POWER QUALITY

# Don't let customers make a mystery of stray voltages

Stray voltages can cause what appears to be mysterious behavioral changes among farm animals. But there's no mystery about the causes of stray voltages or the levels that affect cows. As the result of utility experience and extensive research by the agricultural departments of many universities and the US Dept of Agriculture, stray voltage is now well understood.

But it may still be difficult to resolve a customer's stray voltage concerns because of the need to persuade everyone involved—from dairy farmer to utility linemechanic—to approach the situation as a team effort with a rational understanding of the factors involved. It's very easy for a farmer or dairy equipment supplier, under the stress of serious economic losses, to try and shift responsibility for the solution of real and perceived stray-voltage problems to a single organization. And that organization is usually the electric utility.

The best way to explain stray voltage is to start by talking in terms of currents. In most cases the currents that result in stray voltage are normal neutral-return currents. Under normal operating conditions, these currents flow through nondesignated conductors—such as water lines, stanchion pipes, etc. As a result, they generate voltage differences between points that a farm animal can touch simultaneously. Cows are more susceptible than people because they have a low body resistance, and if current levels are high enough, milk production may be affected. Cows may even refuse to enter the milking parlor.

There are two electrical circuits involved: (1) the farm secondary circuit, in which the distribution transformer is the current source and the destination for return currents, and (2) the primary distribution system, in which the substation transformer is the current source and destination for return currents. Because the National Electrical Safety Code (NESC) requires a tie between primary and secondary neutrals at the distribution transformer and because the National Electric Code (NEC) requires a tie between the secondary neutral and the waterline, normal neutral-return currents from both on- and off-farm sources can find their way to metal equipment in the dairy barn (Fig 1). To best resolve a customer's stray voltage concerns, both circuits must be addressed as possible sources.

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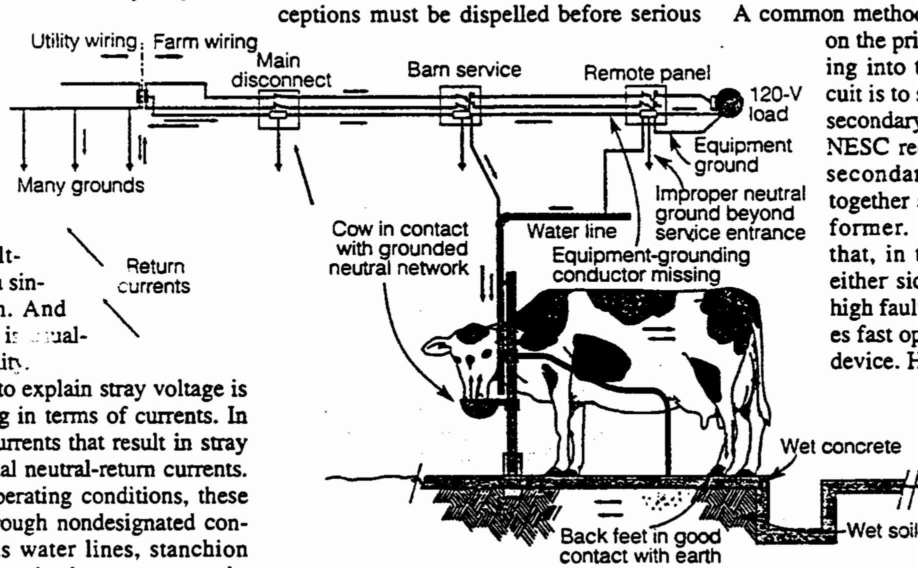
### First, overcome the myths

There are few dairy farmer with a thorough understanding of electricity. Because stray voltage may often be difficult to diagnose and reduce, many misconceptions exist about its cause and effect. These misconceptions must be dispelled before serious effort can be made to resolve concerns. The following are ypical obstructions to a rational solution:




**1. Neutral-return currents** originating from both utility and on-farm sources flow through milking-parlor equipment and generate stray voltage

Myth: Stray voltage, ground currents, and magnetic fields (EMF) are the same thing, and they all have negative effects on farm animals.

Fact: Stray voltage, ground currents, and magnetic fields are normal consequences of operating electrical equipment, but they are not the same thing. Studies indicate that stray voltage can cause small currents to flow through animals, which can cause behavoral changes. There is no evidence to support claims that ground currents or magnetic fields have any effect on farm animals.

Myth: Electrical systems should not be connected to the earth because that will cause currents to flow through the ear and harm farm animals.

Fact: While electrical systems can be operated without a ground, grounded systems offer greatly improved animal and personal safety and better reliability. Correct wiring is the best way to prevent current from flowing where it is not intended.

Myth: Electric utilities cause stray voltage conditions and they should be responsible for correcting them.

Fact: Currents flow to ground from both the utility's and the farm's electrical systems. Operating machinery on an improperly wired farm often results in greater levels of stray voltage than can be contributed by the utility system.

Wisconsin Electric's efforts to keep its customers informed about stray voltage include a booklet, "A Self-Help Guide to Stray-Voltage Detection," and a quarterly newsletter: *Energy and Agriculture.*

### Are isolators the answer?

A common method of preventing currents on the primary neutral from flowing into the farm secondary circuit is to separate the primary and secondary neutrals. Normally the NESC requires that primary and secondary neutrals be bonded together at the distribution transformer. This bonding ensures that, in the event of a fault on either side of the transformer, a high fault current flows and causes fast operation of the protective device. However, the NESC does allow the use of an isolator in the form of a device with a breakdown voltage not exceeding 3 kV. Surge arresters, saturable-core reactors and high-speed electronic switches are most often used to separate the two neutrals. Under normal operation with an isolator the two neutrals are electrically separate, but in the event of a fault on either the primary or the secondary or a lightning strike, the device closes and momentarily reconnects the neutrals.

The arrester has the advantage of being very simple and reliable, but its flashover voltage can be very high. Much more effective are reactor and solid state neutral isolators, such as the solid-state device made by Dairyland Electrical Industries, Oregon, Wis. This device reconnects primary and secondary neutrals within two microseconds when the voltage between them exceeds 25 V (RMS). When closed provides a low-resistance path for fault currents.

Several concerns have surfaced with the use of isolators:

1. Installation of an isolator removes the

benefit of the farm ground network from the distribution-system neutral. This ground network, consisting of well casing, buried water lines, etc, constitutes a low-resistance return path for primary-neutral current. Removal of this path may increase neutral return current, and therefore stray-voltage levels on adjacent farms that have not been isolated.

2. Isolators can be compromised. Electric company personnel or personnel from other utilities making joint use of the pole may do this inadvertently while performing service or line work. All that is needed is creation of a conductive path around the isolator. A compromised isolator may go undetected for some time. Few dairymen have accepted the idea that regular stray-voltage checks should be part of good farm management.

3. Isolating devices, while effective in preventing the flow of primary neutral current into the farm secondary circuit, are considered by some people to be a band aid to cover up deficiencies in the distribution system—such as high-resistance grounds and splices or inadequate neutral conductors. For this reason, the Public Service Commission of Wisconsin has ruled that isolating devices may only be used as a temporary solution to stray voltage from the distribution system. Corrective measures, sufficient to reduce stray voltage from the utility below 0.5 V, must be implemented, and isolators removed, within 90 days.

The 0.5-V level was chosen as the level at which a utility must take action. It is well below levels that have been shown to have any affect on farm animals.

### What to do on primary system

Utility efforts to reduce stray voltages from the distribution system should be centered around reducing primary neutral currents and reducing resistance in the neutral and ground connections of the return path. High resistance in the return path diverts primary neutral current into the farm secondary circuit. The following are steps that can be taken:

- Balance loads on the nearby primary distribution system (assuming it is 3-phase). Single-phase loads are often added to 3-phase feeder taps over time. Such feeder taps should be reanalyzed for load balance and loads reconnected to minimize neutral current. Where it can be justified, existing single and 2-phase taps can be rebuilt to full 3-phase. Open-wye/open-delta transformer connections can be discontinued if three primary phases are available.
- Reduce neutral-conductor resistance. Regardless of the number of phases, new and rebuilt primary distribution lines can be constructed with the neutral conductor the same size as the phase conductors, .
- Hold down connection resistances. Bolted and twisted connections on the overhead primary neutral conductor can be replaced with compression connectors in any area where stray voltage may be a concern.
- Neutral grounding can be analyzed and possibly improved. It may be beneficial to exceed the regulation number of grounds per mile (nine in Wisconsin). Ground rods may also be stacked or driven in parallel to reduce the resistance (below 25 ohms, if possible).
- Improve tree trimming. Because phase-to-ground faults caused by tree contact do not always operate protective devices, they may cause repeated current transients on the neutral.
- Locate the distribution transformer to minimize service-conductor length. When providing new or modified service to a farm, the primary can be extended to a central point among farm facilities so as to minimize the length of service conductors, especially to the milking barn.

**2. Utility engineers** conducting stray-voltage investigations must understand a wide range of farm electrical systems

### What to do on service facility

Whether the secondary service is owned by the customer or the utility, there is a need for inspection during any stray-voltage investigation. All new and replacement secondary service to dairy facilities should be supplied with a full-size neutral conductor. Existing services should be analyzed to see if the conductors are adequate for the customer load. Service conductor length should be kept as short as reasonably possible, bearing in mind any limitation required by standard utility procedures to limit short-circuit current.

- Split-bolt or parallel-groove connectors can be replaced with compression or wedge-type connectors. Neutrals containing multiple splices can also be replaced. All neutral connections, including transformer bushing and meter socket, should be inspected for looseness or corrosion.
- Low-resistance ground rods (less than 25 ohms if possible) can be driven at pad-mount transformer or transformer pole and at all poles immediately adjacent to a transformer pole location.

### What the customer can do

Customers should be urged to do their part in improving their electric system. The Wisconsin Electric assists customers in this work and also provides monetary grants under the company's financial assistance program.

Actions that the customer should take are similar to those recommended for the utility, especially in regard to improving grounding, checking grounding connections and splices, load balancing, and replacing service drops that are lengthy or have many splices. The customer should also be encouraged to use 240-V, rather than 120-V, single-phase equipment.

**Equipotential planes** are an effective long-term solution to stray voltage because they eliminate the possibility of significant voltage differences at animal-contact locations. The key element of an equipotential plane is a wire mesh or metallic grid embedded in the concrete floor of the barn. This mesh is bonded to all metal equipment in the barn—such as stanchions, stall partitions, water line (if metal), feeders, and metal electrical conduit. This ensures that the floor on which the cow is standing is at the same potential as any metal equipment it might touch. A transition area may also be necessary so that as the cow leaves the area with the equipotential plane, there will be a gradual change in voltage.

The NEC recommends and Wisconsin State Electrical Code requires that all newly constructed or remodelled livestock-confinement facilities be equipped with an equipotential plane. Wisconsin Electric publishes a booklet describing how an equipotential plane should be constructed. The booklet also describes several possible methods for retrofitting an equipotential plane in an existing facility.

### Investigator wears many hats

A utility employee sent to a farm to investigate stray voltage must be capable of analyzing a wide variety of farm electrical systems, accurately recording if significant stray voltage exists, deciding on the probable sources, and at the same time, assuring the customer that if stray voltage does exist, whether it comes from the utility or farm system, it can be satisfactorily managed.

The investigator must also tactfully convince the customer that his cooperation is essential if the concern is to be resolved quickly. This is especially true if the significant sources are on-farm sources.

Farms vary widely in secondary wiring complexity and primary distribution circuit characteristics. The investigator must be allowed to decide how the farm will be investigated, based on verbal, visual, and measured data. He must also decide how much time should be spent, the amount of data that needs to be collected, and finally, the actions that should be taken, if any, to reduce the stray voltage level.

Wisconsin Electric uses electrical engineers for the majority of its stray-voltage investigations. The test procedures used are designed to simulate a worst-case scenario so that they can be performed during normal working hours.

Some utilities have their investigations performed by agricultural representatives during actual milking hours, when electricity use on the farm is high. Test procedures vary widely in complexity and precautions must be taken to ensure that voltage measurements accurately represent the amount of current that would pass through an animal in contact with the surfaces being measured.

The most recent information on meters to use, measurement techniques, and mitigation methods is provided in the US Dept of Agriculture Handbook, No. 67, Effects of Electrical Voltage/Current on Farm Animals. This booklet is considered the most authoritative source on levels of current that may affect a cow's behavior and/or milk production ■.

*—Edited by John Reason*

**EQUIPMENT RELIABILITY**

# Avoid overexciting power transformers

When there is a sudden, internal failure of a substation transformer that has been maintained normally and no apparent fault has been recorded on the distribution breaker, electric-utility engineers sometimes are confounded. One cause of such a failure can be attributed to the overexcitation of the transformer because it has not been operated within the maximum voltage specified by standards.

Extreme overexcitation can damage transformers very quickly, but the damage might not be apparent if the overexcitation only lasts a short time. Paint blistering on the outside of the tank might indicate that the transformer has reached an excessively high temperature. However, internal hot spots that could damage the insulation do not provide any external evidence of damage.

Overexcitation can lead to transformer failure through the following steps:

1. An improperly set tap—or some other phenomenon that results in operation at a voltage that is too high—causes stray flux heating in the transformer.

2. Increased flux saturates the transformer's steel core, which causes the stray flux to overflow into winding conductors.

3. The overflow produces heat because of eddy currents. Experience has shown that these eddy currents create hot spots and even melt metal in other parts of the transformer.

4. The excess heat then deteriorates the winding insulation.

The problem can be aggravated further if the heat cannot be dissipated easily, resulting in permanent damage to insulation and eventual transformer failure.

In regions of the country with peak summer loading, high ambient temperatures can combine with simultaneous overexcitation to produce more frequent failures. It therefore is especially important in these regions to select taps carefully to avoid overexcitation.

Overexcitation can be prevented by conforming to several key criteria. A transformer should be capable of operating at 105% of secondary voltage while delivering rated output kVA at a power factor of 80% or higher. It also must operate at 110% of rated secondary voltage at no load. These limits apply to only the rated secondary voltage or to the rated voltage and kVA of any tap when operating at rated frequency. At other frequencies, the limits must be altered accordingly.

Here is an example of proper tap selection for an actual power transformer. The example considers that the transformer is constructed with the assumption that excitation will not exceed 100% of normal. To calculate tap setting, the engineer needs to assume a no-load condition and know the following data:

- Transformer-rated kVA.
- Transformer impedance at rated secondary voltage.
- List of available primary taps from the transformer nameplate or the manufacturer's test report.
- Recorded minimum and maximum voltage swings on the high side of the transformer.

A 7500-kVA power transformer with a 7.3 impedance rated at 12.47 kV is installed on a 46-kV primary subtransmission system. The manufacturer provides taps rated at 46.2, 45.0, 42.6, and 41.4 kV. The recorded primary voltages where the transformer is to be installed are a minimum of 46.4 kV and a maximum of 48.8 kV.

The engineer's first step is to select the 45.0-kV tap and determine if it meets the criteria:

Ratio (R) = V1/V2 = 45.0/12.470 = 3.6

Minimum secondary voltage = Vmin/R = 46.4/3.6 = 12.89 kV

Maximum secondary voltage = Vmax/R = 48.8/3.6 = 13.56 kV

According to these criteria, the minimum and maximum secondary voltage calculated should not exceed 110% of the rated secondary voltage of the transformer; this value is 12.47 kV multiplied by 1.1 or 13.717 kV. Therefore, both minimum ar maximum secondary voltages are less tha 110% of the rated secondary voltage, which meets the criteria.

Using similar calculations, engineers then check the 41.4-kV tap to determine if it meets the criteria. For this tap, R=3.32, the minimum secondary voltage is 13.98 kV, and the maximum secondary voltage is 14.70 kV. The rated secondary voltage still is 13.717 kV. Thus, for this tap, both the minimum and maximum secondary voltages are greater than the rated secondary voltage; this tap does not meet the criteria and, if selected, will overexcite the transformer windings and eventually cause the unit to fail. A check of the 43.8-kV tap yields similar results.

The calculations show that the transformer should be placed at the 45-kV tap for normal operation to meet the criteria and prevent overexcitation.

The primary way of avoiding overexcitation is ensuring that the transformer tap position is set properly. Although proper tap position is one way to reduce overexcitation, another important way is to detect insulation deterioration early, which can be accomplished with routine power-factor tests. The data recorded through these tests show the condition of the insulation. T test is reliable in detecting undesira operating conditions and failures resulting from overexcitation, but relatively few utilities perform it because of its high cost. It is a key part of preventive maintenance testing of power transformers. ■

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