A Review of the Problems Associated with Stray Voltage in Dairy Herds

Juliane Zdrojewski, *D.V.M.*
Collegeville, PA 19426

and

Jeffery N. Davidson, *D.V.M.*
Davis, CA 95616

Summary

The physical basis for the establishment of unwanted electrical potential differences was reviewed. Scarcity of adequate case reports precluded broad inferences concerning the problems associated with various types of stray voltage. Cases were cited of imposed, induced, DC, and neutral-to-earth AC voltage problems. Diagnostic techniques were described.

In recent years the dairy industry has become increasingly aware of the problems associated with intermittent, low-level electrical currents flowing through dairy barns or parlors. Such currents can flow through an animal that establishes electrical contact simultaneously with two points at differing voltages.

Data are lacking on the significance of this problem in the United States. When the stray voltage problem was investigated in the early 1960's in New Zealand, thirty of sixty farms tested at random had over three volts AC between milk line and floor, or measured directly as neutral-to-earth voltage (1). Minnesota researchers investigated fifty farms and estimated that 20% of milking parlors in that state had stray voltage problems (2). Michigan researchers investigated forty farms with stray voltage problems in a twelve-month period (3).

Farm electrification in the United States has been a rapid development. In 1935, 10% of farms used electrical equipment; by 1960, 95% of farms were electrified. Between 1960 and the present, electrical demand on the typical dairy farm has increased, while in many cases corresponding upgrading of farmstead electrical systems has not (4). This will lead to a real increase in the occurrence of stray voltage problems.

Ohm's Law

Ohm's Law describes the relationships among potential difference, current, and resistance: V = IR.

Potential difference		Current		Resistance
(volts)	=	(amperes)	x	(ohms)

Current flows when potential difference is applied across a resistance. Compared to a human, a cow offers less resistance to electron flow because she is larger. (More electrons can flow in a given time through a conductor of large diameter.) The cow is heavier than the human and has four bare feet on the ground, and consequently has more solid contact with the earth. Finally, saliva, milk, the salty secretion of mastitis, and urine are all conductive solutions. Offering less resistance, the cow allows more current to flow in response to a given voltage.

Electrical resistance measurements of the cow are reported between 350 and 1000 ohms. Consider a six-volt battery applied across a cow. Current flowing throught the cow would be computed as follows:

I=V/R
I=6V/1000 ohms maximum resistance
I=0.006 amps, or 6 milliamps.

In comparison, electrical resistance measurements of the human are reported between 5000 and 10,000 ohms. Current flowing through the human would be:

I=V/R
I=6V/5000 ohms minimum resistance
I=0.0012 amps, or 1.2 milliamps.

So a 6 volt battery would induce in a cow a *minimum* current of 6 milliamps, whereas it would induce in the human a *maximum* current of 1.2 miliamps. Thus cows are disturbed by voltages which their human handlers cannot detect.

The average human being cannot detect potential differences of less than 5 volts. The cow is more sensitive by an order of magnitude. She can detect potential differences down to 0.5 volts (15).

Signs

Signs of stray voltage vary with the size of the voltage and it's location within a dairy. Signs commonly noticed are:

1. Uneven milkout of quarters.
2. Decrease in milk production. Milk ejection can be prevented by actual or anticipated pain. A quarter which is not milked out is lacking an important stimulus to produce more milk. (6)
3. Increased clinical mastitis.
4. Nervousness and apprehension, expressed as balking at the parlor threshold, dancing around in stanchions, kicking off machines, frequent urination and defecation during milking, failure to ruminate, and stampeding out

the parlor when released.
5. Refusal to eat from metal feeders.
6. Refusal to drink from water bowls. (2, 7)

Origins of Stray Current

The origins of stray current fall into four categories: imposed, induced, direct, and AC neutral-to-earth.

1) Voltage is *imposed* or "leaked onto" a milk pipeline by electronic pulsators (DC) or other equipment (AC) grounded to the pipeline. Imposed voltages originated directly from the vacuum pump motor in early machines which had a chain drive between motor and vacuum pump. Until chain drive was replaced with V-belts, leaked current flowed from a faulty motor to the pump and thence to the milk line and teat (8). Glass milk lines obviate grounding current flowing on the milk line itself. Nevertheless, a fault in a milk pump, refrigerant pump, or agitator motor can leak current directly to milk. Milk will conduct currect through a milk line and plastic milk hose to the claw.

2) *Induced* AC voltage is produced between one conductor in which current is intended to flow, such as a cow trainer, and nearby isolated conductive material. In one reported case the cow trainer induced a voltage on a metal water line isolated from ground by rubber parts. Two to four volts AC were found between the water pipe and the stanchions and floor. Induced voltage sources are not very potent, i.e. they do not produce very much current. However, the cows in this case were sufficiently disturbed by the momentary discomfort to avoid drinking. The solution was to ground the line by establishing a metallic connection between the pipe and nearby grounded water pump (2).

Another example of induced alternating current occurs with three-wire single-phase circuitry when hot wires of the same phase leg are run in conduit with neutral and ground wires of other circuits. Their combined field strengths have been sufficient to induce 0.6 V AC between themselves and the neutral and ground wires. The voltage is reduced by changing the load balance in the offending circuit so that current on the hot wires is asynchronous, i.e. at opposite phase legs at any moment (9).

3) There has been less testing and reporting of *DC current* effects. Sustained voltage greater than 2 V DC with sustained DC current greater than 5mA have a limited number of sources (5, 10). AC current is rectified to DC to run electronic pulsators. Telephone wires can carry 80 DC volts and so have ground wires attached for safety. But buried ground connections corrode, especially in wet limestone soils. Current can flow from these cables to buried metal water pipes on a farm (11). DC voltages can alsc be created by electric fences and by galvanic action of urine and manure (12).

4) The most common type of stray voltage involves AC circuitry and causes alternating current to flow from grounding an neutral systems through cow contact points on its way to true earth. An AC power grid is illustrated in figure 1. Generators at a power station start electrons moving down the hot wire of a two-wire circuit. A potential difference of 6900 volts exists between the hot and neutral wires. Voltage drops along the line due to line resistance and as power is drawn off a transformer for distribution to customers. The neutral wire ("primary neutral") carries "unbalanced" electrons from one part of the system to another.

The utility pole at a farmstead bears a transformer (figure 2) where electrical energy is transformed into a magnetic field and back again at the voltage and current desired by a customer. At the same time the sytem changes from a two-wire circuit to a three-wire circuit. The power drop consists of this three-wire circuit running from the transformer to the farmstead service entrance. Between either of its hot wires and its neutral wire is a potential difference of 120 volts, enough to run small motors and lights. Current travels between hot and neutral wires as it does on any two-wire circuit. Between two hot wires is a potential difference of 240 volts, enough to run a large motor or stove or to be broken down into subsidiary 120 volt circuits. In the power drop, as in any three-wire circuit, alternating current zips back and forth on the hot wires, flowing on the neutral only when there is uneven draw on one of the hot wires. The neutral is a safety device used to preserve electrical balance on the hot wires. This "secondary neutral" in the power drop is

Figure 1

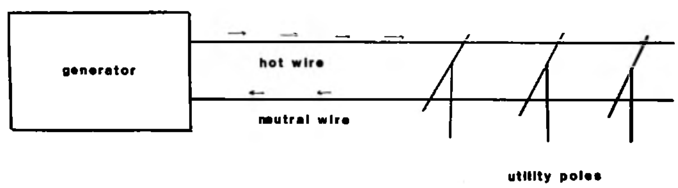
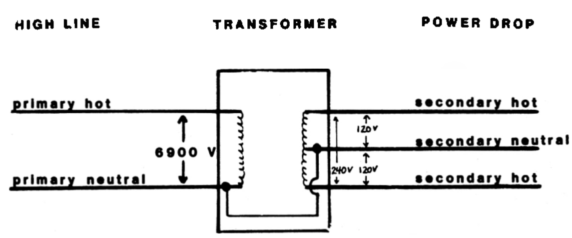


Figure 2



electrically connected to the primary neutral of the power company's high line. So every farm's neutral system is connected to the high line neutral and thus to the neutral system of every other power customer on the grid (4).

The path of least resistance for excess electrons is supposed to be the secondary neutral wire system back to the primary neutral. If there are poor connections on the way to the primary, or if the secondary is clogged by imbalanced or excessively high loads, the electrons will instead take the path of least resistance to the nearest ground. The path may include cows. Futhermore, an overloaded secondary neutral can cause excess current on the primary neutral, which finds its way down the neighbor's secondary neutral wire (2).

On-farm sources of neutral-to-earth AC voltages include faulty farm motors, loose (high-resistance) connections, and unbalanced loading of barn circuitry. In one case a fault in the farm sump pump and unblanced 120 V loads were among the causes of voltage resulting in nervous cows and dropped production (2). On-farm sources include those occurring at other service entrances on the farmstead. A faulty motor in a farm home refrigerator produced periodic 2V AC spikes between cow contact points in the farm's milking parlor (13). In another case the farm home stove created sufficient current in the farmstead neutral wiring that voltage spikes up to 17 V AC were created between cow contact points in the milking parlor. Clinical signs were a 25% decrease in producton, unever milkout, and spontaneous drying off of some cows after five months of lactation. Repeated checks had been necessary to locate the source. The solution was an isolation transformer wired between the farmstead neutral and the barn service entrance so that secondary neutrals from the house and barn were no longer interconnected via the primary neutral (8).

Neutral-to-earth AC voltages arising from off-farm sources occur most commonly in areas and at times where the soil is particularly conductive: from the metal-rich Fraser River Valley of British Columbia, to a single farm on limestone subsoil during a rainy season. The scondary and primary neutral wire system is intended to carry current back to the source at the power station. If those wires are too small for the amount of current they are now required to carry, or the electrical connections are old and corroded, they will no longer form the path of least resistance. From a service entrance ground terminal, to a neutral wire, to a metal feeder, to a cow, to wet concrete, to conductive subsoil might be the easiest path to true earth. A farm at the distal end of a two-wire primary circuit has an increased probability of this occurring, since the resistance of the neutral wire increases with increasing length, as well as with decreasing diameter.

To keep primary neutral current off the farmstead, the power company can disconnect the electrical bond between primary and secondary neutral wires at the transformer, and replace the standard transformer with a "lightening arrestor" transformer. This has a spark gap instead of an electrical bond between neutral wires (2). Regional electrical codes may or may not permit this (5). A similar spark gap installed between the meter and the farmstead service entrance is called an "isolation transformer" and is the property of the customer, who loses some lightning protection and is responsible for grounding the farmstead (2, 8). Another approach is to eliminate the potential differences among cow contact points in a new milking parlor with 2x2 inch welded wire mesh buried two inches or less in the concrete floor. The mesh is electrically bonded to metal structures (siderails, feeders, floor grates) by welded or clamped stainless steel. Copper wire is trailed out from the mesh down the alleys to

Reported Levels of Voltage and Current of Pathologic Significance

Voltage	Current	Probable Significance	Reference
<0.5 V AC		none	4
<1.0 V AC	<0.5 mA	none	3
0.5 to 1.0 V AC		questionable; check again	4
>1.0 V AC		definite	4
1.0 to 5.0 V AC	1.0 to 15 mA	definite	3
>5.0 V AC	>15 mA	indicates a severe probable	3
>1.5 V DC		probable	2
sustained >2 V DC	sustained >5 mA	problem	3

provide gradual transition in floor voltage. This prevents shocks as cows cross the threshold onto the equipotential plane (1, 2, 11).

Detection of Stray Voltage

Stray voltage can be suspected on the basis of clinical signs or on the basis of 0.5 V AC or 1.5 V DC measured between cow contact points in the barn.

If AC or DC voltage is suspected or identified, the problem is to determine on which circuit the problem originates, so that a qualified electrician can make necessary improvements. A high-impedance voltmeter should be used; at least 5000 ohms/volt are necessary for the meter to be sensitive to low voltages (11). The voltage scale should ideally have two to five volts as its lowest full-scale reading, so that one-tenth volt readings can be taken easily. Most meters register DC voltage on the AC scale. An extra lead equipped with a capacitor in series will block DC current. Two, ten, and twenty microfarad capacitors have all been recommended for this purpose (2, 13, 14). Automatic recording voltmeters are ideal because of the transient nature of the voltage on many farms. They are more expensive and may have to be modified to record AC voltage in the desired range. Other necessary equipment includes extra long voltmeter leads, a 350 ohm resistor to be clipped in parallel with the leads, a file for preparing contact surfaces, and a copper-clad ground rod.

A systematic approach to isolation of the circuit containing the voltage source has been described (2, 3) and is here summmarized:

1) A map of the farmstead is prepared. An area to drive a ground rod is chosen 25 feet from the barn and any underground or surface conductors, such as telephone lines or water pipes. A wire is run from the rod to the barn service entrance ground wire, and the voltmeter is connected in series. Since the rod is true earth, voltage measured here is between the barn's neutral system and true earth-neutral-earth ("NE") voltage. NE voltage is the maximum a cow could encounter in the barn from this source. A 350 ohm resistor is placed in parallel on the meter. A drop of more than 20% in NE voltage suggests high resistance in the line to

true earth. The rod is relocated or soaked with brine to lower its resistance.

2) The barn service entrance is disconnected. If the NE voltage remains, the source is not in the barn. If it disappears, the source is barn circuitry. The barn service entrance is reconnected. Its subsidiary circuits are disconnected. Of these, the 240 volt circuits are reconnected one at a time with equipment running. A jump in recorded voltage as one is added signifies faulty equipment or unbalanced load. 120-volt circuits are reconnected. An NE increase of more than three-tenths volt with the 240 volt equipment running means the neutral is overloaded. Wire or service entrance box size should be increased, electrical balance restored, or connections improved.

3) If the source is not in the barn, the barn service entrance and all remaining service entrances on the farmstead are disconnected. A significant drop at disconnection suggests a faulty load on that service entrance.

4) Finally, if all service entrances are open persistent NE voltage must come from off the farm. It will not change when the farmstead main is opened because primary and secondary neutrals are electrically bonded at the transformer. The transformer is the property of the power company. The company can disconnect this bond for testing purposes on request. If the NE voltage then disappears, a spark gap transformer or equipotential plan construction is indicated.

Reporting Stray Voltage Problems

A stray voltage case report should include the following information:

1. Background
   1) herd size
   2) production level
   3) barn design
   4) milking management
   5) level of clinical mastitis (before and after)
   6) leukocyte counts or CMT scores (before and after)

2. Clinical signs
   1) time of day of occurrence
   2) number of cows affected
   3) traits common to cows affected most severely (e.g. cows with cracked skin on teats)
   4) duration and severity of signs

3. Methods
   A. Equipment
   1) voltmeter brand, impedance, scale
   2) method used to prevent reading DC current on the AC scale
   B. Technique
   1) number of times spot checks were repeated
   2) times of day spot check were made
   3) points of attachment of voltmeter leads
   4) total time for continuous or recorded readings
   5) method used to identify the circuit containing the stray voltage source

4. Readings
   1) mode of current
   2) polarity of current
   3) potency of current
   4) persistence, if DC
   5) size of voltage.

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