AGRICULTURAL SYSTEMS ENGINEERING

Agricultural and Structural Engineering

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Farmstead Engineering, Livestock Housing
Manure Management, Ventilation Systems
Mastitis Control, Grain Handling/Storage
Electrical Systems, Extraneous Voltage
Milking System Design/Evaluation

EXTRANEOUS VOLTAGE

DOCUMENT REVIEW

Documents Pertaining to
Farms of Lonnie Nelson and Darrell Franze

Report Prepared on Behalf of and Submitted to
Minnesota Department of Public Service

ASE Project No. 702:9307

Prepared by:
Gerald R. Bodman, P.E.
August 29, 1993

I hereby certify that this plan, specification, or report was prepared by me or under my direct supervision and that I am a duly Registered Professional Engineer under the laws of the State of Minnesota.

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Date 8/29/93 Registration No. 17199

Consultant's Report

The purpose of this report is to present responses to three documents which were submitted by the Minnesota Department of Public Service. The three documents are : (1) Lake Region Reply Comments, dated July 26, 1993; (2) Letter from Harold A. Cloud, dated August 1, 1983 (sic); and (3) Dan D. Mairs, P.E., letter, dated July 22, 1993. A written response was requested. Several points of particular interest were identified.

The documents pertain to tests which were conducted on the Nelson and Franze farms in December 1992 and May 1993, and to other documents which have been presented to the Public Utilities Commission by the Minnesota Department of Public Service. All documents relate to the subject of extraneous voltage.

RESPONSE TO LAKE REGION REPLY COMMENTS

Introduction--On Page 1, Lake Region states that because there were a number of changes, it is difficult, if not impossible, to attribute any particular difference in test results to particular change or modification. The argument that cause cannot be identified because of multiple changes is not totally valid. If this argument is accepted, we would then of necessity have to find that any after-the-fact testing in any situation would be invalid, since conditions are always changing. Use of the procedures of differential diagnosis and process of elimination; the application of engineering principles, knowledge, and logic; and one's experience to each change and what effects it most likely would cause allows us to come to a reasonable conclusion within the realm of engineering probability as to cause-and-effect relationships. These procedures were utilized in developing the conclusions set forth in our July 12, 1993 report.

Initial Data (Page 2)--Failure to have provided a copy of the data gathered during the initial test set-up was an apparent oversight on the part of the testing personnel. It is acknowledged that some erroneous numbers can occur as various connections are being made. However, it is unreasonable to assume that problematic conditions would exist or could occur on the farm only during a designated test period. If this approach is considered valid, one must then assume continual monitoring is the only way in which valid data could ever be collected. At the same time, we acknowledge that care is necessary to assure that any erroneous data associated with the test set-up procedures are properly identified and subsequently discarded. However, if or when problematic conditions should occur during the test set-up and be repeated at other times, whether or not they occur during the "official" testing interval, they might reflect conditions which are intermittent in nature. Thus, they cannot and should not be arbitrarily discarded.

Animal Behavior (Page 3)--Lake Region's position that various complaints of the farmers would justify their having witnesses present to attempt to document those various conditions, including cow behavior, seems to have some logical support. The greatest deficiency was the presence of the witness and the submission of those data without such procedures being part of the agreed-upon protocol. At the same time, the data suggest the problems have been at least in part rectified. Thus, observations during the May 1993 testing very well may not be supportive of or consistent with what the owners have previously claimed existed or occurred under the pre-correction conditions.

Complainant's Comments (Page 4)--Care must be exercised in discarding or discrediting producer observations and comments simply because they appear to be "unsubstantiated allegations." We must recognize that most producers are not equipped with the specialized scientific testing instrumentation nor do many of them have the professional training and background that is sometimes necessary to fully assess a problem. Nonetheless, observations of those who were present on a day-by-day basis are part of the overall data base and must be considered as one attempts to fully understand, evaluate, diagnose, and correct problems.

Non-Testing Period Data (Page 4)--As noted previously, we cannot assume that all problematic conditions will occur only during an arbitrarily or conveniently designated testing period. Consequently, data which are generated during other time intervals must also be considered, although care is necessary to assure proper interpretation, i.e., we must eliminate data which are erroneous because of lead connections, non-typical loadings, etc.

Farm Site Grounding (Page 5)--Let's not confuse the position of the complainants to eliminate the extraneous voltage from their farms with methodologies by which such control can be effected. The complainants must, of course, recognize that achieving a zero level of voltage or current in their farm is not a realistic expectation. Even if all electrical service to the farm were to be eliminated, it is probable that some low level of both alternating and direct current would be found in various conductive paths on the farm. This is due to the impossibility of controlling all flow paths once current enters the soil and because of the multiple sources of direct current which are present on all farms. Our challenge must be to eliminate the voltages and currents which are of a problematic magnitude within the animal environment and then with proper testing be able to demonstrate to the producers that such low levels have been achieved and that the effect on their animals is non-existent or at least negligible.

Equipment Calibration (Page 5)--The use of bench testing is a satisfactory method of determining calibration of equipment if performed properly. Recognizing that the data collection system would print out "uncalibrated data" notations, the procedures and results of this pre-testing verification of performance should have been included in the original data report. Test data should have been provided to show that the system was operating within its specified performance parameters despite the fact that it has not been recently calibrated per official procedures. The concept of cross-testing within the machine itself is unclear. Does this mean one channel was checked against another? Were multiple channels subjected to the same voltage or currents to determine whether the print-outs were the same? A request for a more detailed description of what this entails is warranted.

Data Comparison (Page 6)--The statement that "the results of the December and May tests are comparable" is inconsistent with the argument presented on Page 1. If the argument presented on Page 1 that data cannot be compared because of changes made on the electrical system is correct and valid, then the statement on Page 6 that the data are comparable is incorrect and invalid. While it would be nice if we could, we really cannot have it both ways. More specifically, we cannot pick and choose when to accept or discredit the data and test results.

Similarity of Readings (Page 6)--The data do not clearly indicate when tests were being conducted with primary and secondary neutrals bonded or separated during the May 1993 tests. (Some tests and notes suggest no tests were run with the neutrals bonded during the May tests.) Additionally, different points were monitored. One comparison is the waterline to reference ground voltages. On page A5.5.11 a voltage of 0.16 Vac was recorded. Similarly, on Page A5.5.12 a voltage of 0.61 Vac was recorded. On Page A5.5.13 a voltage in excess of 1.0 Vac was recorded. By comparison, during the December tests when the neutrals were bonded (Test No. 9), the voltage was 1.486 - 1.664 Vac. When a 300-ohm resistor was put in the cow circuit (Test No. 15), the voltage was 0.609 - 2.91 Vac. With separated neutrals and a 300-ohm resistor (Test No. 19), the voltage was 0.226 - 0.254 Vac. When an air gap separation and 300-ohm resistor were used (Test No. 26), the voltages were 0.115 - 0.174 Vac. Thus, it is possible to find conditions when the voltages recorded during the December and May tests were similar. Given the lack of clarity relative to the May tests, it is not clear that these are, in fact, comparable conditions.

Secondary Neutral Current (Page 7)--I agree that the high level of secondary neutral current is beyond the control of LRCEA.

Phantom Voltages (Page 7)--While it is possible that equipment can generate false signals due to the internal circuitry, attempting to discount all of the impulses as phantom voltages, which were presumably self-generated by the BMI equipment, does not seem to be consistent with the data reported. In their comments, LRCEA notes that the transient voltages occurred between 2:00 and 3:00 p.m., but that thereafter the BMI threshold was reset and subsequently no phantom voltages were recorded. Resetting the threshold does not necessarily eliminate the voltages if, in fact, they were valid. Note, however, that on Page A6.5.8 a surge voltage of 8.9 Vac occurred at 3:33 p.m. It was also stated previously that the phantom voltages of concern were of a 2.2 Vac magnitude. Consequently, the argument that all elevated voltages were due to transients does not appear to be supported by the data. Further, if the problem of phantom voltages was corrected on May 24, there should have been no such voltages occurring on May 25.

Transient Energy Level (Page 7)--Merely stating that "Transients were not of sufficient energy to affect the electrical environment to the livestock or the cows" does not substantiate that, in fact, they were non-problematic. As far as could be determined from the data, no tests were conducted to verify or substantiate this conclusion.

Effects of Transients (Page 8)--To claim that a low energy level and short duration voltage automatically means insufficient energy to elicit an animal response is incorrect. Although no one has ever been electrocuted or suffered serious harm when they received a shock after walking across a carpet and touching a doorknob, one can hardly argue that such electrical impulses do not alter our behavior.

Timing of Voltage Surges (Page 8)--All voltage surges did not occur during test set-up interval as claimed by LRCEA. In contrast, some of these occurred during the actual tests. For example, on Page A6.5.12 there are impulse voltages ranging from 2.4 - 3.3 Vac, which occurred between 1627 and 1655. According to the time log, this was during Tests NB5 thru NC5.

System Impedance (Page 8)--Admittedly, a system with an impedance of 1.6 ohms would normally be considered a low resistance system. There is still reason to question the method by which these numbers were determined. General guidance can also be obtained from the 1993 edition of the NESC. Section 96 on Page 25 states "Grounding systems shall be designed to minimize hazard to personnel and shall have resistances to ground low enough to permit prompt operation of circuit protective devices." Similarly, on Page 6 the following definition of effectively grounded is given: "Intentionally connected to earth through a ground connection or connections or sufficiently low impedance and having sufficient current-carrying capacity to prevent the build-up of voltages that may result in undue hazard to connected equipment or to persons."

Admittedly, the NESC does not directly address the needs of animals other than persons. However, it seems reasonable that one could construe the intent of the NESC to also require conditions which do not pose problems to livestock as property.

Regardless of actual impedance tests, the primary neutral-to-reference ground voltages are indicative of problems on the system. I disagree that lowering the impedance of the systems would require additional grounding at the farm sites. Lower impedance can be achieved by improved grounding anywhere along the line between the substation and the subject farms, by increasing neutral conductor size, improving the quality of connections between the farm sites and the substation, and by improving the balance of the three-phase system to reduce neutral current.

The statement that application of Ohm's Law to a resistance of 1.6 ohms and the on-farm current flow would result in the voltages measured seems to be without basis. I found no indication of on-farm loads being sufficient to cause a voltage of 10 Vac on the primary neutral even if that current were flowing through a 1.6-ohm resistor. Achieving that level of voltage (10 Vac) would require a current flow of 6.25 amps on the primary neutral. Given the 30:1 ratio in the transformer windings, that would require an on-farm current usage in the range of 180 - 190 amps. No data have been submitted to indicate that loads on the farm were sufficient to result in that magnitude of current flow.

Primary Neutral Voltage (Page 9)--There appears to be an error in the last sentence of Category VII on Page 9. The word "to" should apparently be deleted. Otherwise I concur with the statements.

Step Potential Voltages (Page 9)--It was noted previously that the leads to the BMI Channel recording step potential voltages was disconnected between 1554 and 1810 (6:10 p.m.) It should be noted that on Page A5.5.20 a step potential impulse voltage of 2.4 Vac was recorded at 1909 (7:09 p.m.). Another 2.5 Vac voltage peak was recorded on Page A5.5.21 at 1918 (7:18 p.m.). Thus, LRCEA's statements that all such voltage surges occurred at times when the leads were either disconnected or during non-testing periods is incorrect. Further, as previously stated one cannot ignore voltage impulses just because of an arbitrarily selected testing interval. Care is always necessary to assure that the voltages were not associated with changes in equipment. Such does not appear to be the case in this instance. The test log makes no mention of equipment modifications.

Influence of Resistor on Surge Voltages (Page 9)--The statement is made that because no 300-ohm resistor was in the circuit, the voltage impulses are somehow not valid readings. While it is possible that a similar ratio in reduction of voltages would occur, as was shown with the RMS values, one cannot be certain this would occur in all instances.

Need for Isolation (Page 10)--I will stand by my original recommendation and conclusion that the test data indicate a need for continued isolation devices on both farms. As noted in some of the previous examples, cow contact voltages are elevated at times during the various tests. This was particularly true because of the impulse voltages which appear to be present on the system.

On-Farm Wiring (Page 10)--Our support of the need for improvement in the on-farm wiring on the Nelson farm and the balancing of on-farm loads is continued. In this regard, we are fully supportive of the LRCEA recommendations.

Milk Film Conductivity (Page 13)--There is no validity to the statement that the milk film in the receiver is not an effective conductive medium for stray voltage. The statement is contrary to instances where current flow through both plastic and rubber milk hoses has been measured. It is also contrary with the practice of using milk conductivity to operate milk pumps, system wash cycle function, automatic milking unit removal systems, the use of milk conductivity as a measure of infection level on a particular cow, etc.

Supply Voltage (Page 14)--Although I was unable to locate the reference, a supply voltage of 120 V ±5% is, indeed, considered a normal and accepted voltage. This, I believe, is the accepted standard of the Rural Electrification Administration. Thus, if LRCEA is an REA borrower, they are bound by the same rules. NEC Article 220-2 states that the voltages to be used for design purposes, i.e., nominal system voltages, include 120, 120/240, etc. The NEC further states that the voltage drop should be limited to 5%. Such recommendations are made in the following sections: 210-19(a), 215-2, 230-15(b), and 310-15(b).

LRCEA's statement that more voltage drop is to be expected because of the greater distance from the transformer to the service is incorrect if good design principles are used. The voltage drop can be controlled for any current by simply properly sizing the service conductors. This is illustrated by the voltage drop tables taken from the *Agricultural Wiring Handbook*. A copy of Tables 16 and 17 from the 1993 edition of the *Agricultural Wiring Handbook* showing a 2% voltage drop for both copper and aluminum conductors for currents ranging from 5 - 400 amps and for distances up to 800 ft. is attached.

Engineering logic obviously concludes that voltage drop will be greater under load conditions than under no-load conditions. However, if the system is properly installed as recommended by the *Agricultural Wiring Handbook*, the supply voltage will be acceptable under both loaded and non-loaded conditions. The concern is that a 5% decrease in voltage will result in a 25% increase in heat generated by electrical equipment. In the case of some electric motors, this can be sufficient to significantly shorten the service life of the equipment. Electronic equipment in terms of automatic detachers, pulsation control, and other forms of control circuitry are common on many farms. The extent to which such equipment is present on the two subject farms is not known.

As stated in our earlier report, verification of the adequacy of the conductor sizes for the length of the service drop and the capacity of the farm service cannot be determined from the information provided. Presumably, this information has been filed with the Public Utilities Commission. Review of those data is recommended in order to prolong the service life of the equipment on both farms.

Test Conditions (Page 15)--At this time, the LRCEA states that the May conditions were done with the neutrals isolated. That being the case, the voltages reflected are even more problematic as they indicate either on-farm faults or a lack of complete separation between primary and secondary neutrals. They once again state "that direct comparison cannot be made." This is in direct conflict with their position on previous pieces of data. It is also interesting to note that during the December tests, voltages with the neutrals separated either via a Ronk Blocker or an air gap were in the range of 0.1 - 0.35 Vac (Tests No. 17 thru 46). The comparable voltages on the Nelson farm were from 0.03 - 0.26 Vac during the December tests (Tests No. 35 thru 52). Test No. 68 showed a voltage up to 0.26 Vac.

Primary Neutral Voltage (Page 17)--It is acknowledged that the voltages recommended by Agricultural Systems Engineering are not official standards adopted by the electric utility industry. At the same time, it is interesting that LRCEA has chosen to adopt a standard from Ontario vs. a standard used by other utilities, even those that are self-imposed or self-developed. Given the statement that LRCEA accepts this standard, they should be asked to produce their documents showing when this standard was accepted as their own operating guideline.

Influence of Neutral Separation (Page 17)--I concur that when the neutrals were separated, there was little or no influence of primary voltage in the barn. This only supports the position stated previously that isolation must be maintained and continued until the quality of the primary distribution system is increased or improved.

Secondary Neutral Current Flow (Page 17)--The statement extracted from Agricultural Systems Engineering report and identified as Item 9 is correct; however, the position of the LRCEA as a response thereto is incorrect. The response does not correlate with the statement in any manner. The statement referenced is relative to secondary neutral current flow. The response is relative to voltage spikes and of very small amperages.

Problematic Impulses (Page 18)--The data on Page A6.5.2 is set forth for two different times. One is from 8:00 - 9:00 a.m. The other is 1:52 p.m. Depending upon the operation of the system, these voltages could be those that were logged between 8:00 and 9:00 a.m. and simply printed out at 1:52 p.m. However, Page A6.5.3 shows a step potential pulse of 24 Vac (2.4 Vac with multiplier of 10 applied). These voltages were supposedly recorded between 2:00 and 3:00 p.m., though the print-out indicates the chart was obtained at 2:40 p.m. Consequently, there is inconsistency between the data. How can one print out data covering the time period from 2:40 until 3:00 prior to 3:00 p.m.? A corresponding hoof-to-hoof voltage of 0.9 Vac RMS was recorded at 2:22 p.m. Given these data, my conclusions remain the same regarding the influence of voltages on the cows and the presence of voltages in the animal environment.

Occurrence of Impulse Voltage (Page 19)--LRCEA's statement that impulses did not appear once the BMI equipment was reset and that such problematic voltages occurred only prior to the official testing at 2:23 is incorrect. On Page A6.5.3 the problematic voltages are shown as having occurred at 2:26 p.m. and 2:22 p.m. for the step potential and hoof-to-hoof voltages, respectively. These voltages are by their own acknowledgement after the start of the official testing. Further investigation of step potential voltages is recommended.

Bonded vs. Unbonded Tests (Page 20)--As noted in a previous item, there are sufficient numbers of tests and sufficient common points between the December and May tests to allow comparisons of some voltages. The May tests still reflect, in general, voltages which are lower than those measured during December 1992 testing for similar system conditions.

Digital Voltmeter Readings (Page 20)--While it is true that with a fluctuating voltage a digital voltmeter might vary readings, I do not concur that readings displayed are necessarily erroneous. If, in fact, there was reason to believe the readings in these instances were erroneous, they should have been so noted. One must rely on the integrity of the individual recording the voltage that the numbers recorded are, in fact, valid numbers. To claim improper equipment operation after the fact with no verification of such statements is inappropriate. It does suggest, however, that the voltmeter saw readings which exceed even the standards the LRCEA claims they use, i.e., a maximum of 10 Vac.

System Impedance (Page 21)--I concur that the impedance calculations reflect the combined effect of grounding resistances, reactances, etc., of the primary neutral system. However, I disagree that a direct reading by any other method is not possible. I have worked with Bill English from the Michigan Department of Public Service on several on-farm testing situations where he used the calculation method and I used an AEMC ground resistance testing meter and arrived at similar values for impedance (within 0.1 ohms). However, with the calculation method it was important that the readings be taken at precisely the right moment because of variability in the system. In contrast, the use of an AEMC ground resistance meter gave repeatable readings at different times regardless of system loading.

Intermediate Regulator (Page 22)--The purpose of regulators and capacitor banks is to provide stable voltage while some rises and falls will occur as system loads change. The equipment is expected to maintain voltages within a given range. The particular range must be selected and the ability of the equipment to maintain that voltage will be dependent upon its design. Without consulting the manufacturer's specifications, one cannot determine what the appropriate variations might be for a given installation. However, the wide variations which were reflected in this instance do suggest a malfunction of at least one electrical system component.

Significance of Waterline to Reference Ground Voltages (Page 23)--In the response to Item 20, LRCEA states that the cow contact voltage is significant. Their basis for this is unclear but it does raise questions regarding the voltages recorded and some of the earlier claims that no problems exist on this farm.

Waterline to Reference Ground Voltages (Page 23)--I disagree with LRCEA's conclusion that the voltages in December were similar to those in May under isolated conditions. During the December tests, voltages between the waterline and the reference ground with the neutrals bonded ranged from 0.609 - 2.312 Vac (Tests No. 8 thru 15). With the neutrals separated, the voltages varied from just under 0.1 - 0.354 Vac (Tests

No. 17 thru 46), except when the farm power was turned off. Voltages of 0.029 - 0.236 Vac were recorded during Tests 61 thru 74. Thus, the voltages under comparable system conditions were lower in May 1993 than in December 1992, as originally stated. I disagree with the conclusion drawn by the LRCEA.

<u>Secondary Neutral Current Flow (Page 24)</u>--Regardless what loads were operating, a secondary neutral current flow of 22 amps is excessive and should not be tolerated.

<u>Neutral Current (Page 25)</u>--The second graph actually shows current of approximately 1 - 2 amps during the majority of the time (approximately one hour). These tests were conducted during the beginning of milking and reflect very good system balance on this farm.

<u>Primary System Sensitivity to On-farm Loads (Page 26)</u>--The conclusion originally reached regarding the need for improvements along the primary distribution system is re-stated. Additional grounding in the immediate farm vicinity is not likely to reduce this voltage to an acceptable level. More substantial changes involving re-conductoring, balancing of three-phase system loads to reduce current flow in the neutral, or improvement of connections between the farm and the substation are most likely going to be required to reduce voltages to an acceptable level.

<u>Step Potential Voltages (Page 27)</u>--I cannot find any data which substantiate the statement that the voltage is an open circuit voltage with insignificant energy content to produce current of a problematic magnitude. While it might be an open circuit voltage, I can find no data where they verified the current-producing potential of this voltage source. This same statement and response apply to the statements on Page 28 of their response. While it is possible that we might find the step potential voltage to be caused by a poor current-producing source, one cannot assume such to be the case.

<u>Step Potential Impulse (Page 28)</u>--While the argument presented by LRCEA could logically apply to the voltage referenced in this section, it does not apply to the 2.5 Vac peak voltage recorded at 1852 hours. Thus, despite the attempt by LRCEA to discredit the individual point-by-point data or by some methodology to reconstruct what was happening at particular points in time, the repetitive nature of these impulses still leads to them being considered a problematic voltage source.

<u>Waterline to Reference Ground Impulse Voltages (Page 29)</u>--As with the step potential voltages, it does appear correct that the particular voltage referenced in the report prepared by Agricultural Systems Engineering was recorded during the impedance tests and, thus, do not indicate normal operating conditions. Similar voltages were recorded as shown on Page A5.5.15 (5:00 p.m.). Thus, the ruling out of a particular voltage as being during non-standard conditions does not automatically rule out unacceptable voltages at other times. The data

clearly indicate that such impulses occurred at times other than during the impedance tests. These voltages are still considered potentially problematic.

Primary System Deficiencies (Page 30)--It is still my opinion that the voltages recorded at times other than during the impedance tests are indicative of deficiencies on the primary distribution system.

Primary Neutral Current Flow (Page 31)--The statement made that all current returns via the primary neutral system under isolated conditions would be true if, in fact, there were no grounding connections on the farm. The presence of even a single grounding electrode and ground rod on the farm will result in a division of current flow. Thus, LRCEA's statement and their emphasis that all current flows over the primary neutral system is not correct. On the other hand, using a broad spectrum interpretation of primary neutral system, one could argue that the soil on the farm becomes part of the primary system grounding by virtue of the grounded conductor. While that is technically true, we must also recognize that once the current enters the soil, there is no way to precisely determine the flow paths. On these particular farms it appears that much of that current flow path is through the livestock environment.

Impulse Voltage Source (Page 31)--I disagree with the conclusion that all impulse voltages were self-generated. The source of this voltage was supposedly eliminated, yet voltages on the Franze farm continued to occur. Similarly, if the source was corrected, then there should have been no impulse voltages on the Nelson farm the following day. The data did not reflect that this was the case. Thus, LRCEA's statement and disagreement with Conclusion No. 6 is appropriate and incorrect.

In conclusion, there are many inconsistencies in LRCEA's response to the reports which were previously submitted. For whatever reason, they appear to have chosen to address specific data points and ignore what was happening at other times. Simply saying that a voltage occurred during a "non-official test period" does not eliminate the significance of that voltage. Their apparent attempt to write off all voltage spikes as being phantom voltages or impulses is likewise inappropriate. In several instances they mentioned the 22-volt peak voltage (2.2 actual), but yet use the same argument with peak voltages of other magnitudes. Simply claiming that a voltage has insufficient energy to be non-problematic is not sufficient. Testing must be performed to verify such conditions or the absence thereof. They also attempt to justify some test data by stating that there were "deliberate disturbances created by test personnel." If this was done, why were such activities not logged in the event log for each of the respective farms?

Their conclusion that there is no difference in cow contact readings with or without neutral separation is incorrect. However, it is agreed that properly installed and maintained, the installation of the isolation devices will do little or no harm to the system. I do support the change from a spark gap to either a Ronk Blocker or a Dairyland electronic switch. Either would provide substantially safer conditions than a spark gap alone.

The on-farm wiring deficiencies must be corrected for the safety of persons involved. This is particularly critical on the Nelson farm.

I share the concern with the cutting of transformer pole grounds on any electrical system. However, as previously noted, I believe that all the producers are actually asking for is a correction of the problem. They are resorting to methods which are unsafe but which they believe helped to alleviate their problems. The test data which had been presented thus far appear to support the idea that any improvements achieved by cutting the downgrounds on the transformer poles or other primary system poles are more imaginary than real, since the tests do not verify any improvement in voltages with changes in the condition of the downgrounds.

To reach the conclusion that the report submitted by Agricultural Systems Engineering reportedly states there are no problems and no significant impact on the animal environment is incorrect. We do identify specific instances, specific tests, specific locations, and specific voltages which appear to be of a non-problematic magnitude. Such statements should not be interpreted as meaning that we believe there are no problematic voltages on the farm under any circumstances. That is incorrect. We will stand by our original conclusions that under conditions of neutral interconnections there are problematic voltages on these farms and the source, most probably, is the primary neutral system.

LETTER FROM HAROLD A. CLOUD

Mr. Cloud is correct that in general a stray voltage or an extraneous voltage is one within the animal environment. We can have stray voltage without having a problematic current flow through the animal body pathway. Our challenge is to determine if any stray voltage or extraneous voltage which is present does, in fact, come from a source or is being produced by a source that has sufficient energy to cause current flow through the body of an animal.

To discount as "unsubstantiated conjecture and speculation" a situation where there is "no voltage" between the animal contact points but a problem exists is incorrect. That is analogous to saying that just because there is little or no voltage between a neutral conductor and reference ground, there is no current flowing through that conductor. Many people have been injured thinking that a neutral is only a "ground" only to find that substantial current is, indeed, being carried on that conductor. There have been instances of severe burning when individuals thought a "grounding" conductor was nothing more than a safety conductor. Faults in the system had resulted in substantial current flow and when the conductor was cut or contacted, arcing occurred, resulting in severe burns.

Since preparation of our report in June 1992, I have had the opportunity to do additional investigation of the phenomenon where I find current flow with little or no measurable voltage. The most recent instance was in Wisconsin where I had current flows of 6 - 16 mA with voltages of less than 0.2 Vac between the gutter and the waterline. The voltages from the gutter and the waterline to a reference ground substantiated or verified the voltage difference between the two points was relatively small. However, the voltage from either point to a reference ground was of a higher magnitude. I do not recall the exact number. Because of the reaction of the animals observed both by myself and the dairyman (synchronized tail-switching by 30 - 40 cows), I elected to do additional testing for current. Using a clamp-on milliammeter, as well as two different brands and models of VOM's with milliamp measuring capabilities, I was able to verify that, in fact, current was flowing between these two points despite the absence of any voltage which would generally be considered problematic.

When we measure voltage, we assume that the voltage difference between the two points of concern is the driving force. In this instance, the driving force is at another location and what we are actually measuring is voltage drop through the conductor between the two points. This is analogous to the voltage drop one would measure along a neutral or phase conductor which is carrying current. Particularly with the neutral, the voltage between any two points would be relatively small assuming a short distance of 4 - 6 ft, i.e, a cow step length, because of the relatively low resistance of the conductor. Similarly, the voltage measured to the ground would be fairly small because we have a "grounded" conductor, i.e., the neutral. However, that does not eliminate the fact that current is flowing in this neutral conductor. Thus, we are measuring voltage drop rather than driving force voltage.

Mr. Cloud is correct that I do not consider a voltage of 6 - 6.5 Vac to be a "limited voltage." Recognize that those are his terms and his apparent attempt to interpret a situation that he has not personally encountered or documented.

I concur with Mr. Cloud that Ohm's Law is held to be a certainty which holds true in all instances. I have never stated that Ohm's Law did not apply. I simply stated that there were situations which I still did not understand, which would suggest that Ohm's Law doesn't apply. I continue to search for solutions and believe that I have now found a plausible explanation as to why these situations are occurring. The most important aspect of this finding is that when we are unable to find voltage in an animal environment but we either observe or the farmer or dairyman has observed cow behavior that suggests problems, it becomes imperative for us to measure and document current.

As stated previously, failure to check for both voltage and current is analogous to simply saying that because the voltage between a neutral conductor and the ground is near zero, that it is not carrying any current. We know from electrical circuit theory that with a 115-volt circuit, that is absolutely not true. Mr. Cloud suggested that it would be appropriate to document the source. In one instance, which involves a lawsuit in Wisconsin and is currently involved in litigation, the source of the current was an underground primary distribution conductor with exposed concentric neutral. We were able to convince the utility company that this conductor should be replaced with overhead conductors. Though current in the barn has since been eliminated, it is interesting to note that when they removed the conductor, they found that sections of the exposed concentric neutral were completely gone due to corrosion. Thus, the only path the primary neutral current had was to flow through the soil.

DAN E. MAIRS, P.E., LETTER

As you are aware, I was not present at the May 21, 1993 PUC meeting referenced in this letter. Thus, I cannot attest to the statements which were made regarding ground impedance. It remains a fact that improved grounding, i.e., lower ground rod resistance, is always beneficial from a safety perspective. My concern, and I suspect one which you voiced and one to which Mr. Mairs is referring, was that lowering the on-farm grounding resistance is not always a solution to extraneous voltage problems. There have been instances, and I suspect there will be more in the future, where people are convinced that the total solution to all voltage problems is additional grounding. It is important that all farms be grounded to the point of meeting NEC minimum safety standards. However, arbitrarily driving additional ground rods to lower the on-farm grounding resistance without properly diagnosing the source of the voltages can result in additional current flow from the primary system onto the farm and lead to an increase in problems rather than the hoped-for decrease.

The second item in Mr. Mairs letter suggests that, perhaps, he misheard what was being stated. I'm certain that when you were talking about 50 - 100 ft. separation distances it was between the primary and secondary ground rods when we are attempting to achieve separation of the primary and secondary systems. Obviously, the separation distance between the transformer and the meter has little influence on voltages other than as it relates to voltage drop on the service conductors between those two points. The NESC and the NEC both specify a minimum separation distance between ground rods that are not bonded together of 6 ft. This is done for safety reasons since few people can reach conveniently between two points 6 ft. apart.

The Codes do not specifically address function of the system. When we are attempting to optimize the performance of multiple ground rods, i.e., ground rods connected in parallel, they should always be separated by a distance that is at least equal to the combined length of the individual ground rods. For example, two 8-ft. ground rods should be separated at least 16 ft. One 8- and one 10-ft. ground rod should be separated at least 18 ft. and two 10-ft. ground rods should be separated at least 20 ft. This is to reduce the overlapping or interaction of the cylindrical volume of soil around each ground rod through which most current dissipation occurs.

If the combined length of the two ground rods is the minimum separation distance for function, the question then arises as to what distance is necessary for isolation. We know that under the right set of soil and moisture conditions, earth coupling can occur. Thus, although there is no standard in place, in consultation with other engineers, it has been generally agreed that where we are looking for separation of ground rods and reduced or minimized interaction, the separation distance should be at least 1.5 times the combined lengths of the ground rods. Thus, two 8-ft. ground rods should be at least 16 x 1.5 or 24 ft. apart. Two 10-ft. ground rods should be at least 20 x 1.5 or 30 ft. apart. Separation distances of two or three times the combined length would yield even more assurance that earth coupling would not occur. Such seems to be the basis for the questions and the probable statements you made regarding separation of ground rods.

Certainly, there are design limitations on secondary voltage drop. The recommendation for all agricultural facilities is a 2% maximum voltage drop between the transformer and the service panel. Voltage drop is a function of conductor length, conductor type, conductor material, and current flow. The NEC recommends a maximum 5% voltage drop in order to assure proper function of all electrical equipment, minimal blinking of lights during equipment starts, etc. Recognize that if we are looking for a total of 5% voltage drop as recommended by the NEC and we use the total 5% between the transformer and the service entrance, we either have no design capabilities beyond the service entrance panel, or we will exceed the NEC guidelines. For example, branch circuits, feeders, etc., all require and will encounter some voltage drop. The recommended 5% is from the transformer to the most distant load. Thus, designing for 2% voltage drop between the transformer and the service panel means we have 3% remaining to use in making design decisions on sizing conductors for individual loads within the installation. The combination of designing for 2% voltage drop and limiting the secondary neutral current to 5 amps or 5% of the phase conductor current will effectively eliminate the vast majority of extraneous voltage problems associated with or caused by secondary neutral voltage drop. The remaining factor, of course, is to assure that we have good connections used at all locations. A single bad connection can add more resistance to a circuit than several hundred feet of conductor.

The recommendation to have the resistance of a ground rod be 25 ohms or less is consistent with the requirements of the NEC (250-84). The NEC requires that if a single grounding electrode does not have a resistance of at least 25 ohms, it must be augmented by at least one additional electrode of some type as specified in various sections of the Code. The low resistance will help assure proper operation of overcurrent protection devices such as fuses, circuit breakers, etc., in the event of fault current. Hence, the requirement of the NEC.

The NESC recognizes that on a multi-grounded system the influence of any one ground rod is relatively small compared to the overall impedance of the total system. Thus, they do not set specific rod to soil resistance requirements.

Wisconsin takes a different approach. The Wisconsin State Electrical Code requires, like the NEC, that the individual ground rods have a resistance of 25 ohms or less or be paralleled with at least one additional ground rod. There are some different interpretations gradually being slipped into the application of this particular rule. Its most stringent interpretation was when the Wisconsin requirements for primary system grounding were similar to the NESC, i.e., four grounds per mile. With the present Wisconsin requirement for nine grounds per mile, the soil to rod resistance requirements are being reduced in many instances.

Other requirements of the NESC can be found in Section 94 which states: "The grounding electrode shall be permanent and adequate for the electrical system involved." This leaves a great deal of room for interpretation by the individual making this specification or installation. Another part of the NESC (92.D) states that "Ground connection points shall be so arranged that under normal circumstances there will be no objectionable flow of current over the grounding conductor." The Code then lists several alternative methods which can be used to eliminate objectionable currents. This, of course, relates not only to the resistance of the ground rod, but also to the separation distances.

I have checked the impedance of many electrical systems throughout my career. Systems with resistances of less than two ohms are less prone to having problems or causing on-farm electrical problems than those with higher resistance. However, as we found with both the Nelson and Franze farms, low system impedance does not guarantee a problem-free installation. This seems to be most related to the existence of poor connections or sections of high resistance conductor between a subject farm and a substation. The 2-ohm impedance value is actually a recommendation from Dan Dasho of the Wisconsin Public Utilities Commission. Dan, like myself, has done a great deal of testing of primary system impedances and has concluded that having the system impedance below 2 ohms will generally minimize the risk of problems. Low values do not guarantee freedom from problems.

CONCLUSIONS

The three documents reviewed in preparing this report all suggest a need for more effective communications between the various individuals involved in conducting electrical tests and evaluating electrical test data. Improved data presentation methods would be helpful. As is often the case, we cannot cite specific industry standards for a recommendation. In contrast, through experience we develop what's become accepted as good operating procedures or simply good practice. It is not uncommon to hear individuals speak of good practices vs. Code minimums. In general, we all agree such improvements are justified when they can be made cost-effectively and can be shown to enhance safety and system performance. Our concerns begin to arise when we find ourselves in a confrontational situation and wish to defend our position for something that we have done, or perhaps not done, in the past, or when we are accused of causing problems for others.

We must caution that in all instances we must remain realistic in our expectations. This applies to performance of the primary and secondary systems alike. As with most things we do in life, there is a compromise that must be made between what we would like to have and what is acceptable, realistic, and practical. We would all like to have zero voltage emanating from the electrical system, both in terms of electromagnetic fields, ground currents, etc. Perhaps unfortunately, if we wish to have the benefits of electrical energy to enhance our lifestyles we must make a compromise as to what is acceptable in terms of EMF and current flow through the soil. We cannot have a safe system without having some of the other situations or side effects exist.

16 Minimum Allowable Size of Conductor

Copper up to 400 Amperes, 230-240 Volts, Single Phase, Based on 2% Voltage Drop

Length of Run in Feet

Compare size shown below with size shown to left of double line. Use the larger size.

Load in Amps	In Air Cable or Conduit: UF**	In Air Cable or Conduit: RH, RHW THW, THWN, USE, NM, SE	In Air Cable or Conduit: THHN	Direct Burial: UF**	Direct Burial: USE	Overhead in Air*: Single	Overhead in Air*: Triplex	50	60	75	100	125	150	175	200	225	250	275	300	350	400	450	500	550	600	650	700	750	800
5	14	14	14	14	14	10	8	14	14	14	14	14	14	14	12	12	12	12	10	10	10	10	8	8	8	8	8	6	6
7	14	14	14	14	14	10	8	14	14	14	14	14	12	12	12	10	10	10	10	8	8	8	8	6	6	6	6	6	6
10	14	14	14	14	14	10	8	14	14	14	12	12	10	10	10	10	8	8	8	8	6	6	6	6	4	4	4	4	4
15	14	14	14	14	14	10	8	14	12	12	10	10	10	8	8	8	6	6	6	6	4	4	4	4	4	3	3	3	2
20	12	12	12	12	12	10	8	12	12	10	10	8	8	8	6	6	6	6	4	4	4	4	3	3	2	2	2	1	1
25	10	10	10	10	10	10	8	12	10	10	8	8	6	6	6	6	4	4	4	4	3	3	2	2	1	1	1	0	0
30	10	10	10	10	10	10	8	10	10	10	8	6	6	6	4	4	4	4	4	3	2	2	1	1	1	0	0	0	00
35	8	8	8	8	8	8	8	10	10	8	8	6	6	4	4	4	4	3	3	2	2	1	1	0	0	0	00	00	00
40	8	8	8	8	8	8	8	10	8	8	6	6	4	4	4	4	3	3	2	2	1	1	0	0	00	00	00	000	000
45	6	8	8	6	8	8	8	10	8	8	6	6	4	4	4	3	3	2	2	1	1	0	0	00	00	00	000	000	000
50	6	8	8	6	8	8	8	8	8	6	6	4	4	4	3	3	2	2	1	1	0	0	00	00	000	000	000	4/0	4/0
60	4	6	6	4	6	8	6	8	8	6	4	4	4	3	2	2	1	1	1	0	00	00	000	000	000	4/0	4/0	4/0	250
70	4	4	6	4	4	6	6	8	6	6	4	4	3	2	2	1	1	0	0	00	00	000	000	4/0	4/0	4/0	250	250	300
80	3	4	4	3	4	6	4	6	6	4	4	3	2	2	1	1	0	0	00	00	000	000	4/0	4/0	250	250	300	300	300
90	2	3	4	2	3	4	4	6	6	4	4	3	2	1	1	0	0	00	00	000	000	4/0	4/0	250	250	300	300	350	350
100	1	3	3	1	3	4	4	6	4	4	3	2	1	1	0	0	00	00	000	000	4/0	4/0	250	250	300	300	350	350	400
115	0	2	2	0	2	3	3	6	4	4	3	2	1	0	0	00	00	000	000	4/0	4/0	250	300	300	350	350	400	400	500
130	00	1	2	00	1	2	2	4	4	3	2	1	0	0	00	00	000	000	4/0	4/0	250	300	300	350	400	400	500	500	500
150	000	0	1	000	0	1	1	4	4	3	1	0	0	00	000	000	4/0	4/0	4/0	250	300	350	350	400	500	500	500	600	600
175	4/0	00	00	4.0	00	0	0	4	3	2	1	0	00	000	000	4/0	4/0	250	250	300	350	400	400	500	500	600	600	600	700
200		000	000		000	00	00	3	2	1	0	00	000	000	4/0	4/0	250	250	300	350	400	500	500	500	600	600	700	700	750
225		4/0	000		4/0	0	000	3	2	1	0	00	000	4/0	4/0	250	300	300	350	400	500	500	600	600	700	700	750	800	900
250		250	4.0		250	00	4/0	2	1	0	00	000	4/0	4/0	250	300	300	350	350	400	500	600	600	700	700	750	800	900	1M
275		300	250		300	000	4/0	2	1	0	00	000	4/0	250	250	300	350	350	400	500	500	600	700	700	800	900	900	1M	
300		350	300		350	000	250	1	1	0	000	4/0	4/0	250	300	350	350	400	500	500	600	700	700	800	900	900	1M		
325		400	350		400	4/0	300	1	0	00	000	4/0	250	300	300	350	400	500	500	600	600	700	750	900	900	1M			
350		500	350		500	4.0	300	1	0	00	000	4/0	250	300	350	400	400	500	500	600	700	750	800	900	1M				
375		500	400		500	250	300	0	0	00	4/0	250	300	300	350	400	500	500	600	600	700	800	900	1M					
400		600	500		600	250	400	0	00	000	4/0	250	300	350	400	500	500	500	600	700	750	900	1M						

* ; ** See footnotes common to all selection tables

17 Minimum Allowable Size of Conductor

Aluminum up to 400 Amperes, 230-240 Volts, Single Phase, Based on 2% Voltage Drop

Length of Run in Feet

Compare size shown below with size shown to left of double line. Use the larger size.

Load in Amps	In Air Cable or Conduit: UF**	In Air Cable or Conduit: RH, RHW THW, THWN, USE, NM, SE	In Air Cable or Conduit: THHN	Direct Burial: UF**	Direct Burial: USE	Overhead in Air*: Single	Overhead in Air*: Triplex	50	60	75	100	125	150	175	200	225	250	275	300	350	400	450	500	550	600	650	700	750	800
5	12	12	12	12	12	8	8	12	12	12	12	12	12	12	10	10	10	10	8	8	8	8	6	6	6	6	6	4	4
7	12	12	12	12	12	8	8	12	12	12	12	12	10	10	10	8	8	8	8	6	6	6	6	4	4	4	4	4	4
10	12	12	12	12	12	8	8	12	12	12	10	10	8	8	8	8	6	6	6	6	4	4	4	4	3	3	3	2	2
15	12	12	12	12	12	8	8	12	12	10	8	8	8	6	6	6	4	4	4	4	3	3	2	2	2	1	1	1	0
20	10	10	10	10	10	8	8	10	10	8	8	6	6	6	4	4	4	4	3	3	2	2	1	1	0	0	0	00	00
25	10	10	10	10	10	8	8	10	8	8	6	6	4	4	4	4	3	3	2	2	1	1	0	0	00	00	00	000	000
30	8	8	8	8	8	8	8	8	8	8	6	4	4	4	3	3	2	2	2	1	0	0	00	00	00	000	000	000	4/0
35	6	8	8	6	8	8	8	8	8	6	6	4	4	3	3	2	2	1	1	0	0	00	00	000	000	000	4/0	4/0	4/0
40	6	8	8	6	8	8	8	8	6	6	4	4	3	3	2	2	1	1	0	0	00	00	000	000	4/0	4/0	4/0	250	250
45	4	6	8	4	6	8	6	8	6	6	4	4	3	2	2	1	1	0	0	00	00	000	000	4/0	4/0	250	250	250	300
50	4	6	6	4	6	8	6	6	6	4	4	3	2	2	1	1	0	0	00	00	000	000	4/0	4/0	250	250	300	300	300
60	3	4	6	3	4	6	4	6	6	4	3	2	2	1	0	0	00	00	00	000	4/0	4/0	250	250	300	300	350	350	350
70	2	3	4	2	3	6	4	6	4	4	3	2	1	0	0	00	00	000	000	4/0	4/0	250	300	300	350	350	400	400	500
80	1	2	3	1	2	4	3	4	4	3	2	1	0	0	00	00	000	000	4/0	4/0	250	300	300	350	350	400	500	500	500
90	0	2	2	0	2	4	3	4	4	3	2	1	0	00	00	000	000	4/0	4/0	250	300	300	350	400	400	500	500	500	600
100	0	1	2	0	1	4	2	4	3	2	1	0	00	00	000	000	4/0	4/0	250	300	300	350	400	400	500	500	600	600	600
115	00	0	1	00	0	3	1	4	3	2	1	0	00	000	000	4/0	4/0	250	300	300	350	400	500	500	600	600	600	700	700
130	000	00	0	000	00	2	0	3	2	1	0	00	000	000	4/0	250	250	300	300	350	400	500	500	600	600	700	700	750	800
150	4 0	000	00	4 0	000	1	00	2	2	1	00	000	000	4/0	250	250	300	300	350	400	500	500	600	600	700	750	800	900	900
175		4 0	000		4 0	0	000	2	1	0	00	000	4/0	250	300	300	350	400	400	500	600	600	700	750	800	900	900	1M	
200		250	4 0		250	00	4 0	1	0	00	000	4/0	250	300	300	350	400	400	500	600	600	700	750	900	900	1M			
225		300	250		300	000	250	1	0	00	000	4/0	250	300	350	400	500	500	500	600	700	750	900	1M	1M				
250		350	300		350	4 0	250	0	00	000	4/0	250	300	350	400	500	500	500	600	700	750	900	1M						
275		500	350		500	4:0	300	0	00	000	4/0	250	300	400	400	500	500	600	600	750	900	1M							
300		500	400		500	250	350	00	00	000	250	300	350	400	500	500	600	600	700	800	900	1M							
325		600	500		600	300	400	00	000	4/0	250	300	400	500	500	600	600	700	750	900	1M								
350		700	500		700	300	500	00	000	4/0	300	350	400	500	600	600	700	750	800	900									
375		700	600		700	350	500	000	000	4/0	300	350	500	500	600	700	700	800	900	1M									
400		900	700		900	400	600	000	4/0	250	300	400	500	600	600	700	750	900	900										

* ; ** See footnotes common to all selection tables