mason, MI 48854, United States
[e] EIT Rockwell Automation, Mequon, WI, United States
[f] Department of Animal Science, University of Florida, Gainesville, FL, United States
[g] Department of Animal Science, Geneticist, University of Florida, Gainesville, FL, United States

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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* Corresponding author at: Michigan State University, 750 Berkshire Lane, East Lansing, MI 48823, United States. Tel.: +1 517 351 9561.
E-mail addresses: Donag1@aol.com, donag1@aol.com (D. Hillman).

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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