

Conference Paper

Presented at the 1997 Rural Electric Power Conference
Minneapolis, Minnesota
20 – 22 April, 1997

Sponsored by the Institute of Electrical and Electronics Engineers, Inc.

Stray Voltage Update 97

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ABSTRACT

The USDA handbook " Effects of Electrical Voltage/Current on Farm Animals" was published in 1991. This handbook serves as an excellent summary of stray voltage research and practice up to the date of its publication. This paper will provide an update of stray voltage issues which have emerged and the results of recent research and field surveys on stray voltage and related electrical phenomena which has occurred since the publication of the USDA Handbook.

WHAT IS STRAY VOLTAGE?

The definition of stray voltage in the USDA handbook is:

"Stray voltage is a small voltage (less than 10 volts) measured between two points that can be simultaneously contacted by an animal. Because animals respond to the current produced by a voltage and not to the voltage directly, the source of the voltage must be able to produce current flow greater than the threshold current needed to elicit a response from an animal when an animal, or an equivalent electrical load, contact both points."

This definition is still considered an accurate description of the stray voltage phenomena. It was meant to apply to steady 60-Hertz (Hz) ac voltages and also applies to steady 50 Hz ac voltages. The sources of steady 60 Hz ac stray voltages are well documented and solutions well understood.

Steady 60 Hz voltages are a normal consequence of the use of electrical power

resulting in current flow on both the primary and secondary grounded neutral system. The amount of current flowing and the impedance of the grounded neutral network determine the level of voltage.

In addition to these steady voltages, short duration, or transient voltages, also exist on the grounded neutral network. These transient voltages may have a phase duration ranging from 8.3 mS, (corresponding to 60 Hz power frequency) to less than 1 μ s. The main source of these transient voltages is switching of electrical equipment. Recent research has been performed to more accurately determine animal response to these electrical phenomena.

Motor Starting Transients

A 60 Hz transient voltage will occur when an electric motor is started. These are among the most common types of transient voltage encountered at animal contact locations (Dasho et al, 94). Elevated current flow on the primary neutral occurs when 240 V motors are started. The current flows into the impedance of the distribution system neutral and produces a voltage transient. The voltage magnitude is dependent on the starting current of the motor, transformer ratio, and the impedance of the grounded neutral system. If the primary and secondary neutrals are bonded, a portion of this voltage will appear on the farm secondary neutral system.

In the same way, elevated current flow occurs mainly on the secondary neutral when 120 V motors are started. The transient voltage produced by 120 V motors

will depend upon the transient current flow on the secondary neutral and the impedance of the grounded neutral system. A portion of this voltage will appear on the primary neutral if the primary and secondary neutrals are bonded.

These motor starting transients consist of from 1 to 20 cycles of 60 Hz (8.3 ms phase duration) voltage and current. The maximum voltage and current usually occurs during the first or second cycle.

If motor starting transients are a concern, the following steps can be taken to reduce their level. Use 240 volt motors whenever possible. Inspect motors for wiring in accordance with the National Electric Code including proper conductor size, and type of connections. Make sure that motors are appropriately sized to the load and not started or stopped under abnormally heavy load. Power factors should be kept above (80%).

The motor starting current can be measured and compared to the rated starting current listed on the nameplate to determine if the motor is being started under heavy load or if the motor is defective. Contact the power supplier to determine the maximum motor size that can be started on the distribution system. Soft start motors or other current limiting devices will reduce starting currents.

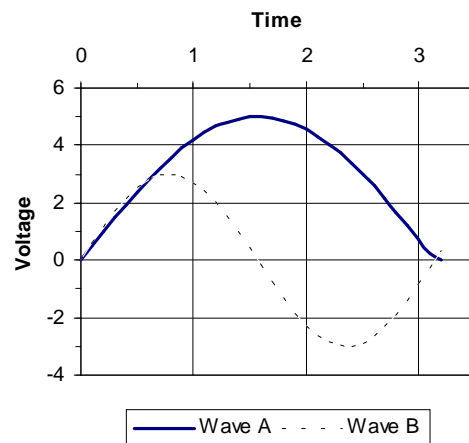
Short Duration Transients

Transient voltages with short duration (phase duration less than 8.3 ms or frequencies higher than 60 Hz) have two main sources: improperly installed electric fences, cow trainers and crowd gates, and switching of electrical equipment. The sensitivity of animals to transient voltages is

highly dependent on the phase duration of these voltages. In order to determine whether these short-duration events may be problematic they must be measured correctly and compared with animal sensitivity at the appropriate phase duration.

The definitions used in this paper are defined using the waveforms in Figure 1. Wave A is single-cycle, sinusoidal in shape and monophasic, going from 0 to some peak positive value then back to zero. The phase duration of wave A is 3.1 time units and the peak voltage is 5 V.

Figure 1. Example Waveforms



Wave B is also single cycle, sinusoidal in shape but is biphasic, going from zero to some positive peak value then passing through zero to a negative peak value and returning to zero voltage. The Phase duration of wave B is 1.6 time units and the peak voltage is 3 V.

When dealing with short duration impulses, the peak voltage and phase duration are convenient numbers to measure with electronic recording equipment such as an oscilloscope. The RMS (Root Means Square) value of these transient waveforms may be difficult to measure or calculate. If biphasic waves are not symmetric about the

zero axes, the ratio of the RMS to peak value will be different than for the symmetric sinusoids usually encountered in steady 60- Hz stray voltages.

For waveforms with phase duration greater than about 1 ms, animal sensitivity is determined mainly by the peak current. For waveforms with phase duration less than 100 μ s sensitivity is determined mainly by the charge of the impulse.

Electric fencers and similar devices produce a very high voltage (5000 - 20,000 V) impulse with very short phase duration (10 - 300 μ s). These impulses are generally a single cycle and may be mono phasic (only a positive spike) or biphasic (spiking both positive and negative). This type of impulse is designed to produce aversion but not cause harm to the animal.

These devices have been used for many years to contain animals to certain areas. The vast body of field experience with these devices suggests that intermittent exposure to voltage transients is not problematic.

Field experience has shown that improper installation of electric fencers, trainers and crowd gates are a common source of short duration transients in cow contact locations (Dasho, 1994). Common installation problems include inadequate separation of the ground for these devices and other grounding, improper insulation on live or grounding conductors and unintentional shorting to metallic objects.

If the impulses from these devices appear frequently in animal contact locations at sufficient levels, animals may avoid those locations.

Switching and other Transient Voltages

Switching of electrical devices may produce transient voltages with phase duration less than 10 μ s. These short duration voltages contain very little energy and decay very quickly. They appear only very close their point of origin. Field data indicates that the main sources of short duration transient voltage and current in cow contact areas originate on the farm being investigated (Dasho, 1994).

Low impedance neutral systems including conductors, and grounding and equipotential planes in animal confinement locations are effective means to reduce steady 60 Hz cow contact voltage as well as transient voltages.

ANIMAL RESPONSE

A response curve showing both expected behavioral and milk production responses to current and voltage is presented in USDA Handbook 696. This figure is the consensus opinion of the authors who conducted and reviewed data from numerous experiments. It does not attempt to illustrate the variations found among experiments or within experiments.

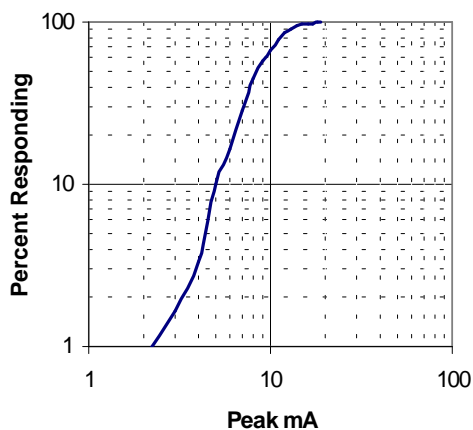
This figure is meant to apply to continuous exposure to steady 60 Hz, voltage and current. The current level given for perception is from 1 to 3 mA, RMS with no production loss anticipated in this range. Moderate behavioral responses are expected in the range from 3 to 6 mA. Any loss in production is not due to physiological change in animals.

Response to 60 Hz Voltage and Current

Research conducted at the University of Wisconsin (UW) has resulted in characterization of the sensitivity of a large number of dairy cows to 60 Hz transient voltages (Reinemann et al, 1996). The distribution of responses for 120 cows exposed to a single-cycle, 60 Hz current is shown in Figure 2. This is a response level at which cows first showed signs that they were aware of the presence of the stimulus.

Subsequent experiments measured no short term (3 day average) or long term (3 weeks average) reduction in water or feed intake, or milk production when current levels at the behavioral response level were applied to water bowls continuously for 3 weeks. A short term (3 day average) reduction in water and feed intake and milk production was measured when current levels 1.5 times higher than the behavioral response level were applied to water bowls continuously for 3 weeks. Cows resumed their pre-stimulus consumption and production levels for the remainder of the 3-week exposure.

Figure 2. Behavioral response to single cycle 8.3 ms phase duration (60 Hz) biphasic, sinusoidal stimulus.



In these experiments cows were exposed to the transient current (1 cycle, 60 Hz) whenever they attempted to drink. In practice transient events are not typically always present.

Predictability of response was improved over previous studies by taking into account individual animal sensitivity e.g. each cow was exposed relative to her individual behavioral response level. This result clarifies previous experiments in which animals had to be removed from experimental trials because of dramatic response.

Behavioral effects, as indicated by delay to drink and gross observation were apparent during the first day of exposure at levels lower than those required to cause measurable changes in daily total water, feed or milk production. This confirms results of previous studies and field observations noting changes in animal behaviors with no measurable decline in water or feed intake or milk production.

Studies conducted by Currence et al, 1990, and Reinemann et al, 1996 indicate that multiple cycle and steady 60 Hz stimulus will produce similar sensitivity and response at current levels 20% to 30% lower than for single cycle stimulus. The distribution in Figure 2 is therefore the peak current level at which behavioral effects would be observed for single cycle 60 Hz transient current and the peak current level at which short term aversion would begin for steady 60 Hz current. The RMS current level for these responses is approximately 0.7 times the value indicated in Figure 1 for symmetric, sinusoidal voltage and current.

There was no evidence in the UW studies or any other controlled study that there is any

direct physiological effect of voltage/current exposures below the levels at which a behavioral response can be documented nor at levels at which aversion to water and/or feed are first observed. The aversive behaviors documented are consistent with response to an unpleasant stimulus.

These results indicate that the response levels presented in the summary table from the USDA handbook are conservative, in that the responses cited (e.g. perception only at 1 - 3 milliamps), will only occur for a small percentage of cows. The vast majority of cows will not perceive currents of this level and will show no harmful effects. Concerns over small sample size in some individual experiments have been addressed, in that independent research groups obtained similar results in repeated studies. Furthermore, the results of these controlled studies are consistent with several sets of field data in which exposures and responses were documented (Southwick et al, 1992, 1993, Hendrickson et al, 1993).

Data from over 1700 farms has recently been collected by the Public Service Commission of Wisconsin (PSCW) and summarized in Dasho et al, (1995). More than 90% of the farms in the PSCW study had cow contact currents less than 2 mA and more than 70% had less than 1 mA. There was a weak correlation between primary neutral and secondary neutral voltage, and between secondary neutral and cow contact voltage, as would be expected from circuit theory.

These data also showed that cow contact voltages were less than 50% of the secondary neutral to earth voltage on 80% of the farms tested and less than 30% of secondary neutral to earth voltage on 50% of the farms tested (Cook et al, 1996). There was no meaningful correlation between cow

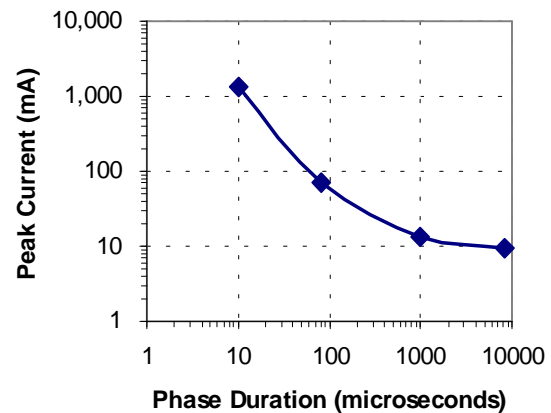
contact voltage and either average milk production or somatic cell count.

The PSCW data shows clearly that cow contact voltage on any individual farm is dependent on the specific characteristics of the on-farm and off-farm voltage sources. Specific measurement of cow contact voltage on each farm is required to determine the potential impact on cows on that farm. Because of the wide variation in the data, gross indicators, such as grounds per mile, secondary and primary neutral to reference voltages, etc., are not good predictors of cow contact currents.

Animal Response to Short Duration Voltage and Current

The threshold current for behavioral reaction of dairy cows found to increase dramatically as the phase duration of the applied decreased (Reinemann et al, 1996). A strength-duration curve is shown in Figure 3. This response curve is for single-cycle, biphasic stimulus. This is a response level at which 50 % of the cows tested showed signs that they were aware of the presence of the stimulus.

Figure 3. Strength-Duration Curve For Biphasic, Sinusoidal Stimuli.

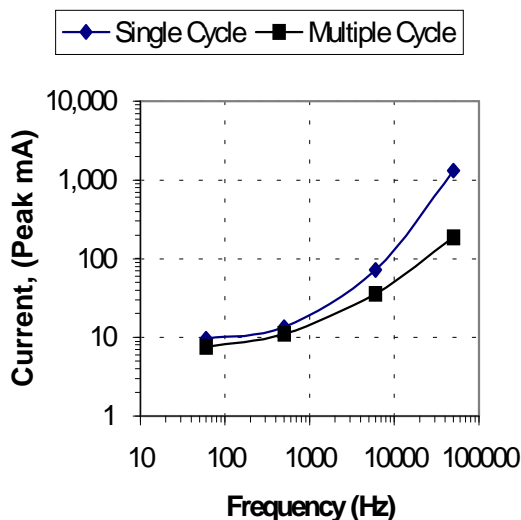


Short-term aversion to water was observed for levels 1.5 times higher than behavioral response levels when a 6000 Hz Transient was applied to the water bowl, as occurred for 60 Hz stimulus. Further details of the range of response levels and responses for different waveforms are given in Table I.

The sensitivity of animals to short duration stimulus is also affected by the number of cycles of the stimulus. Strength-frequency response curves for single cycle and multiple cycle sinusoidal stimuli are shown in Figure 4.

These relationships agree extremely well with neuro-electric models and the large body of research on human sensitivity to short duration voltage and current (Reilly, 1992). This relationship was observed and documented in humans as early as 1901 and has been repeated in numerous experiments since that time.

Figure 4. Strength-Frequency Curves for



Sinusoidal Stimuli.

Measuring Steady and Transient Voltage

The most important part of a stray voltage investigation is to determine how much current could flow through a cow in its normal environment. This involves making measurement connections in the animal's environment to points that the animal could contact.

It is important to use a circuit representative of that including the cow across points that a cow could contact in its normal environment. Open circuit measurements are not representative of the cow circuit. In order to determine the worst case scenario and also for repeatability of measurements it is recommended that the contact points be cleaned and attached with low impedance connections. Common practice is to use a nominal 500-Ohm resistor shunted between the contact points. This method will produce a conservative (worst case) estimate of the 60 Hz current that could flow through a cow.

These cow contact measurements are the only reliable estimate of the potential effects of electrical stimuli on the cow. Other measurements are often made as diagnostic tools to determine the voltage sources. It is important to accurately determine the relative magnitudes of the source voltages before implementing solutions. Unless the source is identified much time and money can be wasted on solutions which have little or no effect. This is not in the interest of the dairy operator, power supplier, or others trying to solve problems.

Measuring equipment commonly used for 60 Hz stray voltage investigations may indicate the presence of the short duration events but may not give an accurate measurement of the phase duration and/or peak voltage of the

event. A digital storage oscilloscope is recommended to accurately measure short duration signals.

A cow impedance must also be included in the circuit when measuring short duration events. The impedance of a cow is reduced somewhat for short duration or high frequency stimuli. A variable cow impedance circuit and recommendations for equipment and procedures have been developed (Stringfellow et al, 1996). A 500-Ohm resistor across contact points will give a reasonable estimate of the current flowing through a cow when used with the appropriate recording equipment. This estimate can be improved if the source impedance of the circuit is measured.

Neutral to Earth Voltage

Neutral voltage is the result of current passing through the impedance of the grounded neutral system. Unbalanced loads, long or undersized conductors and high impedance connections are all common conditions that create neutral voltage. Based on field experience of the authors, secondary neutral voltage drop is the major source of on farm stray voltage in the country. A careful analysis of the contribution to secondary neutral voltage by **all** services on farm is an essential part of a complete stray voltage investigation.

As part of a stray voltage investigation the primary (distribution system) and secondary (farm system) neutral voltage may be measured to a reference ground rod. This reference rod should be located at least 150 ft away from the distribution system and farm system grounding. If the reference rod is too close to the farm or distribution grounding, the measurements may be difficult to interpret. These measurements

are made without a shunt resistor in the measurement circuits and are used to help determine the source of cow contact voltages.

If the primary and secondary neutrals are bonded, a portion of voltage developed on the secondary neutral will occur on the primary neutral and vice versa. Careful assessment of the current flow and impedance of both the primary and secondary neutrals is required to accurately determine the relative voltage contributions.

Neutral to earth voltage can be reduced by reducing the current flow on the neutral, if possible, or by reducing the impedance of the grounded neutral system. This can be accomplished by (1) improving the quality of connections and splices, (2) increasing conductor size or (3) improving grounding. The specific measure to be implemented depends on the major cause of high neutral voltage.

The neutral-to-earth voltage measured at any point on the neutral system can have many possible sources, and is usually made up of several sources. Each on-farm service is a potential contributing source of neutral voltage. If a farm has ten service drops, there are ten potential on-farm sources and one potential off-farm source. This concept can be extended to each branch circuit on the farm. If this same farm has 40 branch circuits then there will be 51 possible voltage sources. A portion of all of these source voltages will show up at all of the measurement points on the farm neutral system and the utility neutral.

Isolation

The rule in the National Electrical Safety Code (NEC) for multi-grounded systems is

that primary and secondary neutrals should be interconnected (Rule 97B). This interconnection reduces the grounding impedance of the electrical supply system, which reduces the damage caused by lightning or other transient high voltages. Isolation of primary and secondary neutrals is permitted "where necessary" (Rule 97D2).

Isolation will significantly reduce the interaction between these two grounded-neutral systems. The authors recommend that isolation be used only after primary neutral voltages have been reduced by construction and/or maintenance based on sound engineering practice. If primary neutral source voltage is still occurring in cow contact locations at levels of concern, isolation can then be considered as an option. In some instances, isolation may be in place for extended periods until the necessary changes to the primary neutral system can be completed.

Engineering methods to reduce the primary neutral voltage are; improve grounding, reduce primary neutral current, and reduce primary neutral impedance (connections and conductor size). On the secondary side, proper conductor size for the load reduces voltage drop, balancing 120-volt loads to reduce neutral current, and proper grounding of services and equipment are tools to reduce secondary neutral voltage.

Many other methods have been proposed to eliminate primary/secondary interaction including secondary isolation transformers and increased distance from the primary supply to the secondary service. The disadvantage of these methods is the greater voltage drop from long secondary conductors and the extra energy cost of losses in the isolation transformer. Dangers

of lightning damage are increased, as the premises are isolated from all the multi-grounds of the electrical distribution system. In addition, isolation may be difficult to maintain as there can be inadvertent connections to the primary neutral through phone lines, cable TV, multiple electrical services, or fences contacting utility grounds.

Where isolation is "necessary", isolation devices between primary and secondary systems on utility equipment are the most energy and cost effective. Lightning suppression devices in parallel with the isolating device will provide system protection for the premises wiring and equipment.

4-wire Service

A four-wire service meeting all the requirements of the NEC is difficult to achieve (Cook et al, 1995). In practice it is rarely done correctly. The authors suggest upgrading three-wire service to reduce neutral voltage drop particularly in existing situations where there are other three-wire services. If a four-wire service is desired, install the new supply to the selected building as a four-wire feeder. The most appropriate use of a four-wire service is for a new facility that has its own electrical service. This eliminates interactions with other three-wire services.

A four-wire system will not prevent neutral voltage developed on one service from affecting other services or the primary neutral voltage from appearing on the grounding conductor ('fourth-wire'). It will only prevent neutral voltage due to the secondary neutral voltage drop on the service with the four-wire system from causing voltages at animal contact locations.

Facility Design and Management for Animal Safety

Stray voltage can cause animals to avoid contact surfaces if the voltage levels are high enough. If cows cannot avoid these contact points behavior problems may result. It has been observed that cows will locate areas without annoying contact voltages if given the opportunity to do so.

It is good management practice to provide multiple locations of feed and water too allow animals free access and the ability to choose locations that are not problematic. Providing an ample supply of dry bedding in stalls will increase contact impedance and reduce or eliminate any potential problems. Animal management practices that reduce forced exposure will improve the animal's ability to reduce or avoid exposures and reduce or eliminate the effects any problematic contact voltages that may develop.

When designing animal confinement facilities locate and install electrical equipment in such a manner to reduce the number of potential animal contact locations. An equipotential plane, if properly installed, will eliminate problematic contact voltages and is required by the National Electric Code in all new animal confinement facilities. Use of equipment such as energy free waterers and nonmetallic wiring materials and fixtures in animal confinement locations will eliminate animal contact voltages.

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Table I. Transient Current Test Summary.

Test	A	B	C	D	E	F	G	H	I	J	K	L
Phase duration, t_p (μ s)	8333	8333	8333	1000	83	83	83	10	10	10	10	10
Frequency (Hz)	60	60	60	500	6k	6k	6k	50k	50k	50k	50k	50k
Number of cycles	1	5	9	1	1	9	100	1	1	1	5	833
Bi/Mono phasic	B	B	B	B	B	B	B	M	M	B	B	B
Waveform	Sine	Sine	Sine	Sine	Sine	Sine	Sine	Square	Sine	Sine	Sine	Sine
Number of Animals	120	24	24	24	24	23	12	12	8	8	8	12
Mean Threshold (Peak mA)	9.6	7.1	7.6	14	71	58	36	182	543	1308	695	186
Standard Deviation	3.0	1.5	2.6	4.9	15	19	5.8	37	42	164	85	38
Min Threshold (Peak mA)	2.8	4.4	2	6.3	41	30	28	129	480	1000	600	124
Max Threshold (Peak mA)	19.1	10.5	13	27	103	103	48	257	600	1500	820	246