Agricultural Engineering Department

Keith Tinsey, P.E.
Michigan State University
103C Farrall Hall
East Lansing, MI 48824
Tel:517.353.0643 Fax:517.432.1563
Email: tinsey@msu.edu

Web: www.egr.msu.edu/age/

CONSTRUCTION STRATEGIES FOR MINIMIZING STRAY VOLTAGE ON DAIRY FARMS

By: Tom Wilson, Keith Tinsey & Truman Surbrook

Background

Stray voltage is of great concern for dairy farmers. At significant levels, stray voltage will cause decreased milk production and affect animal health due to changes in behavior. When constructing new or remodeling existing dairy facilities, steps can be taken to minimize the possibility of stray voltage influencing livestock.

What is stray voltage? Stray voltage can occur when livestock come in contact with metal equipment that has a different electrical potential than the surface the animal is standing on. Current may then travel through the animal to earth in order to return to its source. This electrical potential is typically less than 10 Volts AC 60 Hz (VAC). Voltages above 10 VAC are usually caused by electrical wiring problems and can become safety hazards. Sources of stray voltage include ground faults, and normal ground current from the electrical distribution system in the form of Neutral-to-Earth Voltage (NEV). The electrical distribution system includes on farm wiring as well as off farm electrical utility distribution.

Here is an example or how current flowing to earth can cause NEV. If a service panel ground rod is driven 8 feet into moist earth that is not real sandy, the resistance between that ground rod and the earth might be as low as 20 ohms. Assume that when power is being used in the building, one-tenth of an ampere of the neutral current flows to earth at the ground rod. A basic electrical law called Ohm's law states that current times resistance is voltage. Multiplying the ground rod current (0.1 amperes) and the ground rod resistance (20 ohms) results in 2 volts. If one probe of a voltmeter touches the ground rod and the other probe of the voltmeter is pushed into the earth as far away from the ground rod as the leads will reach, the meter will read approximately 2 volts. This is NEV. When livestock touch some metal objects in that building, such as an electrically heated metal livestock waterer, the animal's body is placed across the neutral to earth voltage.

How does stray voltage affect animals? Stray voltage does not directly affect cows but indirectly through avoidance behavior. When cows change their behavior it can affect their performance. Cows may avoid drinking, eating, letting down their milk or entering stalls. If cows are nervous in the milking parlor, they may not milk out properly, which can affect production and health. If cows receive a shock when drinking or eating they may consume less and affect production. Or, if cows receive a shock when they enter an area, they may avoid that area making management more difficult.

The term stray voltage is used because it is more accurately measured compared to current. However, it is the current that affects a cow's behavior. Controlled laboratory studies have shown that cows can detect relatively low levels of current, as low as one milliamp (mA), however it takes at least 4 mA to cause behavioral changes.*(Effects …, USDA, ARS Agricultural Handbook Number 696)* It is conservatively estimated that a cow's resistance to current flow or impedance is 500 ohms in wet areas. By applying Ohm's law (volts = current x resistance), two volts would have to be measured with a 500 ohm resistor in the circuit before cows will change their behavior.

How to prevent stray voltage problems? There are many questions that are frequently asked regarding stray voltage and several areas where construction contractors and dairy advisors can help decrease the possibility of stray voltage occurring on dairies. The following questions will be discussed:

- How is stray voltage different from NEV?
- How can NEV be minimized?
- What is an equipotential plane?
- What is a 4-wire electrical system and when should it be considered?
- How does equipment planning and load balancing affect NEV?
- Why is wire sizing important and why should future needs be considered?
- How can construction choices make maintaining an electrical system easier?
- How do electric fencers relate to NEV?

How is stray voltage different from Neutral-to-Earth Voltage (NEV)?

The electrical wiring on a farm has a conductor, which is grounded to the earth. This conductor is called the neutral conductor. Also, the primary power lines supplying a farm usually have a neutral conductor, which is grounded to the earth to provide maximum safety and reliability. (Figure 1) The neutral wire carries most of the current flowing back to the power source because of its low resistance. However, electrical systems that are grounded to the earth have a small amount of current flowing through the earth when electrical power is being used. Even though the earth is a relatively high resistance compared to the neutral wire, current will take all paths in order to return to its source. On a farm, the electrical power source is the transformer. On a primary distribution system, the power source is the sub-station. Current flowing back to its source through the earth can cause a small level of NEV between metal objects and the adjacent floor or earth. If a cow can make contact with a metal object with NEV present, then this is called a cow contact voltage or stray voltage. Because it is normal to have some level of NEV present on a farm, the level of cow contact voltage raises the most concern.

There are a number of conditions that can cause elevated NEV. One common cause is a ground fault condition. Ground faults allow current to flow through the earth. Ground faults occur when a wire comes loose from a terminal, wire insulation becomes damaged or electrical terminals become wet. Proper equipment grounding will prevent ground faults from causing stray voltage. Another frequent NEV cause is too much voltage drop along the neutral conductor supplying buildings. Faults and voltage drop conditions may occur on a farm, on power supply lines or at a neighbor's property.

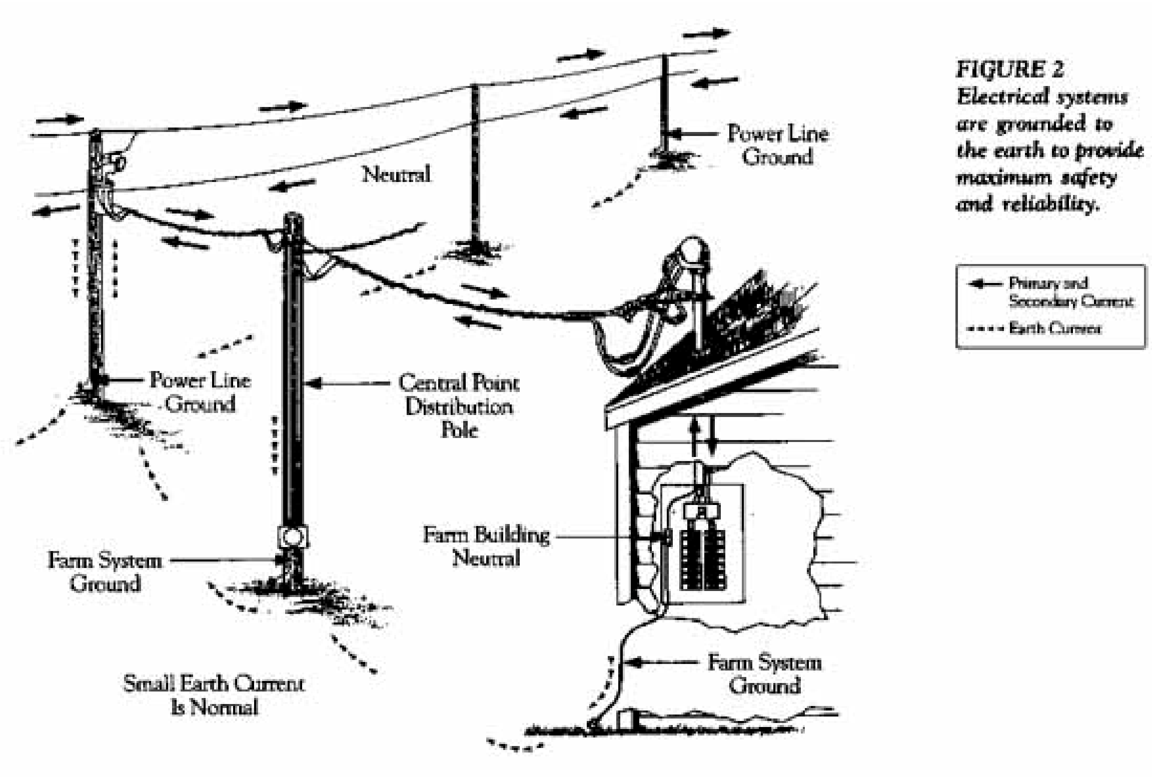

Figure 1 Electrical distribution system – Primary and Secondary Grounding
Adapted from Understanding Neutral-to-Earth and Stray Voltage

How can NEV be minimized?

Stray voltage should be one of the considerations to keep in mind when constructing buildings and installing equipment on dairy farms. Here is a list of important design factors:

- Proper electric equipment planning, placement and maintenance.
- Properly installed and maintained wiring splices and connections.
- Provide adequate sizing of electric wires for load and distance.
- Provide adequate electric service and equipment grounding. Attach a copper wire to all metal equipment likely to become energized.
- Proper installation of an equipotential plane, a grounding grid in the floor that's connected to piping and equipment.
- Provide adequate separation of electric fence grounding from farm electric system grounding.

• Only use wiring materials and methods specifically appropriate for farm wiring.

What is an equipotential plane?

An equipotential plane is a method to minimize NEV at animal contact points. More specifically, an equipotential plane is a surface where wire mesh, reinforcing bars, or other conductive elements are embedded in concrete, bonded to all extensive metal structures and fixed nonelectrical metal equipment in livestock areas that may become energized, and bonded to the electrical grounding system of the facility. This prevents a difference in electrical potential from developing across the plane. The *2002 National Electric Code® (NEC), 547.10*, *Equipotential Planes and Bonding of Equipotential Planes*, provides the guidelines for areas requiring equipotential planes. In general, equipotential planes are required in all concrete floor confinement areas that contain metal equipment that is accessible to livestock and is likely to become energized (Figure 2). Outdoor confinement areas shall have equipotential planes installed around likewise equipment. The outdoor equipotential plane shall encompass the area around the equipment where the livestock stands while accessing the equipment. Equipment examples are automated feeders and electrically heated waterers. Methods of installing equipotential planes and electrically heated waterers are detailed within *ASAE Engineering Practice (EP473.2 JAN01)*, *Equipotential Plane in Animal Containment Areas*, and *ASAE Engineering Practice (EP342.2 DEC99)*, *Safety for Electrically Heated Waterers.* *2002 NEC 547.10*, states that dirt confinement areas that contain metallic equipment that is accessible to livestock and is likely to become energized do not require an equipotential plane, however, all circuits providing electric power to such equipment shall have GFCI protection.

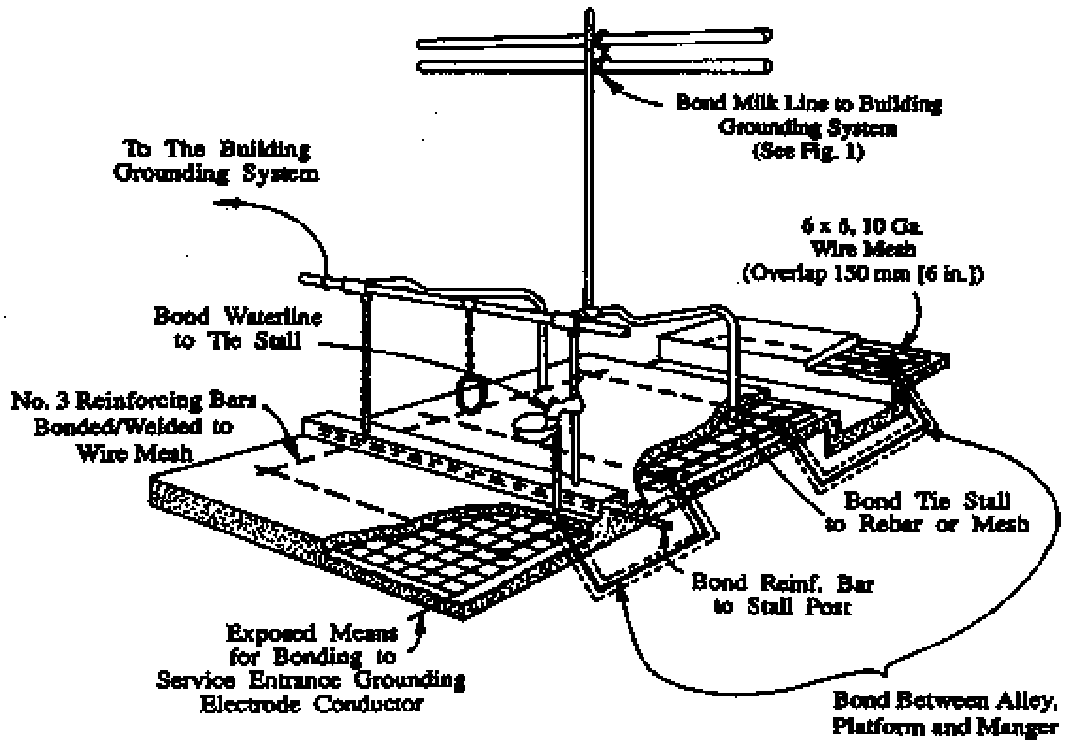

Figure 2. Equipotential plane installation in stanchion/tie-stall barn
Adapted from ASAE EP473.2 Jan 01.

What is a 4-Wire Electrical System and when should it be considered?

Farms are typically a group of buildings supplied electrical power from a common service or distribution point. One method is to supply power to one building, and then supply other buildings from the first building. When this method is used, the service at the first building must be large enough to supply power to all buildings. Power to other buildings on the farm must first pass through the service of the first building. This method of electrical distribution is satisfactory as long as the electrical demand at the other buildings is limited.

A more common approach is for the utility to deliver power to a central distribution point. The kilowatt-hour meter will be at the central distribution point which is generally a structure such as a pole. The *2002 NEC* requires that a disconnect be provided at this location to safely shut-off the electrical supply to all ungrounded conductors. This disconnect can be a hand-operated switch or it can be a circuit breaker. This rule is not always followed, and the central distribution point may be equipped with only a kilowatt-hour meter. Overcurrent protection in the form of fuses or a circuit breaker is not required at the distribution point.

Whether electrical power to the other buildings is supplied from a service at a building or a central distribution point, a question sometimes arises about how to supply power to the other buildings. The issue seems to focus around use of the neutral wire as a current-carrying conductor and as an equipment grounding conductor for the buildings supplied. The *2002 NEC* specifies that a continuous path must be provided from all metal equipment likely to become energized back to the first grounding point for the farm at the main service or distribution point. Equipment is permitted to be connected to the earth at any point, but the earth by itself is not permitted to serve as the grounding conductor (*2002 NEC 250.4 (A)(5)*). One of the grounding conductors as described in *2002 NEC 250.118*, is required to be provided in addition to any earth path.

When a farm is supplied single-phase 120/240 volt power, a building is permitted to be supplied power using three conductors where two conductors are ungrounded (hot) and one conductor is grounded (neutral). This is called a 3-wire electrical supply and is shown in Figure 3. The neutral wire is grounded to the earth at the building being supplied electrical power. When circuits are run in that building, the neutral wires as well as the equipment grounding wires are connected to the neutral at the service for that building. This is permitted in *2002 NEC 250.32.(B)(2).*

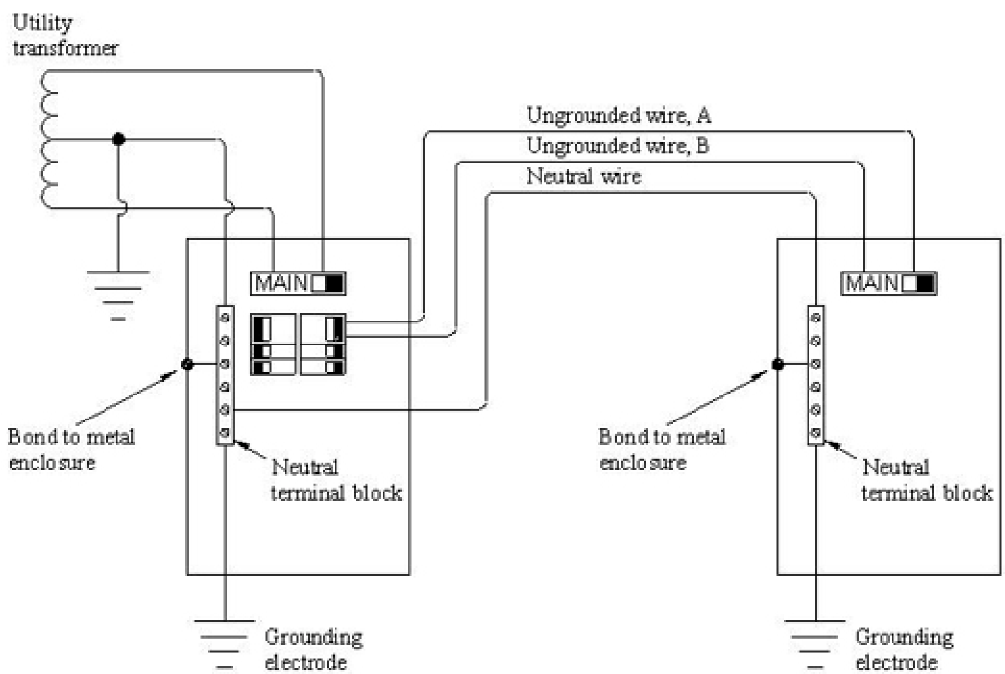

Figure 3. 3-wire single-phase, 120/240 volt supply to a building.

It is also permitted (*2002 NEC 250.32(B)(1)*) to supply power to another building on a farm using what is called a 4-wire system where there are two ungrounded wires (hot) a grounded neutral wire and a separate equipment grounding wire. Back at the distribution point the neutral and the equipment grounding wire are connected together and grounded to the earth. At the building being supplied with power, the neutral wire is connected to a neutral terminal block in the panel that is not connected (bonded) to the metal enclosure of the panel. In this case, the neutral is not grounded to the earth. The separate equipment grounding conductor is connected to a separate equipment grounding terminal block that is connected (bonded) to the metal panel enclosure. This equipment grounding terminal block is required to be grounded to the earth. This method of supplying power to a building is shown in Figure 4.

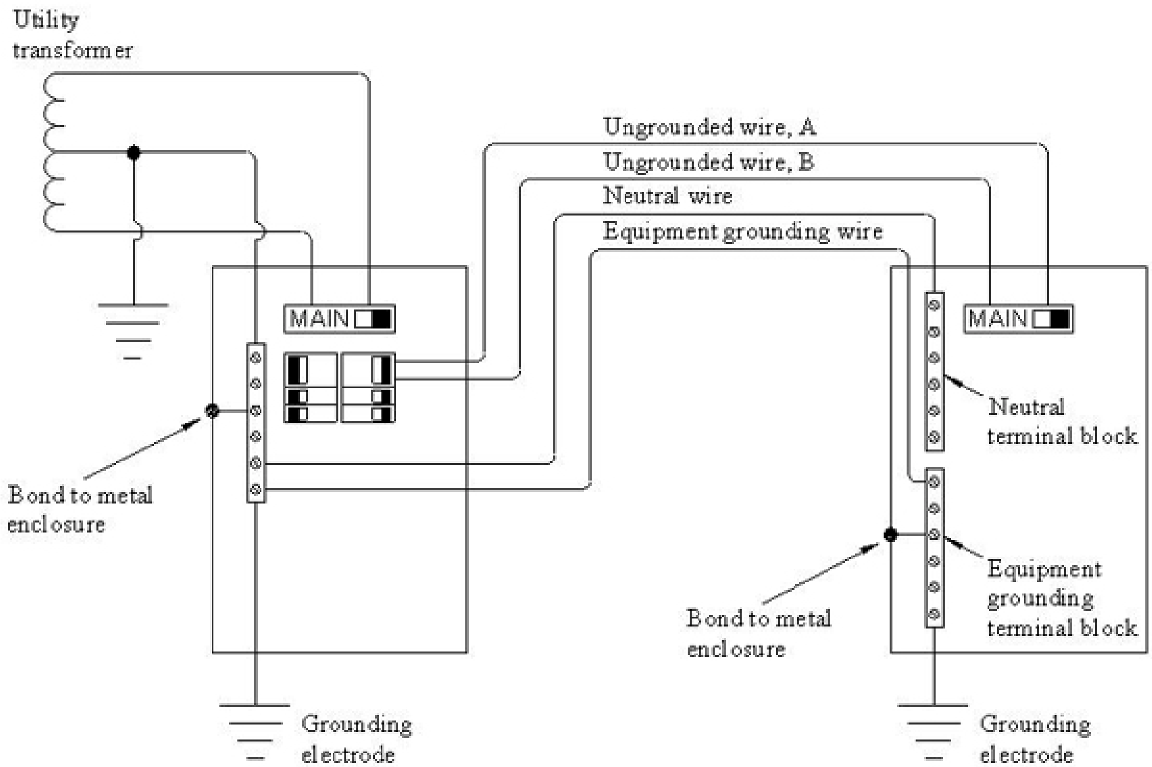

Figure 4. 4-wire single-phase, 120/240 volt supply to a building.

Metal equipment likely to become energized that livestock touch is required to be connected to the grounding point of the service panel to a building. When a 4-wire system supplies a building, neutral current cannot flow to the grounding terminal in the service panel, and therefore, cannot get to the equipment livestock can touch. Even if there is too much current and resistance on the neutral supplying the building, livestock are not exposed to this potential source of NEV. Other sources, however, may still cause neutral-to-earth voltage that can reach livestock. The 4-wire electrical supply system does not prevent all sources of neutral-to-earth voltage.

When a farm building is supplied power with a 3-wire system, neutral-to-earth voltage will not cause a problem for livestock in most cases where the conductors supplying buildings are properly sized, installed, and maintained, and the 120 volt loads are balanced. In some cases, 120 volt loads may operate randomly making it impractical to balance the loads. In cases where the distance from the distribution point to a building is long, and it is impractical to keep the loads balanced, it is recommended that a 4-wire supply be provided to those buildings where livestock may be exposed to grounded equipment such as heated waterers.

How does equipment planning and load balancing affect NEV?

Choosing proper equipment and balancing circuits can reduce NEV. When electrical currents flow along a conductor, such as an overhead or underground feeder to a building, the resistance of the conductor will cause a voltage drop to occur. Voltage drop on the neutral wire supplying a building will result in neutral-to-earth voltage when the neutral is grounded to the earth at the source (usually a central distribution point) and at the building being supplied. Proper wire sizing and installation will minimize this voltage drop and, therefore, the neutral-to-earth voltage produced. Since the level of neutral current is also a factor in voltage drop on the conductor, steps should be taken to reduce the level of current on the neutral. Circuits operating at 240 volts do not use the neutral wire to carry current and, therefore, do not cause secondary neutral voltage drop. The potential for stray voltage can be reduced by installing 240 volt motors and equipment where possible. Fan motors, elevator and auger motors, compressors, and vacuum pumps should all operate at 240 volts. In cases where it is practical to operate circuits at 120 volts, such as lighting, the loads should be balanced at the electrical panel. Determine which 120 volt loads will normally be in operation. Connect the 120 volt loads in the service panel with half connected to one ungrounded wire (hot leg A) and half to the other ungrounded wire (hot leg B). With a single-phase 120/240 volt panel, the current on the neutral is the difference between the current on the ungrounded wires (hot legs). By operating most of the equipment at 240 volts, and balancing the 120 volt loads, the current on the neutral can be reduced to near zero.

In the Eastern United States utilities typically deliver power to customers with a grounded distribution system that has a neutral. A single-phase transformer connects to one of the primary ungrounded wires and to the primary neutral. The more electrical power used on the farm means more current flow on the utility primary wires. Current flow on the primary neutral wire and the farm neutral wire are typically connected at the transformer for maximum safety and reliability. This neutral connection, however, allows NEV produced by the primary line to access the farm. For some farms, three-phase power may be desirable. Three phase loads are similar to 240 volt loads in that they do not require balancing. Utilities can deliver three-phase power to a farm without using the primary neutral as a load conductor. This means less NEV produced by the primary line when motors are operated on the farm.

Why is wire sizing important and why should future needs be considered?

Another way to reduce neutral voltage drop and neutral-to-earth voltage while insuring adequate line voltage for motors and equipment is proper wire size for conductors supplying buildings. The objective is to minimize conductor resistance. This resistance can also be the result of loose or corroded connections due to poor installation or maintenance. For a given conductor, the resistance increases as the conductor length increases. One way to off-set this effect is to install a wire with a larger cross-sectional area, because doubling the cross-sectional area of a wire will cut the resistance in half for a given length. Consideration should be given to equipment that may be installed in the future. Circulating fans and long day lighting are two items that are often additions after initial construction is complete. The power required to add circulating fans in a typical barn can be two times basic lighting requirements. Tables 1, 2 and 3 contain some typical supply conductor ratings:

Table 1. Minimum copper wire size for 120/240 volt, single-phase feeder in raceway or underground with 2% voltage drop with load based upon 80% of circuit rating.

Circuit rating	Wire size in AWG or kcmil Distance to Building				
	100 ft.	150 ft.	200 ft.	250 ft.	300 ft.
100 A	3	2	1	1/0	2/0
150 A	1/0	1/0	2/0	3/0	4/0
200 A	3/0	3/0	3/0	4/0	2@2/0

Table 2. Minimum aluminum wire size for 120/240 volt, single-phase feeder in raceway or underground with 2% voltage drop with load based upon 80% of circuit rating.

Circuit rating	Wire size in AWG or kcmil Distance to Building				
	100 ft.	150 ft.	200 ft.	250 ft.	300 ft.
100 A	1	1/0	2/0	3/0	4/0
150 A	2/0	3/0	4/0	2@2/0	2@3/0
200 A	4/0	4/0	2@2/0	2@3/0	2@4/0

Table 3. Minimum aluminum wire size for 120/240 volt, single-phase feeder overhead multiplex cable in air with 2% voltage drop with load based upon 80% of circuit rating.

Circuit rating	Wire size in AWG or kcmil Distance to Building				
	100 ft.	150 ft.	200 ft.	250 ft.	300 ft.
100 A	3	1/0	2/0	3/0	4/0
150 A	1/0	3/0	4/0	2@2/0	2@3/0
200 A	3/0	4/0	2@2/0	2@3/0	2@4/0

How can construction choices make maintaining an electrical system easier?

There are many construction choices that can make maintaining the electrical system easier. Using proper equipment and material can reduce deterioration of the electrical system. (Stetson, 1998) All materials and equipment should bear a label indicating they are listed by a recognized testing agency, e. g., Underwriters Laboratories (UL®), Electrical Testing Laboratories, (ETL®), etc. Types of suitable enclosures, cables and wiring systems for installation in agricultural buildings are specified in *2002 NEC 547.5 and 547.6.*

Wiring should be run in schedule 80 rigid non metallic conduit in areas where animals can reach or damage wiring. Type UF cable or conduit should be used in all areas with damp or corrosive environments. Conduit mounting and runs must allow for expansion and contraction. Where vibration or movement is likely to occur, e.g. in suspended lights or fans, properly rated flexible cord with sealed connections should be used. Weather proof molded plastic boxes with gasketed covers that can be sealed should be used for switches and junction boxes. Avoid aluminum or steel enclosures as they will corrode. Household plastic boxes with knockouts are not suitable for use in agricultural buildings. Poor connections due to corrosion or improper connecting devices increase the resistance and potential for stray voltage. Uncovered boxes and corroded equipment should be replaced and repaired. Panels should be protected from animal contact and located for easy access by workers and service personnel. Accurately labeling circuits can save time and be a safety issue when service is required on branch circuits. Keeping moisture out of boxes reduces corrosion and deterioration of switching devices and connections.

What is the proper way to install an electric fencer?

Electric fences control livestock by delivering an uncomfortable current flow through the body for a sufficiently short duration so as not to cause injury to the animal. Depending on the electric fence energizer model, these electrical impulses can range from 3,000 to 10,000 Volts DC with a duration less than 100 microseconds or 0.0001 seconds (one-half of a 60 Hz AC cycle has a duration of 8,300 microseconds or 0.0083 seconds). In order for the animal to receive a shock, the animal must touch the fence wire and complete the circuit from the "hot" terminal of the fence energizer, through the animal to earth, and back to the "ground" terminal of the energizer.

An improperly installed electric fence system can result in unintentional shocks to livestock at grounded equipment such as at waterers, feeders or even in a milking barn. The most frequent cause of unintentional shock is due to improper grounding of the energizer. The energizer must have its own grounding electrode located well away from any other grounds or metal object in the earth (50 feet minimum recommended). An energizer must never be grounded to the farm electrical system grounds, to the utility system grounds, to metal water pipes, or to metal objects in a building such as stalls, fences, or dividers. Such improper grounding puts the metal objects and livestock in the electric fence earth return path. One of the most important aspects of making sure an electric fence system works effectively is proper grounding of the energizer. If an energizer does not control livestock, the solution is not necessarily a more powerful energizer.

Improving the grounding may be the lowest cost, most effective means of improving the operation of the electric fence system (Fick, 1999).

- The grounding required by a fence energizer will vary depending on the soil type and moisture.
- For an average soil, it is recommended that a five Joule low impedance charger be grounded with three, 8-foot ground rods spaced at least 10 feet apart.
- Doubling the Joule output of the energizer would double the grounding needed.

One method to check the adequacy of the earth return system is to measure the voltage between the energizer ground rods and a connection to the earth a few feet away such as to a screwdriver stuck in the ground. If there is a perceivable voltage between these points with the fence wire touching the earth, the energizer grounding should be improved. This voltage can be measured with a tester designed to measure high voltage fences.

An energizer should be placed at a location where it is possible to maximize separation of the energizer grounding and electrical wiring system grounding. The best place for the energizer may be outdoors away from animal buildings and grounded equipment. If an energizer is installed indoors, the high voltage must be taken to the outside using high voltage lead cable (20,000 volt insulation is recommended). Electrical wire of the type used for the building wiring, with 600 volt insulation, must never be used for this purpose due to the propensity of the impulse to escape the insulation.

Another problem that can occur with an electric fence energizer is the creation of NEV. It has been shown that it is possible for an electric fencer to create NEV if there is high resistance in the neutral conductor of the 120 VAC supply circuit in which the fencer is connected (Fick, 1998). A relatively large amount of current can be drawn each time an energizer recharges its capacitors in order to deliver the next electrical impulse. The supply current drawn must also return to its source via the neutral wire. However, if the neutral is undersized, corroded or damaged causing it to have a higher than normal resistance, then it is possible that current trying to find its way back to its source via an additional pathway can cause NEV. Animals can perceive this intermittent NEV if it is of sufficient magnitude.

Energizers today are generally of the low impedance type that delivers a very high current to the fence for a very short time. Even when some grass or other vegetation is touching the fence, the system can still deliver enough current to control livestock. A low impedance energizer with an inadequate number of ground rods drastically reduces the current delivered to livestock. Choosing an energizer that is labeled by a testing laboratory is recommended. Caution should be taken to prevent animals and humans from becoming entangled in electric fences. Small children should be prevented from contacting high energy output electric fences. All individuals should take extra care to avoid electric fence contact with your head or neck.

Summary

The potential for stray voltage to affect livestock can be greatly reduced by proper wiring practices. The electrical system needs to be an integral part of the building and equipment plan. Consideration of future equipment needs can minimize future problems and expense. Undersized or overloaded circuits can lead to elevated NEV levels and increase the potential for stray voltage.

Of greater concern than stray voltage is proper wiring for safety of both animals and workers. The cost of wiring and electrical equipment is less than 10% of construction costs for most agricultural buildings. This is not a place to cut corners on building projects. Inferior or improperly installed equipment is a safety concern for both animals and workers. Because of the corrosive and harsh environment in cattle housing and milking parlors, using approved weatherproof fixtures (*2002 NEC 547.5 (C)*) and using approved conductors and/or conduit increase both the life and reliability of the electrical system on farms. Allowances should be made to protect wiring and fixtures from damage caused by animals and equipment. Only properly trained and qualified personnel should install electrical equipment or wiring on farms. Care should be taken to be sure that equipment grounds are properly installed so that in case of an electrical fault, there is a direct path through the equipment ground back to the transformer. It is important that neutrals are properly bonded and that the neutral and equipment ground are bonded in the main service panel or disconnect.

Proper installation of electric fences and equipotential planes can reduce the potential for problems related to stray voltage. 4-wire electrical systems, balancing 120 volt loads and proper wire sizing can reduce the potential for problems with stray voltage. Selecting equipment that does not use the neutral wire as a current carrying conductor can also reduce the potential for problems with stray voltage.

References

Agricultural Wiring Handbook, 12th Edition, National Food and Energy Council, Inc., 601 Business Loop, 70 West, Suite 216D, Columbia, MO 65203

Effects of Electrical Voltage/Current on Farm Animals, How to Detect and Remedy Problems, USDA, ARS Agricultural Handbook Number 696, December, 1991

Equipotential Plane In Animal Containment Areas, ASAE EP342.2 December 1999, The Society for engineering in agricultural food, and biological systems, 2950 Niles Rd., St. Joseph, MI 49085-9659

Equipotential Plane in Livestock Containment Areas, ASAE EP473.2 January, 2001, The Society for engineering in agricultural, food, and biological systems, 2950 Niles Rd., St. Joseph, MI 49085-9659

Farm Buildings Wiring Handbook, Mid West Plan Service; MWPS-28, Second Edition, 1992, 122 Davidson Hall, Iowa State University, Ames, IA 50011-3080

Fick, Robert J., Surbrook, Truman C., and Holycross, Mark G., Electric Fence System Influence On Animal Contact Voltage, ASAE paper no. 98-3007l ASAE, St. Joseph, MI 49085-9659

Fick, Robert J., Surbrook, Truman C., and Bivens, William M., Safe and Effective Electric Fences, 1999, Michigan State University Extension E-2706, East Lansing, MI 48824

National Electric Code 2002, National Fire Protection Association, Inc., One Batterymarch Park, Quincy, MA 02269

Stetson, LaVerne E., Electrical Codes and Standards in Rural Applications, Paper ICPSD-98-D4, presented at the 1998 IEEE Rural Electric Power Conference, St. Louis, MO, April 26-28, 1998,

Stetson, LaVerne E. and Zulovich, Joseph M., Electrical Wiring and Equipment for Swine Facilities, Contribution from USDA-ARS in cooperation with the Agricultural Research Division, University of Nebraska for presentation at the First International Swine Housing Conference in Des Moines, IA October 9-11, 2000

Understanding Neutral to Earth and Stray Voltage, 1993, Consumers Power Company, 212 W. Michigan Avenue, Jackson, MI 49201