4. voltage/Current Sensitivity by Contact Location and Animal Type

4.1. Exposure at watering devices

Farm animals' Contact with watering devices has been the most widely studied area of stray voltage exposure. Water intake is essential for animal productivity and health. Metallic water pipes are required by electrical codes to be bonded, or electrically connected, to the grounded neutral system of a farm. This connection to the grounded neutral system provides a path for fault current in the event that an energized or 'live' wire comes into contact with metal pipes. This fault path allows the circuit breakers to activate and de-energize the faulted wire to prevent the risk of electrocution. This connection also provides a conduit for neutral voltage to access watering devices. Watering devices are therefore one of the more likely points of contact between farm animals and neutral to earth voltage.

4.1.1. Contact pathways and risk reduction

The watering device provides one contact point to the animals' mouth or muzzle. The resistance of this contact point is quite variable depending on the specific type or watering device. For example, in a large concrete tank from which cows can drink without making physical contact with the concrete, the contact resistance is quite high, as water is a relatively poor conductor of electricity. When drinking from a metallic water bowl, typical of a tie-stall or stanchion barn application, a large area of a cow's muzzle must make firm contact with a large metallic paddle in order to start the flow of water into the bowl. The contact resistance in this scenario is quite low. There are other types of watering devices that have intermediate muzzle contact resistance such as heated waterers that may use a float to control water levels. Some watering devices are made of plastic which is also a relative poor conductor of electric current.

The second contact point at watering locations is usually the floor surrounding the watering device. The contact resistance of this surface will be influenced by the type of flooring (usually concrete), the amount and type of debris that may be present of the floor and the wetness of the floor. The experiments that have been done using used flooring conditions designed to minimize this contact resistance (a clean, wet metal plate with some contouring to clean hooves and provide points of high pressure to facilitate a low resistance electrical connection) that it has not been possible to maintain this low resistance continuously and during the course of a day this contact resistance ranged from a few Ohms up to several hundred Ohms (Gorewit, 1992). Experiments that have been done using a more normal concrete floor have indicated that this contact resistance typically ranges between several hundred and several thousand Ohms depending mainly on the amount of water and/or urine standing on the floor surface.

The 'worst case' or lowest resistance value for the contact resistance recommended by the authors of USDA handbook 696 is about 150 Ohms. This combined with that average cow body resistance from muzzle to 4 hooves provides a cow + contact resistance of 500 Ohms. This value is supported well by experimental evidence and is a reasonable value to use for cow + contact resistance at watering devices. Exposure risks can be reduced by:

- Using watering devices that do not required firm contact with grounded metallic components, or using non metallic watering devices
- Avoid the use of electric heating elements in watering devices if possible.
- Provide an equipotential plane around watering devices containing electrified and/or electrically conductive materials, as required by electric codes.
- Providing good drainage around watering devices to avoid standing water and urine on floor surfaces
- Provide several watering locations that are easily accessible to animals in the event that voltage exposures are excessive at one of the watering locations.

4.1.2. Symptoms of exposure and other causes of these symptoms

The primary symptoms of stray voltages at watering are changes in drinking behaviors. Mild changes in drinking behaviors, such as reduced number of drinks per day and longer interval between drinks have been documented in several studies. These changes in behavior may not be sufficient to affect total daily water intake. More severe aversions have also been observed at extreme levels of voltage/current exposure resulting in depressed daily total water intake and in some cases refusal to drink for an entire day.

Experiments have shown that when given free choice, cows show a preference to warmed water over cold water (ground water temperature) which may be perceived as an avoidance of the cold water locations. There are a number of other sensory differences that may incline cows to show a preference to one watering location rather than another, which may be perceived as avoidance of that alternate source. Avoidance of watering locations could also be due to unpleasant tastes or smells, however, the powerful drive to drink will normally overcome all but the most foul of tastes.

Lapping or playing at a watering device has been attributed to stray voltage exposure, but no controlled study has ever confirmed this behavior in the presence of voltage/current exposure. Cows may demonstrate avoidance or modified drinking behaviors in response to group dominance challenges. Cows have been shown to develop what may appear to be unusual behaviors as a way to cope with stressors such as confinement and for many other unknown reasons.

There are well developed experimental techniques to establish cause and affect relationships between a specific stimulus and a specific behavior or avoidance. It is very difficult to establish these relationships on an operating farm unless careful measurement of behaviors is done and sources variability and confounding effects are controlled for.

4.1.3. voltage/Current Sensitivity levels

Cattle

Mild behavioral modification would be expected at current levels of 2 mA for the most sensitive dairy cows, 5 mA for 50% of cows, and about 8 mA for the least sensitive cows. Using a worst case cow+contact resistance of 500 Ohms at poorly drained, wet locations surrounding watering devices, this corresponds to voltage exposure levels from 1 V for the most sensitive, 2.5 V for 50% of cows and 4 V for the least sensitive cows. While these levels have been well documented for dairy cows, it is expected

that they would also apply to beef cattle. In well designed, constructed and managed facilities in which higher contact resistances are more typical this would correspond to voltage exposure levels of 2 V for the most sensitive cows, 6 V for 50% of cows and 8 V for the least sensitive cows.

Short term avoidance behaviors, which may result in short term depression of milk production, would be expected at about 3 mA for the most sensitive cattle (1.5 to 3 V), 7.5 mA (3.8 to 7.5 V) for 50% of cattle and 12 mA (6 to 12 V) for the least sensitive cattle. Reduction in water intake and resulting decreases in milk production would only be expected if there were no other source of water than that which applied this level of current during drinking and if the current dose were consentient enough during the course of a day so that cows could not fulfill their water needs during periods of low exposure.

Swine

Kennedy (1995) found that gilts adapted avoidance behavior within 10 minutes of contact with an electric fence. Drinking behavior changes were reported at levels of 3.0 mA (Gustafson, 1986) and at 5 V (Robert,1992). Continuous exposure to 5 V with Intermittent exposure to 8 V produced some behavioral changes but did not change water intake (Goodcharles, 1993). Short term reduction in water intake has been observed at levels of 4.0 mA (Gustafson, 1986), and 8 V (Robert 1992) but that exposure up to 8 V did not impair the welfare, reproductive performance, or health of sows and suckling pigs (Robert 1996). The body + contact impedance of 12 pigs has been measured as 1031 Ohms on wet metallic flooring and 3041 Ohms on dry metallic flooring (Matte, 1992). Research thus suggests swine adapt to voltage exposure in a similar way to cattle behavioral modification in the range of 5 V in swine with avoidance behaviors at exposures of 8 V. The body + contact resistance for swine appears to be somewhat higher than for cows and 1000 Ohms appears to be a conservative value for measurement purposes.

Sheep

Ewes began to avoid electrified feed bowls when exposure levels exceeded 5.5 V (Duvaux-Ponter 2005). Lambs showed this same preferential behavior when exposure levels exceeded 5 V (Duvaux-Ponter, 2006). Neuro electric principles suggest that the current sensitivity of sheep is lower than for cows, but that their body resistance is higher than cows. Both of these would be expected because of their smaller body mass. The results from Duvaux-Ponter (2005, 2006) confirm that voltage exposure sensitivity for sheep are about twice those for cows. Future studies will provide better information on current sensitivity and body + contact resistance value.

Poultry

Exposures to voltages as high as 18 V had no effect on the hens' production and behavior. This is likely due to the very high electrical resistance of poultry which has been documented to be between 350,000 and 544,000 Ohms

4.2. Exposure at feeding devices

There have been relatively few studies that have specifically examined animal responses to voltage exposure at feeding devices. Notable in the literature are the recent studies performed in France by Roussel (2007) in which Holsteins showed preference for non-electrified feed bowls when exposures

exceeded 2.3 V, and by Rigalma (2007) in which behavioral modification (but not feed reduction) was noted at exposure levels of 3.3 V. These studies indicate that dairy cows have similar sensitivity to feeding exposures as to drinking exposures; however, the feed bowls used in these studies were not typical of those used in farm practice as they were specifically chosen to be small enough and deep enough so that cows would make contact with the electrified surface when eating.

While there are many ways in which feed is delivered to animals, it is relatively uncommon to have feeding devices that require animals to come into direct contact with metallic or conductive elements in order to obtain feed. Feeding locations also pose less of a risk because both mouth and floor contact resistances are typically higher than for watering locations because both are dryer and covered with a high resistance, dry feed or feed debris. Situations in which feed is placed on a concrete floor (feed manger) are unlikely location for problems because, even if an equipotential plane has not been purposefully installed, conductive elements are almost always present in concrete creating at least a partial equipotential plane in some areas of the barn.

The primary symptoms associated with voltage exposures at feeding locations would be the same sorts of avoidance behaviors produced by excessive voltage present at watering locations. These behaviors may be very difficult to observe in situations in which animals have free choice of several feeding locations and/or large feed mangers. The behaviors would be more apparent for situations in which animals had only one feeding location, as may occur for swine.

4.3. Exposure during milking

Several studies have been done on behavioral responses to voltage/current exposure during milking. voltage exposures are less likely to occur for dairy cows in milking parlors than at drinking locations because the metallic components of milking parlor stalls are more likely to be bonded to conductive elements in concrete floors and the floors are more likely to contain a substantial number of conductive elements. This will act to reduce both touch and step potentials.

The milking machine has been shown to be a very unlikely pathway for problematic current flow because of the very large resistance values of the milk hose and milking machine components. Milking machine components, including the long and short milk tubes, long and short pulse tubes and milking liners are good electrical insulators. The mixture of milk and air in milk tubes also has relative high resistance resistances making milk hose resistance in the range of 30,000 Ohms to 80,000 Ohms (Gustafson, 1983) depending on the milk flow rate. Several studies have documented these resistance values and the unlikely path of voltage/current exposure through the milking machine unless source voltages are well in excess of those commonly considered stray voltage, up to hundreds of V for 60 Hz and thousands of V for high frequency sensing pulses.

Cows are not required to make muzzle contact with any metallic components during milking, except in the uncommon situations in which feed might be provided during milking. The contact resistance through a pathway that includes dairy cow's coat is much higher than for muzzle contact resistance because it is drier and hair covered, thus making stall to floor potentials of less concern that water bowl potentials.

Current sensitivity levels are similar for udder-hooves pathways as for muzzle-hooves pathways but cow+contact resistance values are typically higher. A cow + contact resistance value of 1000 Ohms or more is appropriate for milking machine exposure estimation. There are numerous behavioral symptoms associated with cow's unease during milking due to fear of operators, unfamiliar surroundings or aggressive or faulty milking machine settings. Very careful measurement technique and comparison with a negative control condition would be required to differentiate electrical exposures from the many other causes of behavioral modification during milking in a field situation.

4.4. Exposure at building transitions

Step potentials may occur at building transitions where animals are walking onto concrete floors or walking from one section of floor to another which are not electrically bonded by an equipotential plane. Cows are somewhat more sensitive to single hoof-single hoof exposures than to muzzle-to-all-hooves exposures

The contact points for this exposure is from front to rear hooves. The same considerations for hoof contact resistance as was discussed in the feeding exposure section apply here. If floors are well drained and contain organic debris, the hoof contact resistance can be considerable. Cows have been shown to be slightly more sensitive to currents applied from one front to one rear hoof than for muzzle-all-hooves pathway because of the concentration of current in one hoof.

The symptoms of step potential exposure would likely be cows' hesitation to cross budging entrances, exits, or transitions. The discomfort associated with step potentials less than 10 V would not cause most cows to completely avoid the transition but could cause balking at the transition and/or rapid passing through the transition. The author had a report of a milking parlor that had in excess of 50 V at the entrance to the milking parlor. The reported behavioral modification was cows hesitating at the entrance and then 'jumping' into and out of the parlor. There were no apparent effects on milk yield or milking performance, likely because cows had developed adaptive behaviors to avoid undue stress from voltage/current exposure and once the cows were inside the relatively well bonded milking parlor the step potential was eliminated.

There are also a number of other reasons that animals might hesitate to enter or leave a building or move from one part of a building to another including; changes in light levels, shadows on the floor that may appear as obstacles, exploration of a new environment, identification of dominant herd mates and changes in temperature or ventilation levels.

The consequences of a step potential at a building transition are not likely as problematic for animal performance as similarly annoying exposures at watering devices. This exposure pathway is much less of a concern with beef cattle, swine, sheep and poultry that typically stay in the same housing area during the day, than for dairy cows that are moved 2 or 3 times per day to a different building location for milking. Beef cattle are less likely to be housed in buildings that have a concentration of electrical equipment.

5. Mitigation Measures

The source of stray voltage is a voltage that is developed on the grounded neutral wiring network of a farm and/or the electric power delivery system. The magnitude of the voltage source is a product of the current flowing on the neutral system and the resistance of that neutral system. Grounding is provided to keep the voltage potential between the neutral system and the ground below levels that could be harmful to people or animals. Neutral-to-earth, or stray voltage sources can therefore be reduced in three fundamental ways:

- reduce the current flow on the neutral system,
- reduce the resistance of the neutral system, or
- Improve the grounding of the neutral system

Equipotential planes are effective in eliminating contact potentials even if substantial levels of neutral-to-earth voltage are present.

The first step in a competent stray voltage investigation is to determine the major sources of neutral-earth voltage. Any major faults or code violations in the wiring system that could pose an electrocution hazard or are a major source of neutral to earth voltage should be corrected immediately. If the wiring systems (farm and utility) are operating correctly then the above three actions can be assessed to determine which is most practical, safe and efficient way to reduce neutral-earth voltage.

5.1. On-Farm Mitigation Measures

The quality of the farm wiring system has the largest single influence on voltage exposure levels. Farm wiring has been shown to be a major contributor to voltage sources on farms (PSCW, 2007) and equipotential planes provide effective voltage reduction even when voltage sources are considerable.

5.1.1. Farm Wiring

Farm wiring codes are designed to protect the safety of both humans and animals from electrocution and also reduce the level of neutral voltage developed on a farm. The first step in reducing neutral voltage on a farm is to ensure that wiring practices conform to electrical codes. Electrical codes are designed to limit the voltage developed on neutral wires by properly sizing these wires for the intended load. Neutral currents can be reduced by balancing 120 V loads and converting 120 V equipment to 240 V equipment whenever possible. Making good electrical connections and making sure that these good electrical connections are maintained by the proper choice of wiring materials for wet and corrosive locations will reduce the resistance of the grounded neutral system and thereby reduce neutral to earth voltage levels.

5.1.2. Equipotential Planes

Equipotential planes are part of electrical code requirements in animal confinement areas. They are especially important in areas surrounding electrically heated waterers and watering devices that have

conductive elements that are part of the farms grounded neutral system (see section on exposures at watering devices). Equipotential planes reduce exposure from both on-farm and off-farm sources of contact voltage. Every new animal confinement building should be fitted with an equipotential plane. Retrofitting equipotential planes into existing floors can be difficult and expensive but is and effective way to reduce voltage exposures. While the first priority for minimizing stray voltage is to reduce the neutral voltage source, equipotential plane provide substantial exposure reductions and also provide 'insurance' in the event of a fault (broken wire, corrosion or loose connection) that could produce a substantial neutral voltage source.

5.1.3. On farm isolation, Filters, and voltage Suppression

There are a number of devices that have been developed to be installed on farms to reduce animal contact voltages. These technologies usually act to provide isolation or partial isolation of a farmstead or to actively cancel neutral voltages by the application of a 'negative' voltage. These devices can be expensive to install and have not enjoyed a large market penetration. This may be because while some of these devices do reduce contact voltages, they are rarely needed if farm wiring conforms to electric codes. Improving the quality of farm wiring is almost always a less expensive and safer way to reduce neutral voltages than the addition of special voltage reduction devices. These special devices also require additional testing and maintenance to ensure that they remain effective.

5.2. Utility Mitigation Measures

5.2.1. Distribution Wiring

Distribution sources of neutral voltage can be reduced by;

- Reducing neutral current (increasing distribution voltage and balancing 3-phase loads)
- Reducing neutral resistance (Improving the quality of connections and increasing conductor size)
- Improving neutral grounding

A thorough investigation and engineering analysis will provide a determination of whether the distribution line is operating according to its intended design and estimate of the magnitude of neutral-to-earth voltage reduction from each of these measures.

5.2.2. Neutral Isolation

Neutral isolation acts to decouple the distribution neutral system from the farm neutral system. Neutral isolation does not directly act to reduce neutral-to-earth voltage sources. Neutral isolation may change the relative magnitude of neutral-to-earth voltage appearing at different parts of the farm and distribution system and must be exercised with caution.

Neutral isolation does not directly act to reduce neutral-to-earth voltage sources. Neutral isolation will reduce off-farm sources of neutral-to-earth voltage from accessing animal contact points if, and only if, the off-farm sources are a substantial contribution to the animal contact voltage/current. The on-farm and off-farm neutral systems are normally connected and situations can arise in which an off-farm

source of neutral-to-earth voltage is acting to reduce an on-farm source of neutral-to-earth voltage. In these situations, neutral isolation can act to increase animal contact voltage/current on the farm. Neutral isolation also removes grounding from both the farm and utility distribution system. Care must be taken to ensure that both systems are adequately grounded when their interconnection is severed. The effects of neutral isolation on a distribution system depend on the number of services that are isolated relative to the total number of services on the feeder.

5.3. Mitigating Other Sources

Voltage sources from other utility services such as phone lines, water lines and gas lines can be transported to farms by interconnection with farm grounding systems. These grounding connections can also form a parallel path across isolation devices, rendering them ineffective. The procedures for mitigating these uncommon voltage sources are to identify the specific source voltage and a careful inspection and correction of grounded neutral networks.

6. Regulatory Approaches and Guidelines to Reducing the Impact of Stray voltage on Farm Operations

Several states have conducted scientific and technical reviews and held public hearings to address concerns and inform public policy on stray voltage issues. Some States have adopted regulations dealing with stray voltage while others have developed multi-agency and stakeholder groups to develop guidelines and standard practices. Following is a brief summary of the regulatory approaches and/or guidelines adopted by several states in the USA.

6.1. Wisconsin

The State of Wisconsin has a well established inter-agency cooperative program headed by the Rural Electric Power Services Program (formerly Stray voltage Program) jointly administered by the Public Service Commission of Wisconsin and the Wisconsin Department of Agriculture, Trade and Consumer Protection with research and educational support provided by the faculty from the University of Wisconsin-Madison and the University of Wisconsin Cooperative Extension service. These activities have resulted in the development of standardized measurement protocols and a long series of educational programs and publications. Public Service Commission of Wisconsin (PSCW) has also conducted several public hearings and investigations that have resulted in orders that define and regulate stray voltage.

Docket 05-EI-106 defines stray voltage is a special case of voltage in which the neutral to earth voltage is present across points (generally grounded metal objects) in which a current flow is produced when an animal comes into contact with them. These contact points can include any two conductive points which the animal may simultaneously contact to complete a circuit which allows current to flow. PSCW also adopted standardized tests and measurements to screen for the presence of stray voltage and to diagnose the source. The PSCW ordered the utilities to use these specific, standard tests and no others. The PSCW concluded that a specific testing protocol was necessary in order to:

1. provide a consistent systematic analysis which can readily be documented and duplicated,
2. avoid needless controversy over whether an adequate analysis was performed or whether the nature of the tests were valid, and
3. To best recognize the various interests of [all] parties working on a stray voltage analysis.

The standardized tests and measurements are set forth in the 106 Order. In the 106 Order, the PSCW established a level of concern for stray voltage in Wisconsin. The level of concern is the point at which the average cow's behavior may be adversely affected. The level of concern is expressed in mA (mA), the unit of measurement for current. As previously noted, stray voltage is the voltage difference between points. However, it is actually the current flowing through the animal that affects it and, therefore, the Commission finds that the level of concern should be stated in mA measurement unit of current flow.

In Docket 05-EI-115 the PSCW updated its earlier decisions about stray voltage and its effects on cows. In the 115 Order, the PSCW modified the level of concern in Wisconsin to take into account a customer's contribution of stray voltage. The level of concern in Wisconsin for stray voltage is 2 mA of current flowing through a cow. This level of concern is a conservative, preventative level and is well below

where a cow's behavior or milk production would be harmed. In its Ultimate Findings of Fact in the 115 Order, the PSCW found that the level of concern for stray voltage that the Commission established in docket 106 is extremely conservative, because only one percent of cows perceive the presence of 1.0 mA of electrical current.

Reasonable regulation for Wisconsin, a dairy state, is to set a stray voltage level of concern at a conservative, preventative level that is below the point where moderate avoidance behavior is likely to occur. A conservative, preventative level of concern in Wisconsin is 2.0 mA of AC RMS 60 Hz current, steady state. This level of concern is well below where a cow's behavior or milk production would be harmed.

Stray voltage can occur from both on-farm and off-farm sources, so it is reasonable to apply the 2.0 mA level of concern as an overall standard that includes both sources. It is also reasonable to split this 2.0 mA overall level of concern equally between the utility and the farmer. The utility's level of concern is therefore 1.0 mA, for stray voltage from off-farm sources, and the farmer's level of concern is 1.0 mA, for stray voltage from on-farm sources. If the utility's contribution of stray voltage exceeds 1.0 mA, the utility must reduce its contribution to 1.0 mA or below. If the stray voltage from on-farm sources exceeds 1.0 mA, the Commission recommends that the farmer improve the farm wiring, grounding or equipment or take other measures to reduce the level from these sources below 1.0 mA.

In the 115 Order, the PSCW determined that stray voltage measurements should be made using a 500 ohm resistor to approximate a cow's actual resistance. Using a 500 ohm resistor in the testing protocol is conservative, because it calculates stray voltage levels that equal or exceed the actual amount of current a cow in the barn would experience.

The PSCW relied on, and found persuasive, the United States Department of Agriculture's Effects of Electrical voltage/Current on Farm Animals, Agricultural Handbook No. 696: December 1991. In the 115 Order, the PSCW issued these Ultimate Findings of Fact concerning the Handbook:

- A scientific consensus exists about the effects of stray voltage.
- The major work published on this subject is the USDA Handbook.
- The conclusions in the USDA Handbook are still shared today by all of the authors.
- Figure 4 (in this document) from USDA Handbook 696 shows research results about the effect of steady state, 60 Hz current passing through a cow. This Figure indicates that 1 mA is the lowest threshold at which the most sensitive cows perceive the presence of electricity. Stray voltage at this level has no effect on milk production.
- Currents up to 4.0 mA do not appear to inhibit the milk ejection reflex, depress milk production significantly, or increase the incidence of mastitis or other diseases of the cow.
- Above 6.0 mA, a cow's behavioral response can become severe and the loss in milk production may be due to changes in the animal, such as increased stressed hormone levels.

Long-term and on-farm experiments conducted after the publication of the USDA Handbook confirm the Handbook's conclusions. The USDA Handbook's conclusions are reasonable and remain valuable today.

The level of concern set forth in the 115 Order applies to earth currents and ground currents. For a cow to be affected by electricity, current has to flow through the cow. The level of concern of 2.0 mA of current flowing through a cow applies regardless of the source of the current.

In Docket 05-EI-108 the PSCW investigated the effects of electromagnetic fields, direct currents, and ground currents on dairy cows. Earth currents are an inherent, inevitable, and unavoidable result of a multi-grounded neutral distribution system. On normally operated grounded wye distribution systems, both ground current and earth current will flow as a result of voltages on the grounding system. The Minnesota PUC had already established a scientific advisory panel and the PSCW worked with the PUC on that study and concurred with their conclusions (see below).

The PSCW also maintains an extensive database of on-farm stray voltage investigations that dates from 1989. Data from over 8000 first time on-farm investigations from investor owned utilities and electric cooperatives. These data were collected using a standardized measurement protocol developed by the PSCW which quantifies the highest level of animal-contact current on the farm, the contribution from on-farm and off-farm sources as well as many other electrical and herd production data.

6.1. Michigan

The State of Michigan's Public Service Commission defines a preventative action level as a steady state animal contact current that meets or exceeds 2 mA RMS using a nominal 500 ohms resistor at 60 Hz from all sources, including off-premises and on-premises sources.

Measurement Methods: The level of animal contact current shall be determined from measurements of animal contact voltage using Ohm's Law. The voltage measurement shall be made between 2 points, which an animal can simultaneously contact and under which animal contact voltage is most likely to occur. When measuring from the floor or earth, a single metallic plate with an area of 12 to 16 square inches shall be used to simulate the foot of the animal. One lead of the measuring instrument shall be connected to the plate, which shall be placed on the floor or earth where an animal may stand. The other lead of the measuring instrument shall be connected to a conductive object that an animal could reasonably contact while 1 of its feet is at the location of the plate. For all measurements of animal contact voltage a shunt resistor shall be used to simulate the resistance of the animal. A suitable material, such as a medical grade electrode contact gel, shall be used to simulate real conditions and maintain conductivity to the floor or earth for the duration of the testing period.

Action required to mitigate animal contact current: If the steady state animal contact current from all sources as measured by the utility in accordance with this rule meets or exceeds the preventive action level, and if the utility contribution exceeds 1 mA RMS, then the utility shall commence action within two business days, or at a mutually agreed upon time frame between the complainant and the utility, to reduce the utility contribution to 1 mA or less.

Further sections detail procedures for: Request for an investigation, Appointment of Experts, Request for a contested case hearing, Protocol to evaluate utility contribution.

6.3. Vermont

Scruton (2003) reported that in 1994 the legislature held hearings and a program was initiated with the Public Service Board, Public Service Department, Vermont Department of Agriculture, Food and Markets, The University of Vermont and Vermont Utilities. Utilities agreed to test all farms for stray voltage. Neutral isolation devices are installed, at the unities' expense when neutral to earth voltage in excess of 0.5 V are encountered. If less than 0.5 V are found, the utility may install an isolator; or voltages will be monitored for a sufficient period to ensure that voltage does not exceed the 0.5 V threshold.

6.4. Idaho

In March 2005 the Idaho Legislature passed the Stray Current and voltage Remediation Act requiring the Idaho Public Utilities Commission to promulgate stray voltage rules. The Idaho Public Utilities Commission (IPUC) has developed Stray voltage Rules composed of four Major Sections:

- Qualifications of persons analyzing stray voltage data
- Calibration and standards of recording equipment
- Six stray voltage tests and data collection forms
- Analyzing data and conducting remediation actions, if required

The IPUC has accepted the following definitions of Stray Current and voltage as:

a) Any steady state, sixty (60) hertz (Hz) (including harmonics thereof) root mean square (rms) alternating current (AC) less than twenty (20) mA through a five hundred (500) ohm resistor (i.e. shunt resistor) connected between cow contact points, as measured by a true rms meter; or

b) Any steady state, sixty (60) Hz (including harmonics thereof), rms AC voltage of less than ten (10) V, across (in parallel with) a five hundred (500) ohm resistor (i.e. shunt resistor) connected between cow contact points, as measured by a true rms meter.

c) Stray current and voltage is a normal, inherent and unavoidable result of electricity traveling through grounded electrical systems, including a dairy producer's on-farm system and a utility's distribution system. These systems are required by the National Electrical Code (NEC) and the National Electrical Safety Code (NESC) to be grounded to the earth to ensure safety and reliability.

d) Unless the context otherwise requires, the term stray voltage shall mean stray current or stray voltage.

6.5. Minnesota

The Minnesota PUC assembled a team of Science Advisors study farmers' claims that electric currents in the earth from electric distribution systems caused behavior, health, and production problems in cows

in Minnesota. The Science Advisors were a multidisciplinary group with expertise in the fields of agricultural engineering, animal physiology, biochemistry, electrical engineering, electrochemistry, epidemiology, physics, soil science and veterinary science. The Science Advisors to the Minnesota PUC issued its Final Report to the Minnesota PUC in July 1998. In its Final Report, the Science Advisors to the Minnesota PUC reached three conclusions:

1. We have not found credible scientific evidence to verify the specific claim that currents in the earth or associated electrical parameters such as voltages, magnetic fields and electric currents, are causes of poor health and milk production in dairy herds.
2. At the present time there is no basis for altering the PUC approved standards by which electric utilities distribute power onto or in the vicinity of individual dairy farms.
3. There are many well-documented non-electrical factors that are known and accepted by the scientific community, and by most farmers as well, to cause dairy cow health and production problems. Among the most noteworthy stressors are poor nutrition, poor cow comfort and hygiene, and low or no use of vaccinations and related preventive veterinary practices. Those who want to improve performance of dairy herds should always address these factors.

6.6. New York

The New York State Stray voltage Committee was formed in the early 1980's as a forum for utility risk management personnel to share information about existing or potential litigation on 'stray voltage' (28). New York investor owned utilities shared experiences, solutions and research funded by the Stray voltage Research Council. In 1993 efforts were directed to neutral isolation devices for cable television and underground telephone services due to the expansion of cable television into traditionally agricultural areas and electric utilities found itself at odds with cable and telephone policies on bonding and grounding. The expertise of Cornell University was requested to develop a standardized test procedure and to outline required tests and test methods and allow the utilities to formalize the procedures based on their internal work rules. At this time the Empire State Electric Energy Research Council also funded additional research on 'the effects of transients and multiple stresses on dairy cows'. The New York State Stray voltage Committee continues to disseminate information and work with Cornell University, local, state, and federal agencies on stray voltage issues so that problems can be avoided rather than perpetuated.

6.7. Pennsylvania

The Pennsylvania State University began a research project for the Pennsylvania Department of Agriculture (PDA) in February 2001 to examine stray voltage issues on PA dairy farms (161). Based on the initial project findings a second project proposal was funded in 2002 to develop an interdisciplinary approach to respond to farmers' stray voltage concerns. This study found that less than 10% of investigations found stray voltage levels high enough to affect cow behavior. The author notes that while the instances that stray voltage directly affects animal performance is infrequent, the resources that farmer and utilities spend chasing stray voltage are significant, and that misinformation and

misdiagnoses of stray voltage and its symptoms are expensive to both farmers and utilities. The following steps were recommended:

1. Establish a statewide stray voltage task for with representatives from utilities, state government, extension, farm organizations, veterinarians, equipment suppliers, nutritionists and other service providers.
2. Establish a standard protocol for stray voltage investigation.
3. Establish a minimum threshold for mitigation.
4. Public and private collaboration on a multidisciplinary response to stray voltage complaints.
5. Education.

The final conclusions of the stray voltage committee were that it is in the best interest of utilities and farmers to accurately diagnose and identify problems that can be associated with stray voltage. For utilities, repeat service calls, customer dissatisfaction and litigation can all be the result of an unhappy farmer. For farmers, believing that stray voltage is the issue when it is not is costly because it delays solving the real problem.

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Stray Voltage

Causes of Stray Voltage

Stray voltage and its impacts on livestock and other confined animals have been studied in detail by state and federal agencies, universities, electric utilities, and numerous scientists since the late 1970s. The PSCW has opened investigations, encouraged the upgrade of rural distribution systems, established measurement protocols, and compiled a stray voltage database to track investigations, all in order to develop successful strategies for minimizing stray voltage in farm operations (http://psc.wi.gov/utilityInfo/electric/strayVoltage.htm). Over the decades, significant resources have been allocated to understand this issue.

Electrical systems, including farm systems and utility distribution systems, are grounded to the earth to ensure safety and reliability, as required by the National Electrical Safety Code and the National Electrical Code. Because of this, some current flows through the earth at each point where the electrical system is grounded and a small voltage develops. This voltage is called neutral-to-earth voltage (NEV). When NEV is measured between two objects that are simultaneously contacted by an animal, a current will flow through the animal and it is considered stray voltage. Animals may then receive a mild electrical shock that can cause a behavioral response. At low voltages, an animal may flinch with no other noticeable effect. At higher levels, avoidance or other negative behaviors may result. Stray voltage may not be noticeable to humans.

Low levels of alternating current (AC) voltage on the grounded conductors of a farm wiring system are a normal and unavoidable consequence of operating electrical farm equipment. In other words some levels of stray voltage will always be found on a farm. For example, a dairy cow may feel a small electric shock when it makes contact with an energized water trough. The issue of concern is stray voltage that occurs at a level that negatively affects an animal's behavior, health, and more specifically, milk production.

Stray voltage can be caused by a combination of on-farm and off-farm causes. One off-farm contributor to stray voltage is the operation of transmission lines in close proximity and parallel to a distribution line. As a means to minimize new transmission line impacts, new lines are often co-located near a distribution ROW or the distribution line is underbuilt on the new transmission poles. This configuration can contribute to stray voltage issues. To minimize the likelihood of stray voltage occurrences, utilities sometimes propose to relocate these paralleling distribution lines further away from the transmission line and/or burying the distribution line underground. Additionally, the PSCW may require the utility to conduct pre-construction and post-construction testing of potentially impacted farms and lines.

Potential Impacts of Stray Voltage

Herd problems can be difficult to diagnose. There are many factors to consider such as the herd's environment, diet, and health. Dairy cow behaviors that may indicate the presence of stray voltage include nervousness at milking time, increased milking time, decreased milk production, increased Somatic Cell Count, increased defecation or urination during milking, hesitation in approaching waterers or feeders, a reluctance to enter the barn or milking parlor, or an eagerness to leave the barn. Some of these symptoms are interrelated. For example, a dairy cow that does not drink sufficient water due to shocks may have decreased milk production. However, these same symptoms can be caused by other factors that are unrelated to stray voltage such as increased mastitis or milk-withholding problems for farms with milking parlors or in barns with milk pipelines. If stray voltage is suspected to be the cause of herd problems, the farm should be tested.

In 1996, the PSCW established a stray voltage "level of concern" of 2 milliamps (PSCW docket 05-EI-115). The level of concern is not intended as a "damage" level but as a very conservative, below-the-injury level, below the point where moderate avoidance behavior is likely to occur, and well below where a cow's behavior or milk production would be affected. The PSCW and DATCP consider that at this level of current, some form of mitigative action should be taken on the farmer's behalf.

The level of concern is further defined with respect to how it should be reduced. If a utility distribution system contributes one milliamp or more to stray voltage on a farm, the utility must take corrective action to reduce its contribution to below the one milliamp level. If the farm electrical system contributes more than one milliamp, the farmer may want to consider taking corrective measures to reduce the level below one milliamp.

Mitigation of Stray Voltage

When stray voltage is a concern, electrical measurement in confined livestock areas should be done using the established PSCW-approved testing procedures with appropriate equipment. These testing protocols have been developed to collect a reasonable set of data useful in the analysis of the quantity and quality of stray voltage that may be present under a variety of conditions, and the source (including on-farm versus off-farm sources) of such stray voltage.

Field research shows that cow contact current is often dependent on both on- and off-farm electrical power systems. A common on-farm source of stray voltage is the inappropriate interconnection of equipment grounding conductors with the neutral conductors of the farm wiring system. Mitigation of stray voltage can be achieved through a variety of proven and acceptable methods, such as additional grounding or the installation of an equipotential plane.

Farm operators may receive additional technical assistance from the Wisconsin Rural Electric Power Services (REPS) program (as defined and authorized by Wis. Stat. §§ 93.41 and 196.857). The REPS program is jointly managed by the PSCW and DATCP. DATCP (http://datcp.wi.gov/Farms/Wisconsin_Farm_Center/Farm_Rewiring/Stray_Voltage/index.aspx) provides an ombudsman, veterinarian, an energy technical advisor, and a program assistant to the REPS program. REPS staff provides information about stray voltage and power quality issues; work to answer regulatory questions; conduct on-farm and distribution system investigations that can assist farmers in working with the utility or electrician to resolve a power quality concern; provide a format for dispute resolution; and continue to research electrical issues. REPS staff also works with farmers, their veterinarians and nutritionists to resolve herd health and production problems.

Water Resources

Potential Impacts to Surface Waters

Waterways in the form of creeks, streams, rivers, and lakes are abundant throughout Wisconsin. Many of these waters have been designated as special resources that have state, regional, or national significance. Construction and operation of a transmission line across these resources may have both short-term and long-term effects. The type and significance of the impact is dependent on the characteristics of the water resource and the transmission line design. Waterway use, physical features such as channel width, herbaceous plant cover, and water quality, recreational use, and the scenic quality of the river and its surrounding landscape are important factors in assessing potential impacts.