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 complaints because of the need to persuade everyone involved—from dairy farmer to utility investigator—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 the 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 voltages are very low—return currents. Under normal operating conditions, these currents flow through undesignated conductors—such as water lines, stockyard pipes, etc. As a result, they generate voltages differences between points that a farm animal can touch simultaneously. Cows are more susceptible to these voltages differences 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 distributor transformer and because the National Electric Code (NEC) requires a tie between the secondary neutral and the watertable, 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.

First, overcome the myths

There are few dairy farmers 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 typical misconceptions to a national survey.

Myth: Electrical systems should not be connected to the earth because that will cause current 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 resolving them.

FACT: Current flow is grounded 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 systems.

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 NEC does allow the use of an isolator in the form of a device with a breakdown voltage not exceeding 3 kV. Surge arresters, earthing 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. 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 reactors and solid-state neutral isolators, such as the solid-state device made by Dairyland Electric-industries, Oregon, Wis. This device connects primary and secondary neutrals with two microswitches when the voltage between them exceeds 25 V (RMS). When closed, provides a low-resistance path for fault current.

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 grounded network, consisting of well-casing, hazed-water lines, et., constitutes a low-resistance return path for primary-neutral current. Removal of this path may increase neutral return currents, 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 utilities 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 effect on livestock.

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 reassigned for load balance and loads reconnected to minimize neutral currents. This applies to the primary, existing single and 2-phase taps can be rebalanced to full 3-phase. Open-wye-delta transformer connections can be discontinued if these 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 rewelded 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 pole (none 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.

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 poss-

ible, bearing in mind any limitation required by standard operating procedures to limit short-circuit currents.

• Split-bolt or parallel-groove connectors can be replaced with compression or wedge type connectors. Neutrals containing multiple splices can 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) should be driven at 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 the part in improving their electric system. The Wisconsin Electric assistance 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 tees. The customer should also be encouraged to use 240-V, rather than 120-V, single-phase equipment.

Equipment planes are an effective long-term solution to stray voltage because they eliminate the possibility of significant voltage differences as a animal-contact locations. The key element of an equipment 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 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 remodeled livestock-confinement facilities be equipped with an equipotential plane, Wisconsin Electric publishes a brochure describing how an equipotential plane should be constructed. The brochure also describes several possible methods for installing an equipotential plane in an existing facility.

Investigator wears bunny hats

A utility employee sent to a farm to inspect
Avoid overexciting power transformers

When there is a sudden, internal failure of a substations transformer that has been maintained normally and in apparent fault, then it has been recorded on the distribution breaker, electrical utility engineers sometimes are confronted. One cause of such failures can be attributed to the overexcitation of a transformer, which 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. Pulsating heat on the outside of the tank may 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 some 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 cause hot spots and even a fire in other parts of the transformer.

4. The steady 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 is therefore especially important in these regions to select taps carefully to avoid overexcitation.

Overexcitation can be prevented by confining to several key criteria. A transformer should be capable of operating at 102% of secondary voltage without delivering any output at a power factor of 0.80 or higher. It also must operate at 80% of rated secondary voltage at no load. Three limits apply to only the rated secondary voltage, or to the rated secondary 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 factors:

- Transformer-rank kVA.
- Transformer impedance at rated secondary voltage.
- List of available primary taps from the transformer manufacturer or the transformer test report.

A 7500-kVA, power transformer with a 7.2 impedances at rated 27.1 kV is installed on a 46 kV primary subtransmission system. The transformer provides taps read at 46.2, 45.0, 42.6, and 41.4 kV. The maximum primary voltage where the transformer is to be installed are a maximum of 46.2 kV and a minimum of 41.4 kV.

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

Radius (O) = 1/\sqrt{2} = 0.5×12.470 = 3.6
Minimum secondary voltage = \frac{\text{Vmax}}{1.5} = 46.55 kV
Maximum secondary voltage = \frac{\text{Vmax}}{1.0} = 46.2 kV

According to these criteria, the minimum and maximum secondary voltage calculated should not exceed 10% of the rated secondary voltage of the transformer; this value is 12.47 kV multiplied by 1.1 or 13.77 kV. Therefore, both minimum and maximum secondary voltage are less than 110% of the rated secondary voltage, which meets the criteria.

Using similar calculations, engineers can determine if any kVA taps to determine if it meets the criteria for this tap, Red 3-2, the minimum secondary voltage is 13.98 kV, and the maximum secondary voltage is 14.70 kV. The rated secondary voltage still is 13.71 kV. Thus, for this tap, both the minimum and maximum secondary voltage are greater than the rated secondary voltage; this tap does not meet the criteria and, if selected, will overexcite the transformer and eventually cause the unit to fail. A check of the 46.2 kV tap yields similar results.

The calculations show that the transformer should be placed at the 45.0 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 to detect insulation degradation early, which can be complicated with extremely power-factor tests. The data recorded through these tests show the condition of the insulation. The test is reliable in detecting undue operating conditions and failure results. However, extremely few utilities perform it because of its high cost. It is a key part of preventive maintenance testing of power transformers.