Paper No. 963072
An ASAE Meeting Presentation

RELATIONSHIPS BETWEEN SECONDARY NEUTRAL AND COW CONTACT VOLTAGES

by
Mark A. Cook , Daniel M. Dasho P. E. and Richard Reines
Public Service Commission of Wisconsin, Stray Voltage Analysis Team

Douglas J. Reinemann, Ph.D.
University of Wisconsin-Madison, Department of Agricultural Engineering

Written for presentation at the
1996 Annual International Meeting
sponsored by
THE AMERICAN SOCIETY OF AGRICULTURAL ENGINEERS
Phoenix, Arizona
July 14-18, 1996

Summary:

This 1700 farm data base comparison looks at the relationship between the source voltage and the cow contact voltage. The authors looked at the possible use of neutral to earth voltage as a predictor for the voltages measured at cow contact. Understanding this relationship can help in analysis of stray voltage.

Keywords: Stray Voltage, Measurements, Neutral to Earth Voltage

ASAE, 2950 Niles Rd., St. Joseph, MI 49085-9659 USA.
Voice: 616.429.0300 FAX: 616.429.3852

RELATIONSHIPS BETWEEN SECONDARY NEUTRAL AND COW CONTACT VOLTAGES

Introduction

A data base of over 1700 on-farm measurements of cow contact voltages and related electrical parameters has been compiled by the Public Service Commission of Wisconsin (PSCW). Most of this data has been reported to the PSCW from investor owned utilities in the state. The remaining data is from field investigations conducted by the PSCW stray voltage assessment team. This paper presents comparisons between open circuit voltages measured from the secondary neutral to remote earth and voltages measured at cow contact.

Stray Voltage is defined in the United States Department of Agriculture Handbook 696 (USDA, 1991) as a difference in voltage measured between two surfaces that may be contacted by an animal. Potential exposure of cows to stray voltage is defined in this paper as a contact voltage. PSCW orders have, however, referred to cow exposure as a current likely to flow through the cow. The accepted method of relating cow contact voltage and current is with measurements taken with a 500 Ohm resistor across cow contact points. This measurement method provides a worst case scenario for the current likely to flow through a cow for a given level of contact voltage.

The PSCW has recently held public and technical hearings (Docket 05-EI-115) to reassess its "level of concern" (LOC). The new level of concern is two milliamps of current flowing through a cow. The accepted measurement of this current is with a 500 Ohm resistor across cow contact points, translating into a cow contact voltage of 1 Volt. This is meant to be a very conservative level, not a damage level, but a pre-injury level designed to allow action to be taken prior to any adverse effect on the animals.

The National Electric Code (NEC) requires bonding of any metallic objects which could be energized for safety purposes. On a farm, this bond is made to the secondary grounded neutral system. Voltages measured at cow-contact are related to, but typically lower than, secondary neutral-to-earth voltages (NEV).

The NEV measured at the primary (Vp) is a combination of sources from the utility system neutral and typically multiple the on farm sources. Each on farm service contributes a source voltage of it own due to secondary neutral voltage drop (Vps) on the service conductors. If a farm has ten service drops, there are eleven potential voltage sources. One being the utility system and the others are the ten on farm services. This concept can be extended to each branch circuit on the farm. If this same farm has 40 branch circuits then the possibility exist that there will be 51 source voltages. A portion of these source voltages can show up at all of the measurement points on the farm and utility system. It is therefore not possible to determine the source of a cow contact voltage (Vcr) without a detailed investigation.

These results are presented to help dairy operators and stray voltage investigators better understand the causes of and cost effective solutions for stray voltage. Any serious attempt to

investigate and possibly recommend measures to reduce neutral to earth voltage must include based on sound electrical principles, accurate measurement methods. The occurrence of neutral to earth voltage and current flow on neutral and grounding conductors are unavoidable consequences of the use of electrical power. Complete elimination of these phenomena is an unreasonable and costly goal. As NEV is always a combination of multiple on and off-farm sources, accurate determination of these sources is essential before recommending any mitigative action.

Measurement Technique

The PSCW has defined a common measurement technique to be used by all Investor Owned Utilities for purposes of reporting the results of their stray voltage investigations which make up the database analyzed here. Five (5) measurement points are required to perform these tests:

1. A remote reference ground rod. Place the remote reference a distance of three to four times the depth of any buried metallic structure connected to the service entrance neutral (i.e. 24 to 32 feet away from an 8 foot driven ground rod). For grounded metal objects which are buried very deep, such as well casings, field experience has shown that a distance of 100 feet is usually satisfactory. If the remote reference ground rod is positioned as indicated it should measure within 5 % of the secondary neutral to true earth voltage. The same remote reference ground rod should be used for all reference ground measurements.

2. A connection to the transformer neutral grounding electrode, usually the conductor from the primary neutral to the primary neutral grounding electrode at the primary end of the circuit.

3. **A connection to the ground bus in the service entrance panel supplying power to the animal confinement area.**

4. A connection to the metallic structure(s) which the animals contact in their normal daily experience (typically the watering bowls).

5. A connection to the floor on which the animal stands.

Measurements of the secondary neutral-to-earth voltage (Vs, measured from point 3 to 1 above)[1] and primary neutral-to-earth voltage (Vp, measured from point 2 to 1 above) are made without a shunt resistor (open circuit). Measurement of animal contact voltage (Vcr, measured from point 4 to 5 above), are made both with and without a shunt resistor to determine the source resistance (Rs). The recommended value of the shunt resistor is a nominal value of 500 Ohms, some investigators use multiple resistance values when making measurements (e.g. 350, 500, 1000 Ohms).

[1]. Terms are defined in Appendix A.

A parameter of interest is the ratio of the animal contact voltage to the secondary neutral-to-earth voltage. The animal contact voltage, Vcr, will usually be less than the secondary neutral-to-earth voltage, Vs. This ratio is referred to in this paper as the K factor and can be measured both with a shunt resistor(Kwr = Vcr/Vs) and without (Kwor = Vc/Vs) at the cow contact measurement point.

The following method should be used when determining the value of K:. If the farm is bonded (not isolated) turn off all on-farm loads by opening the yard pole switch or turning off all breakers serving farm load. In this condition, the voltage measured in the animal contact (Vcr) areas will be due solely to the voltage measured at Vs regardless of it source

It is recommended that a 240 volt resistive load box with a minimum 50 amperes rating be used for this test. A convenient place to connect this 240 V load is to the line side of the secondary main disconnect with all farm load off. Turn on the 240 volt load and record Vs and Vcr and compute Kwr. Then remove the shunt resistor from the animal contact location, record Vs and Vc and compute Kwor. The K ratio determined in this way will be the same for both "Off-farm" and "On-farm" sources.
If the farm is not bonded (isolated) substitute the 240 volt load for 120 volt on farm load. If any changes are made in the primary or secondary systems, testing must be repeated and the value of Kwr recalculated.

Relationship between secondary NEV and cow contact voltage across farms

In a previous study by Southwick et al, (1989) associations were made between neutral to earth and cow contact voltages. They found a small positive correlation between NEV and cow contact measurements. The authors concluded that only 8% of the variation in cow contact voltage could be explained by the NEV. The Pearson correlation coefficient was .29 based on the 84 farms studied.

Data from the PSC database are presented in figures 1 and 2 and Table I. The average of the secondary neutral to earth voltage measurements was 1.3 volts, with the vast majority of reading below 2 Volts. The average of the cow contact voltage measurements (Vcr) was 0.43 volts, with the vast majority of reading below 1 Volt.

Of the 1700 farms in the data base, 98% of the time Vcr was less than Vs. However, 2% of the time Vcr is greater than or equal to Vs. This can occur when the reference ground rod is placed to close to the voltage source being measured or the major source of NEV is very near the cow contact measurement point??. Or when the barn has multiple services that are not bonded together.

Table 1: Summary of the data from the 1700 farms in the PSCW data base.

	Rs	Shunt Res	Vp	Vs	Vcr	Vc	Kwr	Kwor
Median	179	502	1	1.03	0.261	0.374257	0.302623	0.433007
Max	1250	663	9.48	10.98	6.3	9.633301	7.849462	10.84796
Min	55	360	0.01	0.01	0.0005	0.000609	0.000347	0.000414
Mode	500	500	0.5	1.2	0.2	0.2	0.25	0.333333
Mean	216.6538	503.1914	1.23629	1.303906	0.435293	0.603665	0.397414	0.568607

Figure 1. Secondary Neutral to Earth Voltage (Vs) on 1700 Wisconsin Farms

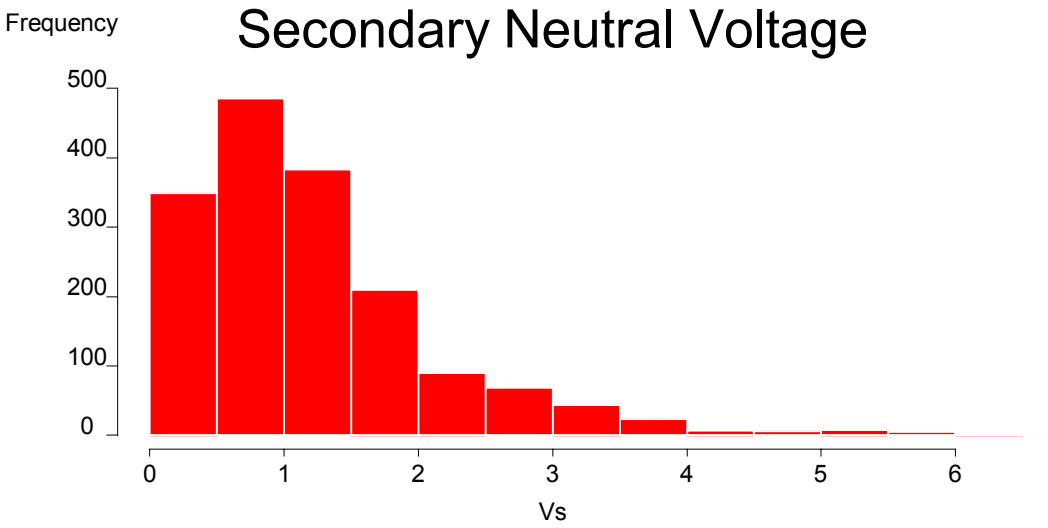
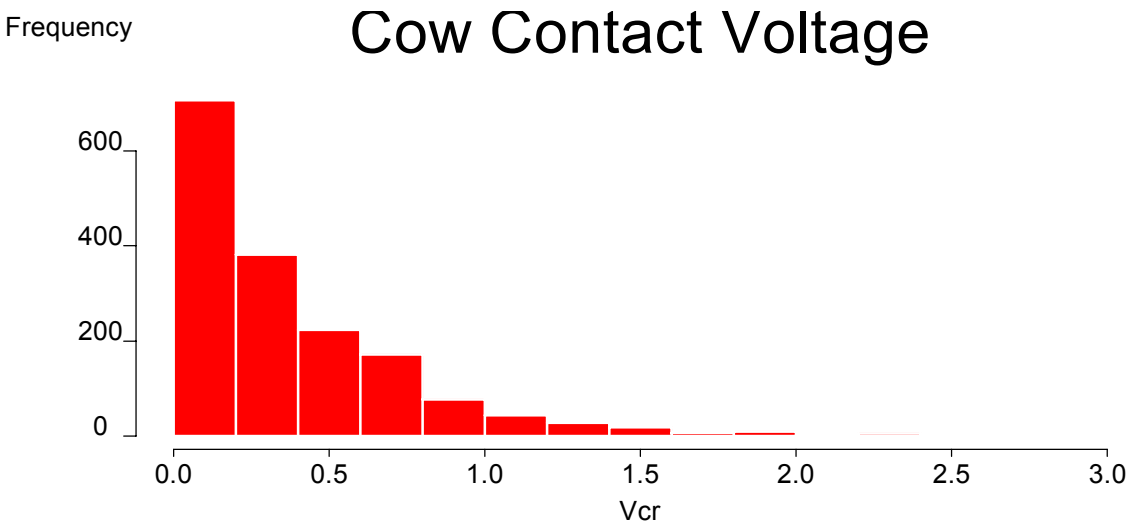


Figure 2. Cow Contact Voltages (Vcr) on 1700 Wisconsin Farms.



Regression analysis was done using Vs as the independent variable and Vcr as the dependent variable. The results of this analysis are shown in Table II. While the p values indicate that the correlation coefficient is significant (different from zero), The Pearson Product Moment Correlation (R2) shows that only about 50% of the variation in cow contact voltage could be explained by Vs. The visual residual analysis revealed no non-random trend which indicates a constant variance. The correlation between Vs and Vcr is higher than that observed by Southwick et al, (1989), however Vs is still a poor predictor of Vcr.

Table II:

	All Data	> 0.5 volts	> 1.0 volts	>1.5 volts
P	< .001	< .001	< .001	< .001
R squared	0.5	0.51	0.59	0.55
N	1700	533	145	60

Relationship between NEV and cow contact voltage on an individual farm over time

Field data has shown that the Kwr across 1700 farms is usually between 0.2 and 0.5 but in unusual cases can range from 0.0003 to greater than 1. Further investigation was performed to determine if the value of Kwr changed on an individual farm as the various source voltages change with time (i.e., changes in electrical loads both on the farm and on the distribution system).

Data from 10 farms on which Vs and Vcr had been measured over 24 hours were evaluated. On theses 10 farms over 80,000 matching measurements were analyzed. The data was matched using event times from the Waverider Data System. If an event occurred at Vs and Vcr simultaneously the data points were used in the Kwr factor study.

Regression analysis produced a value of R2 of 0.98 for all farms (Figure 3). We can therefore conclude that Vs is a good predictor for Vcr on any individual farm if the Kwr factor has been measured as described above. However, if any changes are made to the farms wiring system or the utility grounding system, Kwr must be re-measured.

Figure 3. Vs versus Vcr for individual farms.

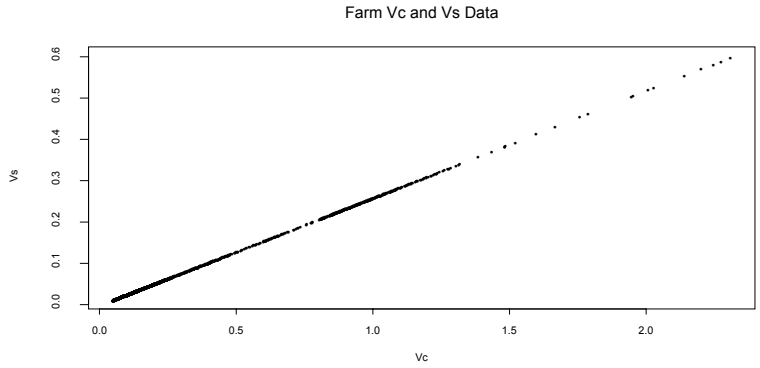
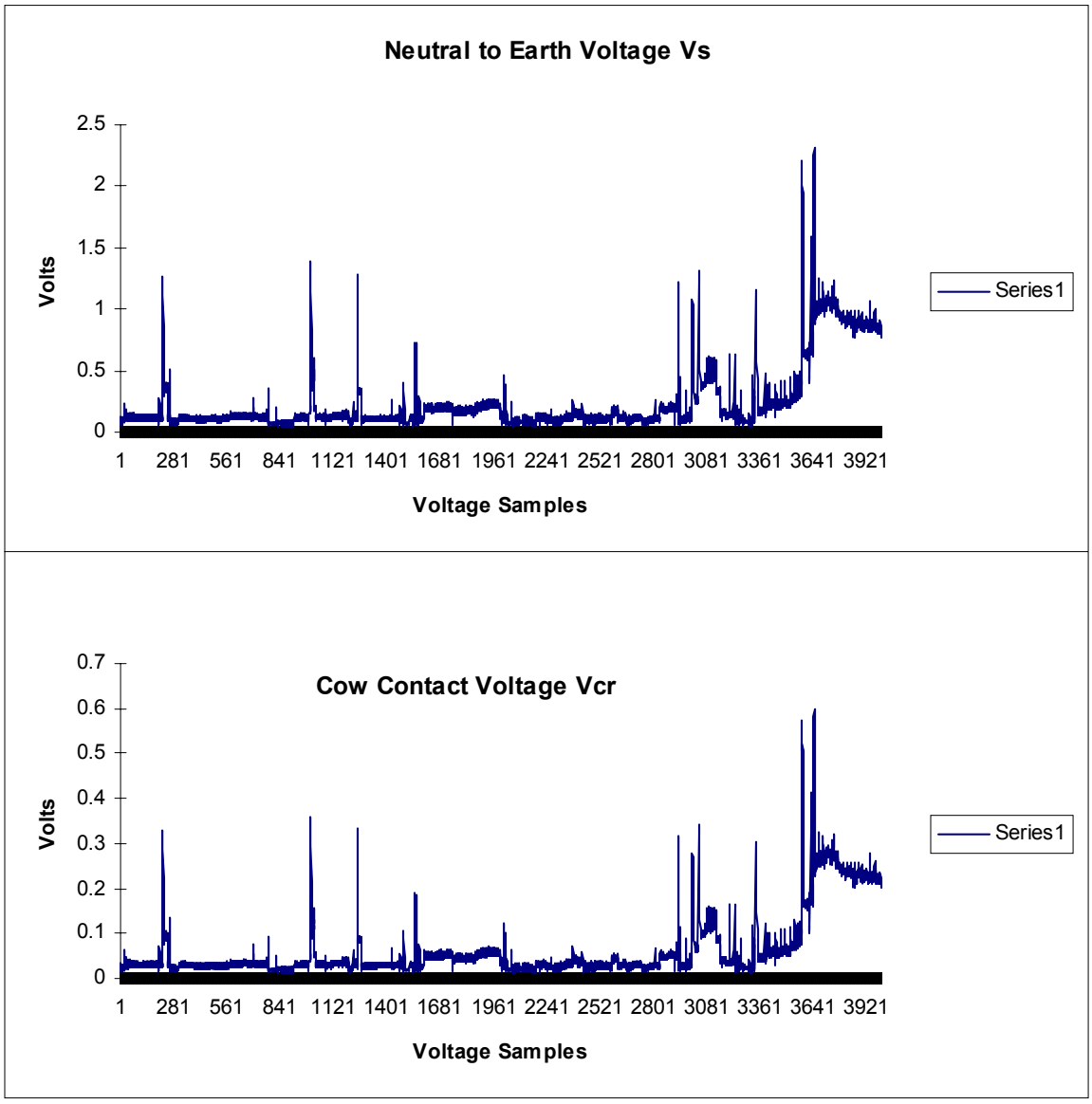


Figure 4. Vs and Vcr Data from the Waverider data acquisition System.



summary and Conclusions

Wisconsin stray voltage investigators found that on 80% of farms, the ratio between secondary neutral and cow contact voltage (Kwr) was less than 0.50. The average value of Kwr was for this database is 0.39. Less than 2% of the farms measured had values of Kwr greater than or equal to one.

Table 3: Kwr factor frequency table.

Kwr Factor	< 30%	< 40%	< 50%	> 50%	> 100%
Frequency	51%	66%	80%	19%	2.00%

The correlation between Vs and Vcr across farms is too low to use secondary neutral to earth voltage (Vs) as an accurate predictor of cow contact voltage (Vcr). Testing needs to be conducted by skilled investigators on all farms to determine the levels of Vcr.

On individual farms, however, Vs can be to predict Vcr if the Kwr ratio is measured as described here. This can be a useful tool for stray voltage investigators and dairy operators.

REFERENCES

NFPA 70, 1993. National Electrical Code, National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02269.

USDA 1991. Agriculture Handbook No. 696, Effects of Electrical Voltage/Current on Farm Animals: How to Detect and Remedy Problems. U.S. Government Printing Office. A. Lefcourt, 1991.

Cook M. A., D. M. Dasho, W. K. Dick, D. J. Reinemann, and D. F. Winter 1994, Distinguishing Stray Voltage Contribution From" On-Farm" and" Off Farm" Sources. ASAE Paper No. 943065

Southwick L. H., English P. B. , Sears P. M. 1989, Association Between Neutral-to-Earth and Cow Contact Voltage on New York Dairy Farms. J Dairy Sci 72-2417-2420

Appendix A

Vp Voltage neutral-to-earth measured at the transformer (V)
Vps Secondary neutral voltage drop measured from Vp and Vs. (V)
Vs Secondary neutral-to-earth voltage measured at farm service entrances. (V)
Vc Animal contact voltage measured without shunt resistor (V)
Vcr Animal contact voltage measured with shunt resistor as required by PSCW (V)
Kwr Ratio of animal contact to secondary neutral-to-earth voltage (Kwr = Vcr / Vs)
Kwor Ratio of animal contact to secondary neutral-to-earth voltage (Kwor = Vc / Vs)???
Rs Source resistance of animal contact location (Ohms)
Ic Maximum current likely to flow through an animal in contact with Vcr (A)
Ra Resistance of shunt resistor used to simulate animal resistance (Ohms)
Rsn Secondary neutral resistance (Ohms)