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Cow Resistance: 500 Ohms in the Minnesota Stray Voltage Guide

The collaborative and voluntary effort between utilities, agricultural stakeholders, and the state of Minnesota to develop the *Minnesota Stray Voltage Guide* was guided by a substantial body of research. Rigorous research has been occurring for decades. A strong and consistent body of knowledge published in scientific journals after extensive peer-review consistently indicates 500 ohms is the appropriate resistor level to use when testing for stray voltage. Since the research clearly establishes this, it has been used in all states that have acted to develop standards. Specifically, the deliberations in developing Minnesota's guide relied upon efforts in Wisconsin and Iowa as a starting point. In fact, every state that has established a stray voltage standard recommends using a 500 ohm resistor for taking measurements, and recommends taking remedial action at the same levels of concern, or actionable thresholds, identified in the *Minnesota Stray Voltage Guide*.[1]

In Minnesota, measurements of cow body resistance are being conducted in the field, and the data collected is being used to spread misinformation. Misleading interpretations of these field tests fail to tell the whole story, and are used to level an unfortunate attack on the large body of quality research on stray voltage. These tests do not provide useful information. They ignore critical elements of the electrical circuit in question for stray voltage conditions, resulting in erroneous estimates of the current likely to pass through a cow if stray voltage is present.

These claims cause needless and counter-productive animosity between dairy farmers and the electric power suppliers whose mission is to supply them with safe and reliable electrical energy. No university has been involved, and they have not produced any published research that scientists in the field reviewed and commented on to establish legitimacy. Unfortunately, this is not just an academic matter. To successfully test for and address stray voltage, dairy farmers and utilities need to apply findings from sound research, and work together in partnership. Sowing distrust results in unnecessary barriers, inhibiting the success of farmers by making it harder to find and resolve problems.

Body Resistance of a Cow

The resistance level used in standard stray voltage testing to represent a cow must account for both the *cow and the contact resistance*. The measurement of body resistance[2] is a complex subject as there are many factors that influence the measurement method and measured values. However, these phenomena have been extensively studied and explained. Accurate measurements of body resistance must include the resistance of the interface, or contact resistance, as well as the resistance of the skin, a 'spreading' resistance that accounts for how current is distributed in the body, and finally the third element of the 'body resistance.'[3]

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[1] *Minnesota Stray Voltage Guide*. Published September 2015. A collaborative effort between MREA, MP, MN Farmers Union, OTP, MN Dep of Ag, Cooperative Network, MN Farm Bureau, MMUA, Xcel, and the MN Dept. of Labor & Industry. www.minnesotastrayvoltageguide.com.

[2] More precisely 'impedance' instead of resistance. Impedance is the term that accounts for both resistive and capacitive attributes of a circuit, which are both relevant to accurate measurements. For simplicity sake, the more common term of 'resistance' is used here.

[3] Reilly, JP. 1998. *Applied bioelectricity: from electrical stimulation to electropathology*. New

Studies have demonstrated the relationship between the internal 'body resistance' and the total resistance of a body including its skin and electrode interface resistances. Over the course of the many experiments done on dairy cows, body resistance has been measured with a variety of pathways and contact methods. In some cases experiments were performed by implanting electrodes into soft tissues to eliminate skin resistance. Other experiments replicated more realistic exposures on farms, where a cow typically drinks from a metallic water bowl while standing on a concrete surface. At voltages representative of stray voltage contact levels the total *body and skin* resistance is about double the internal body resistance.[4]

The United States Department of Agriculture (USDA) published analysis of the resistances of various electrical pathways through cows in Handbook 696 (*Effects of Electrical Voltage/Current on Farm Animals: How to Detect and Remedy Problems)*.[5] The information drew upon peer reviewed research from several groups published over a period spanning more than 20 years. Based on these studies, the authors recommend a 500 ohm resistor be used for field measurements to represent the sum of the body, skin, and contact resistance, referred to herein more simply as the *cow and contact resistance*. Utilizing this resistance level in tandem with other standard testing procedures ensures stray voltage levels remain below what a cow can perceive in worst case real-life scenarios, such as wet conditions. Critically, this value has never been intended to represent only the cow body resistance, as suggested by those doing field test attacking these conclusions. Instead, 500 ohms has consistently been the level of resistance used to represent the combination of body, skin, and contact resistance.

Consistent Research Conclusions

Measurements of cow *and contact resistance* have been conducted by universities many times over several decades in farm-like conditions. This research has been reviewed by other scientists and researchers and published in peer-reviewed literature. In 2008, the Ontario Energy Board commissioned a comprehensive review of the research on the topic. This included reviewing 15 separate and credible university experiments, by 9 distinct research groups. This research clearly affirms the appropriateness of using a 500 ohm standard for *cow and contact resistance*.[6]

Perhaps the largest set of data measured in any one study was compiled in 2010 by a French research group, who obtained an average *cow and contact resistance* value of 516 ohms for cows drinking from an electrified water bowl and standing on a metal plate.[7] This same group found an average value of 1086 ohms for cows eating from an electrified feed bowl and standing on a metal plate. These values are in remarkable agreement with the recommendations of the authors of USDA 696 of 500 ohms for *cow and contact resistance* for 'worst case' (wet) conditions and 1000 ohms resistance for more typical conditions.

The Institute of Electrical and Electronics Engineers (IEEE) is a world leader in developing consensus based standards using an open and transparent process. They have developed over 200 standards with fair and balanced procedures, including the National Electrical Safety Code. They published the *IEEE Guide to Understanding, Diagnosing and Mitigating Stray and Contact Voltage*

York: Springer-Verlag; Fig. 2.8

[4] Reilly, JP. Fig. 2.15

[5] Lefcourt AM, ed. 1991. *Effects of electrical voltage/current on farm animals: How to detect and remedy problems. USDA Handbook 696,* U.S. Dept. of Agriculture, Washington, D.C., USA. Table 3.1

[6] Reinemann DJ. 2008. *Literature review and synthesis of research findings on the impact of stray voltage on farm operations.* Report prepared for the Ontario Energy Board, 31 March 2008. http://www.ontarioenergyboard.ca/OEB/_Documents/EB-2007-0709/report_Reinemann_20080530.pdf

[7] Rigalma K, Duvaux-Ponter C, Barrier A, et al. 2010. *Medium-term effects of repeated exposure to stray voltage on activity, stress physiology, and milk production and composition in dairy cows.* J Dairy Sci. 93:3542–52.

in July of 2016.[8] This publication occurred following a multi-year process considering all the research and perspectives available throughout the world. This open and transparent process required addressing all comments from any party wishing to participate, which included utilities, consultants, university professors, and regulators. No interest category, such as utility engineers, could comprise more than a third of the ballot pool approving the guide. This IEEE Guide once again confirms the appropriateness of using a 500 ohm resistor to represent the cow and contact resistance levels. It also supports the actionable thresholds, the levels of stray voltage at which action should be taken, and testing methodologies, called for by the *Minnesota Stray Voltage Guide*.

Recent Field Testing No Surprise

The recent field measurements in Minnesota, conducted by Mr. Neubauer, have been reviewed and discredited by Dr. Reinemann, who has conducted substantial research in this area. Upon reviewing these measurements, he noted:

> *The average nose-4 hooves average values obtained by Neubauer et al. are in the range of 200 Ohms or about 40% lower than the Mouth to all hooves values reported in USDA 696. This result is not surprising given the test methods used by Neubaurer et al. Neubauer et al. use a metal clip applied with considerable pressure to the soft mucosal tissues on the interior of the cow's nose. The cows are also standing on a sharp-edged metal grate. Neither of these is representative of real-world contact conditions and act to reduce or eliminate the contact resistance and skin resistance. The resulting 'body resistance' values are therefore not representative of the conditions occurring with real cows on real farms.*[9]

The claims resulting from these field measurements are not new. They are the very sort of misrepresentation mentioned by the authors of the USDA's Handbook. Dr. Lefcourt, who conducted stray voltage research and served as the principal editor of this handbook, included the research of essentially everyone working in the field at the time. He coordinated affirmation among those participants of its conclusions, including that, "We consider 500 ohms for the sum of contact and body resistances to be a very conservative estimate of the worst case, or minimum, resistance that is likely to be encountered." Revealingly, the contributors went on to note:

> *There were two primary reasons for publishing this handbook. First, we, as scientists, were distressed that our research results were being misinterpreted and misconstrued in media and in courtrooms. Second, we were disheartened by the animosity that sometimes arose among livestock farmers, dairy equipment manufacturers, and public utilities companies because of a lack of understanding of the causes and effects of stray voltages on farms.*[10]

The Public Service Commission of Wisconsin issued a letter in August of 2016 reaffirming the use of the 500 ohm resistor level in taking stray voltage measurements. The Wisconsin Commission, still addressing this same concern, concluded these testing protocols were necessary to "avoid needless controversy" and "recognize the various interests of all parties working on stray voltage analysis."

[8] IEEE Power and Engineering Society. 2016. *IEEE Guide to Understanding, Diagnosing, and Mitigating Stray and Contact Voltage* (Publication No. Std 1695-2016). New York, NY: IEEE.
[9] Reinemann, D. 2016. "Review of cow resistance measurement, resistance values, and estimation of cow current", affidavit of Dr. Douglas J. Reinemann, University of Wisconsin-Madison, Aug. 15, 2016.
[10] Lefcourt, AM, USDA Handbook 696

Partnerships Resolve Problems

Dairy farmers are member-owners of rural electric cooperatives, important electrical loads for utilities, and vital members of our communities. We all have a vested interest in their success. As noted in the *Minnesota Stray Voltage Guide*:

> *When farmers and utility companies work together, stray voltage concerns are more likely to be satisfactorily resolved.*

Helping farmers requires we put what we know to work to solve problems. The *Minnesota Stray Voltage Guide* was developed to establish common statewide approaches and standards for tackling these concerns. It was done through a collaborative effort to solve problems and help dairy farmers succeed. We continue to welcome genuine efforts to advance the interests of our farming communities. The unconstructive efforts to undermine these successes are counterproductive, erode trust, and hinder our work together in solving problems.

Sincerely,

Darrick Moe, P.E.
President/CEO
Minnesota Rural Electric Association