

PSC STAFF REPORT: **The Phase II Stray Voltage Testing Protocol**

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BACKGROUND

The State of Wisconsin first investigated the concept of stray voltage (SV) in the early 1980's. The topic was relatively new to the country at that time, but many farm operators expressed a concern to Wisconsin government officials about the as-yet not well documented effects of stray voltage. Many methods have been used over the intervening years to acquire electrical and other data relevant to the effects of small voltages and currents in animal confinement areas. Through a long and sometimes arduous process, basic scientific techniques of data acquisition were applied to the process of SV investigation. While stray voltage measurements have been taken on dairy farms for many years, the number, types, and interpretation of these measurements can vary greatly. Depending on the investigator making the measurements, any number of different quantities can be recorded at different times of the day, using a wide variety of data acquisition equipment and using various protocols for the equipment's connection into the barn environment (for instance, the concern with the length of test leads was studied in 1996). As a result of these activities, the output of any specific measurement process may or may not generate the valuable or critical information needed for determining the character of the stray voltage present or its source. If the data is not collected with a minimum protocol that ensures its veracity, it should not be used to make economic decisions. The following discussion is offered to outline a specific protocol for obtaining a coherent set of measurements which, when used together, should provide SV investigators with a method useful in determining the character, conditions, and source of any stray voltage present on single- or multiple-service dairy farms. This test protocol is not mandatory in Wisconsin, but is routinely performed by investor-owned and other utilities prior to a visit by the Rural Electric Power Services (REPS) team of the Public Service Commission of Wisconsin (PSCW). As predecessor to the Phase II investigation, the Phase I investigation was developed in Wisconsin for first-time visits by utility SV investigative personnel, dairy field-men, veterinarians, and other dairy trade allies to "spot-check" for possible stray voltage at a small number of cow contact areas. It is also used to assess the basic characteristics of the farm's electrical system and the utility distribution system in the vicinity of the farm.

The PSCW, in its 1989 docket 05-EI-106, proposed a battery of tests for SV investigators whose goal is to determine the source of the stray voltage. The test set consists of a load box test, a secondary neutral test, and an equipment signature test, as well as the basic procedure of setting the cow contact measuring points. One must also determine the source resistance for each such point and determine if any cow contact voltages can be found above the "level of concern." From the 1996 PSCW docket 05-EI-115, the "level of concern" is defined as 2.0 milliamps, alternating current (AC), 60 Hertz (Hz), rms (root mean square), steady-state or 1.0 volt, AC, 60 Hz, rms, steady-state across a 500-ohm resistor in the cow contact area¹. The State of Wisconsin deems that this level of voltage/current is an amount of electricity where some form of mitigative action is taken on the farmer's behalf, although only some small percentage of cows may actually perceive its presence. The "level of concern" is not a damage level. Instead, it is a very conservative, pre-injury level, below the point where moderate avoidance behavior is likely to occur and well below where a cow's behavior or milk production would be harmed. The "level of concern" refers only to the exposure of farm animals in a confinement area to electricity from off-farm or on-farm electrical supply systems and not to any farm personnel in the same area. The "level of concern" is further broken down into two parts. The first part is a 1-milliamp contribution from the utility, at which level mitigative

¹"Steady-state" is defined by the Institute of Electrical and Electronics Engineers (IEEE) as "the value of a current or voltage after all transients have decayed to a negligible value."

action must be taken by that utility to reduce its contribution to below the 1-milliamp level. The second part is a 1-milliamp contribution from the farm system, at which level mitigative action should be taken by the farmer. Numerous studies at the University of Wisconsin and other quality research institutions have documented avoidance behaviors in the range of 3 to 6 milliamps of current flowing through the cow. This response assumes that the cow comes into contact with conductive objects that have different voltages and that this voltage difference causes sufficient current to flow through the cow. The exact methodology and the value of the data gathered by the aforementioned tests were not further explained in the docket nor were the techniques for analyzing the data. This paper is offered to expand on the concepts presented in docket 05-EI-106.

PURPOSE AND FORM

The Phase II protocol was developed to provide SV investigators with a tool to collect a reasonable set of data useful in the analysis of the quantity and “quality” of stray voltage that may be present under a variety of conditions, and the source of such stray voltage. The farm customer should expect that a written comprehensive SV investigation report be provided to him/her as the final result of a thorough investigation. It should contain reliable, scientifically-derived numbers indicating where any significant levels of stray voltage were found on his/her farmstead and the physical mechanisms whereby those voltages arose. The utilities, in their ongoing mission to assist farm customers to the best of their ability, need to employ consistent testing methods applied by well-trained personnel. With the Phase II protocol, farms may be inter-compared on a level playing field and test results from the same farm taken a number of times over a period of years may be compared against each other with some statistical confidence. Lastly, regulatory agencies, such as the PSCW, charged with collecting the utilities' test summaries, need to be assured that the data collection methodology was independent of the specific equipment used or the specific personnel performing the tests.

Phase II testing is intended to determine AC, 60 Hz, rms, steady-state animal contact voltages on livestock farms. Unfortunately, some farms in Wisconsin have modified electrical system wiring so that it no longer meets the safe operating provisions of the National Electrical Code (NEC). In these cases, the PSCW advises utility personnel to critically assess their risk in beginning a SV investigation on such a farm. If the situation warrants, they may inform the farm customer that SV testing will not continue until the electrical system is brought into compliance with the NEC. That code specifies the minimum wiring requirements for a safe electrical system. The PSCW rules in effect for SV investigations refer strictly to the 60 Hz fundamental voltage or current and not to any harmonic content that may or may not be present in addition to the fundamental frequency. Other electrical phenomena that are not specifically included in the PSCW orders are medium frequency transients (>3 kHz) and RF-source transients (>500 kHz) induced from sources outside the distribution power system including currents in the earth. While these transients can be measured with the proper equipment, there is no defined “level of concern” for these phenomena in the PSCW dockets dealing with stray voltage. In a joint venture of the state of Wisconsin with the state of Minnesota in 1998, a study was conducted that concluded that “no credible scientific evidence supports the claim that currents in the earth or associated electrical parameters such as voltages, magnetic fields and electric fields, are causes of poor health and milk production in dairy herds.” Therefore, utilities in Wisconsin have been specifically instructed by the PSCW to monitor AC, rms, 60 Hz, steady-state cow contact voltages to properly determine animal exposure.

The Phase II protocol consists of six data input forms to record the results of a set of five individual electrical tests of the farm/distribution power system network. The main form also provides an area to record background information that is important for the overall understanding of the farm/utility electrical system. Typical forms are found in Appendix A of this paper. These were developed by the PSCW as prototypical and the physical layout of each specific form is somewhat arbitrary. Also included are instruction sheets and diagrams for the uniform wiring and arrangement of the test equipment. It is important to emphasize that this protocol creates a set of data records useful in analyzing SV on multiple service as well as single service farms. However, multiple electric service farms may require other specialized tests to be devised as needed. Each electrical service must be tested individually per the Phase II protocol. Load box testing is not affected by multiple service situations as long as each is tested independently. The stray voltage investigator needs an extensive knowledge of multi-service interactions to fully understand and interpret the data and to draw the proper conclusions. There have been rare instances where neighboring farms have influenced testing on the subject farm, both through the power system and

other utility systems and through the earth. In some cases, a well-trained and experienced SV investigator can easily determine that a simple and solvable condition exists which obviates the direct need for the more extensive Phase II testing.

THE PHASE II FORMS

Appendices A-1a and A-1b are used for documenting the basic background information and animal contact set-up protocol. The information recorded, such as the existing mitigation devices present at the time of the visit, the basic character of the distribution system, and the farm production data, are important in the end analysis of the data and as an historical record of the farm. After a cow contact point is established, the all-important source resistance check is made and recorded. This value should be less than 500 ohms to ensure that the cow contact current/voltage is both meaningful and worst-case. From the PSCW database, the average source resistance in the cow contact area on nearly 3,500 Wisconsin dairy farms is 192 ohms. A second source resistance check is made just prior to tear down to ensure that the original value has not changed significantly over the period of testing. A voltage ratio (VR) test is included to determine if the selected reference rod location is too close to (under the influence of) the distribution or secondary electrical system. The voltage ratio calculated should be greater than 80 percent and less than 120 percent of the measured primary neutral to reference voltage to indicate correct reference rod placement.

Secondly, a load box test is performed and the data logged into the load box test forms (Appendices A-2a, A-2b, and A-2c). This is the most basic test to determine how much the primary system might be contributing to cow contact voltage levels. The load box should be a non-inductive 240-volt rated heater-type load in the range of 18-kilowatt (kW) to 25-kW. If the farm is found in an isolated condition, two load box tests should be performed. The first test records the “as-found” (isolated) condition and the second test records the bonded (non-isolated) condition. It is also important that the main electrical panel serving the animal confinement area be adequately bonded, according to all applicable codes, to the metallic water line/barn metal system. If the metallic water line/barn metal system was not bonded in the “as found” condition, testing in both the bonded and non-bonded condition may be needed.² The load box test is performed in four or five stages depending on the type of load box used. First, the background activity of the distribution system from the farm's point of common coupling is recorded with the 240-volt load box de-energized and the farm shut off. The load box can be either a split 9-kW/18-kW (or a split 12.5 kW/25-kW) type that is turned on half, then full or just an 18-kW (25-kW) type. (The PSCW has found that an 18 kW load box is usually adequate to create a worst-case scenario for most small to moderate sized farms). The data is recorded for this load-box-on, farm-off section. Then the farm is turned on in addition to the full load box to record the conditions under maximum electrical impact. Lastly, the load box is turned off and the data recorded representing the background electrical activity of the functioning farm. The types of data typically collected are primary line current (I_p), primary neutral current (I_{pn}), secondary neutral current (I_{sn}), net secondary neutral current (I_{sn-net}),³ voltages from primary neutral to reference (V_p), secondary neutral to reference (V_s), and the voltage values at cow contact (V_{cc}). The cow contact point is selected so as to measure the greatest (meaning worst case) voltage value. The difference in voltage from the primary neutral to the secondary neutral is also recorded (V_{ps}). It is interesting to note that, for over 3,000 dairy farms in Wisconsin, the average primary neutral to reference voltage is 1.39 volts while the average secondary neutral to reference voltage is 1.27 volts (the source of these voltages was not determined). V_p is measured at the bottom of the transformer pole where the primary neutral is connected to its ground rod. V_s is measured at the main electrical service panel of the animal confinement area where the connection is made to the grounding electrode system. Calculations are made as indicated on the form for various resistances, the K-factor and the current return ratio (CR).

The forms in Appendices A-3a, A-3b, and A-3c log the results of a set of secondary neutral voltage drop tests. Secondary neutral voltage drop has been found to be the main on-farm source of stray voltage in Wisconsin. This test is used to determine the source and impact of each secondary service on the farm. For this test, a proxy load of known characteristics, such as a 120-volt rated hair dryer or paint peeler drawing about 10 - 15 amps AC

²Note: Extreme caution must be exercised when working on or near equipment and metal structures that are not bonded, because injury or death may occur.

³ This is recorded by using a current clamp simultaneously around both secondary phase wires and the neutral wire.

rms, is used to create a known and stable neutral current and subsequent voltage drop for each neutral serving a main panel, sub panel, or end of service area. It is important that all other service entrance main disconnects be turned off at this time so the impact of just one service at a time can be determined. The data collected for each such service are neutral wire gauge, exact length of neutral wire, neutral current measured, voltage drop measured, and Vcc, the primary neutral to reference voltage (Vp), and secondary neutral to reference voltage (Vs) at both ends of the circuit. It is important to have the last three voltages measured both before and after the hair dryer load is turned on so that just the difference, found by subtraction, is seen. Ohm's Law is used to calculate the expected neutral voltage drop, based on the measured current and calculated neutral conductor resistance. This can then be compared with the actual recorded voltage drop either as a difference in voltage to reference measured at each end of the circuit or the voltage drop directly measured from one end of the circuit to the other.

Appendices A-4a and A-4b are used to log the data generated by a signature test where individual pieces of major current-drawing electrical equipment are started and stopped at specific times and for specific intervals to determine their impact on the farm's electrical system. Additionally, a proxy load can be used to provide the signature of a long-run circuit that has a 120-volt outlet associated with its far terminus. The signature test is best accomplished shortly after the load-box test when minimal farm electrical activity exists and only one service at a time is energized. For this test, the person recording the data should be in contact (via voice or radio) with the person controlling each load device. He/she must also have a watch or other timing device in synchronization with a recording voltmeter so the data recorded can be properly interpreted. A digitizing data recorder is usually used during this test with the sample interval set to 1 second. The data recorder should be set to monitor a minimum of four data points: voltages from primary neutral to remote reference (Vp), secondary neutral to remote reference (Vs), primary neutral to secondary neutral (Vps), and the cow contact voltage (Vcc). The physical locations monitored are the same as for the load box test. For each piece of electrical equipment for which a signature is desired, the type and location are noted along with the start and stop times, usually separated by 15 or 20 seconds. For clarity, the start times should ideally be on an even minute, half minute or quarter minute. If a piece of equipment is discovered in a running condition, a stop and then restart is performed and the condition annotated (via an asterisk, e.g.) to make proper sense of the sequence in stop and start times.

The forms shown in Appendices A-5a and A-5b are used to record the results of a "primary profile" test that may be performed either during a morning milking or an evening milking or when the electrical activity on the primary distribution system is likely to be at a maximum. This test uses a meter or meters that measure both ground rod resistance and ground rod current at one time. The primary system ground rods for three-fourths of a mile on each side of the farm (if possible) are measured. It is best to start at one end point and work towards the other, if possible, and include such branch circuits or sections thereof that may be within the needed sphere. This may be the case if the farm is not on a linear segment of distribution system. It is important to note the condition of each pole, if out of the ordinary, as well as other devices present such as transformers, capacitor banks, telephone pedestals, or broken ground connections as well as the farm tap pole or transformer pole. This test should ideally record the ground rods of a minimum of about 13 or 14 poles over 1.5 miles. The investigator should then use Ohm's Law to calculate the primary neutral to earth voltage, which exists at each pole.

The form, Appendix A-6a, is used to summarize the results from a long term ("24-hour") monitoring test where the investigator places a recording voltmeter for about 24 hours to cover at least two milking periods. The four channel assignments are the same as in the signature test described previously. The report form suggests the proper settings and the data to be collected. The "average rms" report graph from the recording voltmeter is the most useful in determining if the steady state level of concern has been exceeded at any time during the recording interval.

DATA ANALYSIS

The greatest benefit of using the results of the Phase II forms is in the overall analysis of the farm and utility electrical systems. In the every day life of dairy farming in Wisconsin, the two should be considered one single system that work together enabling the dairy farmer to perform all the tasks necessary to get his/her product to market in the most efficient, cost-effective manner. Even if the cow contact voltages/currents are found to be below the present "level of concern," many useful suggestions for improving either the farm wiring system or the

utility distribution system can be offered with proper analysis of the data collected. This proactive approach to SV investigation is meant to avoid future concerns as both the farm electrical system and utility system increase in age or are modified by the normal growth of either system. It has been noted in the past that it is better to prevent possible stray voltage from occurring than to deal with the unmitigated consequences at a later date.

The data collected via the Phase II protocol is intentionally wide ranging to provide some means of cross-checking data, much like the accountant who cross-checks a double-entry bookkeeping system. By examining the primary profile, the load box test, the signature test, and the secondary neutral voltage drop test, the operational characteristics of the primary electrical system, the secondary electrical system, and the individual components of each is revealed. The “24-hour” test should demonstrate that each side of the system has a specific impact on the overall operation of the farm at specific times of day. If the farm is to be isolated in the future, Phase II testing can offer some predictions on the consequent impact to the primary neutral voltage in the area of the farm and to the secondary neutral and cow contact voltages on the farm under the conditions of isolation.

The primary profile should reveal that most primary neutral to earth voltages found in the region of the farm's tap or transformer pole are similar in magnitude to the primary neutral to reference data from the load box test. It is best to graph the data versus consecutive poles to see if a specific pattern indicates an area that may need attention (see Appendices A-5c, A-5d and A-5e). The average value of distribution system ground rod current in Wisconsin from over 3,355 poles measured, is 41 milliamps. The average ground rod resistance is 78 ohms. The average primary neutral to earth voltage calculated is 1.05 volts. Because the primary profile data are taken at a time of nearly maximum electrical activity on the primary system, the influence of neighboring farms can often be seen. It is sometimes the case where one farm's electrical troubles are passed on via a common interconnection by the utility from the previous or subsequent farm on the distribution system. In these cases, a recording device may be set on various points of the primary system to monitor contributions in voltage and current from other sources. In the proper interpretation of the primary profile data, care must be exercised in including the possible contributions of capacitor banks, other transformers and telephone systems to the neutral voltages. A parallel communications system (telephone or cable-access television) interconnected with the distribution system neutral can create a large ground loop and consequently larger than expected neutral voltages or currents.

Load box testing ideally confirms that nearly zero volts should exist between the primary neutral to reference voltage (V_p) and the secondary neutral to reference voltage (V_s) for a non-isolated farm with farm loads off ($V_{ps} \approx 0$). If this is not the condition recorded, an unintended condition of semi-isolation may exist. This may take the form of a high resistance connection between the primary and secondary neutrals. For farms that are intentionally isolated, the secondary neutral to reference voltage with the farm off should ideally be 8 to 10 times less than the primary neutral to reference voltage, to indicate that the isolation device is effectively doing its job. The currents and voltages should increase in a logical progression as one adds more load in each step of the load box test. If a current or voltage decreases when more electrical load is added, phase or interference conditions could be assumed. If there is no corresponding linear increase in voltage and current for a linear increase in the applied load, phase shift or power factor interference may be indicated. Most obvious is the direct impact of the neutral voltage on the cow contact. Because the farm's electrical loads are disconnected, the direct connection between the two neutral systems is the lowest impedance path from the primary neutral to the cow contact area. In Wisconsin, when the voltage at cow contact exceeds 0.5 volts during the full load test, action by the utility is mandated. From the calculated values, the primary neutral resistance should ideally be less than 0.75 ohms, but can reasonably range from about 0.1 to about 3.5 ohms. The farm neutral resistance should ideally be less than 2.0 ohms, but can reasonably range from about 0.3 to about 5.0 ohms. The total system resistance should ideally be less than 0.5 ohms, but can reasonably range from about 0.05 to about 2.5 ohms. The K-factor should ideally be less than 33 percent, but typically may range from 5 percent to 85 percent. The lower this number is, the less impact neutral voltages will have in the cow contact area. The CR should ideally be 66 percent or more. The range is typically about 35 percent to 90 percent. The typical ranges referred to above are based on PSCW REPS team experience. When the farm loads are turned back on, in addition to the full load box being on, the effects of combined secondary neutral voltage drops can be seen. The cow contact voltage may increase or may decrease, depending on the phase of the dominant farm loads drawing current at that time.

The secondary neutral voltage drop test provides data on the calculated drop and the actual measured drop for each major service on the farm. If the measured value of the drop differs from the calculated value, some condition may exist in that circuit that needs attention (e.g. a poor connection or splice). The effect of each service on the cow contact voltage can also be seen. In the overall farm system, the various voltage drops connected to the primary/secondary neutral/ground system may add to or subtract from the neutral to earth voltage at the point of common coupling to influence the readings with the farm on. This is because the service generating the voltage may be either in-phase or out-of-phase with other source voltages. There may also be some minor phase shifting due to the fact that there are complex impedances, not just pure resistances, involved in most circuit load devices. When these undesirable additional voltage drops are found and minimized, the calculated and measured voltage values should agree. Sometimes the actual and calculated values are in agreement but both are larger than desired for the service being measured. Only experience with typical secondary electrical systems can provide information on what the overall value should ideally be, but many times, the neutral conductor size is smaller than required, resulting in excessive secondary neutral voltage drop. Each service neutral on a farm is a potential source of stray voltage. Because each service is characterized at a standard load in this test, the relative impact of each at the cow contact area can be gauged. It is important to remember that this is a 120-volt test and is not characterizing 240-volt loads at each service. Only 120-volt loads use unbalanced secondary current carried by the neutral. Because the 120-volt load may be connected to one hot phase or the other as the test progresses, the total effect may add to or subtract from the combined cow contact voltage.

The signature test is analyzed by examining the impact of each major electrical device and circuit in the farm system. The SV investigator should annotate significant contributions to the cow contact voltage (V_{ec}) from the electrical system device or circuit under investigation. The test may indicate a certain piece of electrical equipment generates excessive neutral voltage when it is running or may generate excessive voltage drop upon start up. Most motors use 2 to 8 times their normal running current for several cycles to as much as a full second during a start-up operation. If the signature displays currents and voltages in excess of those expected for the size of the load energized, a condition needing attention may be indicated. The effect of the individual start, run, and stop cycle can also be seen at the cow contact area. Many times it is important to “stage” the signatures to re-create normal operational conditions on the farm. The investigator may ask the farm operator to start a number of pieces of electrical equipment that normally all run at the same time so that the total cumulative effect on the neutral may be recorded. The stopping sequence will be the reverse of the starting sequence. The effect of 240-volt rated devices can be seen which ideally should not affect the secondary neutral voltage except by its common coupling to the primary neutral voltage. It is especially important to include the operation of fencers, trainers, and crowd gates during the signature test. These electronic devices generate very high voltage, low to moderate current signals as a part of their normal operation. Great care must be taken in the installation of these devices such that the high voltage does not couple into animal contact areas at points where it is not intended. The signature library developed during this test may provide interpretative information to some charts resulting from the “24-hour” test and will be valuable as an historic record to gauge any change in operational characteristics of loads for future investigations.

The “24-hour” test can be viewed in a number of different ways. The “average rms” report should be the only source of values used to determine if the cow contact voltages or currents exceed the “level of concern” in addition to the load box test data. Using the “average rms” voltage graph, the investigator can visually track the effects of both the primary and the secondary neutral to reference voltages on the cow contact voltage. The ratio between the secondary neutral to reference voltage (V_s) and the cow contact voltage (V_{ec}), defined as the K-factor, should be a relatively constant proportion which agrees with the value derived in the load box test. The channel recording the difference in voltage between the primary and the secondary neutral to reference voltage should be close to zero for a non-isolated farm and be a larger voltage for an isolated farm. The software used to view graphs allows enlargement of selected portions for more detailed analysis. This tool lets the SV investigator determine the exact voltage levels recorded and the exact duration of specific events. The ‘maximum rms report’ (non-steady state) may be useful in determining if any faulting condition or transient activity exists which may require further investigation. It should be used for diagnostic and research purposes only. This is because this report logs the single highest rms voltage value reached during the recording interval, usually set at 10 seconds. There is only one 60 Hz. cycle which reaches maximum among the 600 cycles of the recording interval, but the data point is plotted as if all 600 cycles were at this level. If this higher voltage cycle occurs once in each successive data recording

interval, the entire graph appears to present data at a much higher level than actually exists. Therefore, the data from this report must be viewed selectively with the aforementioned interpretation in mind. As mentioned in the signature test section above, the operation of specific equipment used during the daily milking and feeding cycles should be discernable on the “24-hour” test report graph.

CONCLUSIONS

The Phase II protocol can be a very useful format for collecting and documenting data relative to stray voltage investigations on single and multiple electrical source dairy farms. The data acquired can be used to record the amount of AC, 60 Hz, rms, steady state stray voltage found during the investigation and the specific conditions under which it is present. An experienced SV investigator may use the Phase II information to suggest the source of such stray voltage and offer mitigation methods based on scientifically collected data that will properly address the situation.

There are many valid tests that produce useful information in a stray voltage inquiry. The five tests within the Phase II protocol may be basic to any SV investigation and can be used during a comprehensive stray voltage inquiry if the source of stray voltage has not previously been identified. Load testing for on- or off-farm contributions is typically not part of an initial or preliminary (Phase I) stray voltage inquiry. If the source has been determined by some other valid means, such as but not limited to data supplied by a recording voltage meter, a competent SV investigator may deem that a portion of or perhaps all of these five tests may not be required. Stray voltage testing and diagnostic procedures and protocols continue to be utilized on a case-by-case basis for the type of inquiry desired. More often than not, the site-specific characteristics of a SV investigation will require some flexibility on the part of the SV investigator and generally preclude the mandatory use of uniform tests in all situations. This flexibility of investigators is critical during preliminary testing to produce the most satisfactory results as quickly as possible.

**STRAY VOLTAGE PHASE II
DATA INPUT FORM**

DATE(S): _____

Cow Contact above L.O.C.? **Y N** If Yes, Cow Contact Location: _____

Farm customer: _____ Recorded by: _____

File No: _____ Utility: _____ Type: Muni IOU Coop

Miles to substation: _____ Grounds/mile _____ End of Line? **Y N**

Primary Line Voltage: _____ Transformer KVA: _____ Primary Service 1 2 3 4

Conductor size: _____ Neutral size: _____

(AS FOUND) FARM ATTRIBUTES:		COMMENTS:
EPP	Y N	
EGS	Y N	
4-WIRE	Y N	
ISOL XFMR	Y N	
NEUT ISOL	Y N	

HERD SIZE _____ MILK PRODUCTION _____ lbs DHI? **Y N** SCC (x1,000) _____

SOURCE RESISTANCE CHECK #1: (SET-UP)

R_{shunt} = **Ω**

V_{wo} = _____ **V_w** = _____ **R_{source}** = [(V_{wo}-V_w)xR_{shunt}]/V_w =

SOURCE RESISTANCE CHECK #2: (TAKE-DOWN)

V_{wo} = _____ **V_w** = _____ **R_{source}** = [(V_{wo}-V_w)xR_{shunt}]/V_w =

V_r TEST

I_{pg} meas = _____ mA **R_{pg} meas** = _____ Ω

V_{pncalc} = I_{pg} meas x R_{pg} meas = _____ mV **V_r** = V_p / V_{pncalc} =

V_p (from load box test) = _____ mV

PHASE II DATA INPUT INSTRUCTIONS

ITEM EXPLANATION

-
- | | |
|----|--|
| 1 | Enter date(s) of testing period. |
| 2 | LOC = Level of Concern exceeded?, i.e. ≥ 1 volt (2 mA) in cow contact area. |
| 3 | Exact location of any SV above LOC. |
| 4 | Customer name. |
| 5 | Name of person recording data. |
| 6 | File reference number. |
| 7 | Name of utility serving farm. |
| 8 | Type of utility (IOU = Investor Owned Utility). |
| 9 | Circuit miles from farm to substation. |
| 10 | Number of grounds per mile average for 3/4 mile each side of farm. |
| 11 | Check if end-of-line customer (This is a customer who is the last one on a radial distribution feeder or the last one served by a tap off the main feeder located more than 0.5 mile from the source distribution facility where it goes in two different directions.) |
| 12 | Primary line voltage to neutral serving farm transformer (4,800, 7,200, 14,400, etc). |
| 13 | Farm transformer kVA rating (note multiple transformers separately). |
| 14 | Type of service: 1 = single phase, 2 = two phase, 3 = three phase, 4 = multiple phases. |
| 15 | Phase conductor size and wire type (#8 CW, 1/0 ACSR, #4 CU, etc.) |
| 16 | Same for neutral conductor size and type. |
| 17 | Circle if attribute present at this time: EPP = Equi-Potential Plane, EGS = Electronic Grounding System, 4-wire = 4 or 5 wire secondary system, ISOL XFMR = Isolation Transformer, NEUT ISOLATOR = Primary/Secondary isolation device present (Note type: Ronk, Dairyland, etc.). |
| 18 | Record any useful comments about devices present (i.e. "EGS not working or disconnected"). |
| 19 | Note farm characteristics of milking herd size, rolling herd average production, if on DHI and the present somatic cell count. |
| 20 | Record shunt resistor value and data from two source resistance measurements: one just after setting the cow contact point and the other just before tear down. |
| 21 | Voltage ratio test to see if the reference rod is under the influence of the farm/primary electrical system. Measure farm primary pole ground resistance and current. (If main disconnect is within 30 feet of this ground rod, use the next existing rod back towards the substation). Calculate primary neutral voltage and compare to value measured by load box test with load box off, farm on. If the two values are within 20 percent (hi or lo), reference rod is in the correct location. |

LOAD BOX TEST

DATE: _____ Customer Name: _____

	FARM OFF:			FARM ON:	
TIME:					
Condition:	NO LOAD	½ LOAD	FULL LOAD	FULL LOAD	NO LOAD
Ip	A	A	A	A	A
Ipn	A	A	A	A	A
Isn	A	A	A	A	A
Isn net	A	A	A	A	A
Vp	V	V	V	V	V
Vs	V	V	V	V	V
Vps	V	V	V	V	V
Vcc	V	V	V	V	V

(lo)

(hi)

CALCULATIONS (FARM OFF):

SUMMARY:

$$R_t = \frac{V_p \text{ hi} - V_p \text{ lo}}{I_p \text{ hi} - I_p \text{ lo}} = \underline{\hspace{2cm}} = \boxed{\hspace{2cm} \Omega}$$

$$R_p = \frac{V_p \text{ hi} - V_p \text{ lo}}{I_{pn} \text{ hi} - I_{pn} \text{ lo}} = \underline{\hspace{2cm}} = \boxed{\hspace{2cm} \Omega}$$

$$R_f = \frac{V_s \text{ hi} - V_s \text{ lo}}{I_{sn} \text{ hi} - I_{sn} \text{ lo}} = \underline{\hspace{2cm}} = \boxed{\hspace{2cm} \Omega}$$

$$K = \frac{V_{cc} \text{ hi}}{V_s \text{ hi}} = \underline{\hspace{2cm}} = \boxed{\hspace{2cm} \%}$$

$$C_r = \frac{I_{pn} \text{ hi}}{I_p \text{ hi}} = \underline{\hspace{2cm}} = \boxed{\hspace{2cm} \%}$$

LOAD BOX TEST INSTRUCTIONS

Note 1: Testing may be accomplished by a single 18/25 kW load box or a dual element 9/18 or 12.5/25 kW load box. The difference between full load and no load measurements is used in most calculations. There must be a continuous metallic bond between the main disconnect's neutral/grounding electrode system and the barn water pipe/stanchion structures.

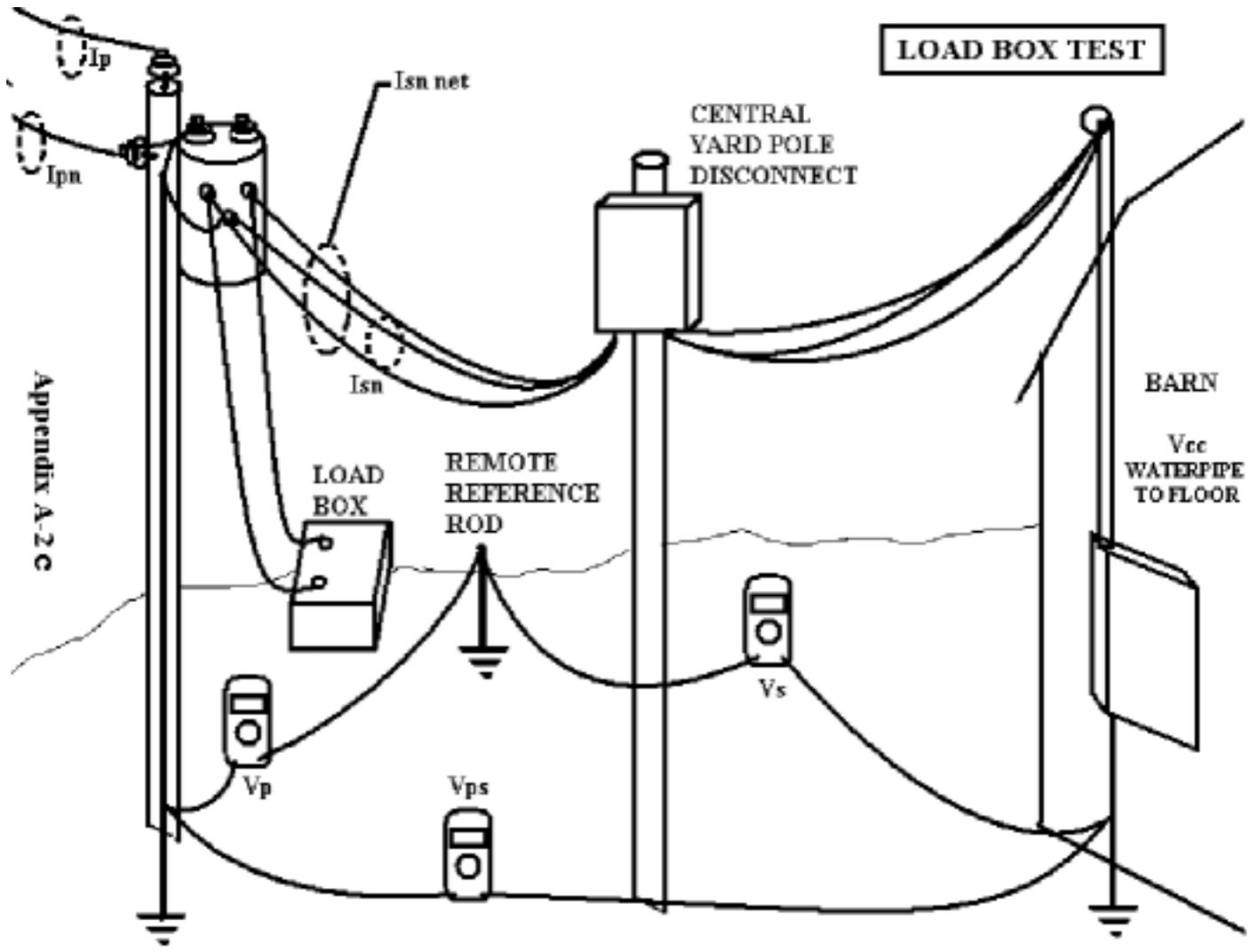
Note 2: If the farm is found in an isolated condition, two load box tests must be performed: an isolated test and a non-isolated test.

Note 3: If the farm is served by a three-phase system, measure and record only the farm-off, load box off column and the farm-on, load box off column or test only one phase of the three.

ITEM	EXPLANATION
1	Enter date and customer name.
2	Attach load box to the 240-volt secondary side of transformer. With load box off, shut off all electrical service to farm and record time. Measure and record 7 data points as follows: I_p = current on primary phase line, * I_{pn} = current on primary neutral line, I_{sn} = current on secondary neutral line, V_p = voltage from primary pole ground rod to remote reference rod, V_s voltage from barn's main disconnect neutral/ground electrode system to remote reference rod, V_{ps} = voltage between last two points, V_{cc} cow contact area voltage
3	If dual element load box is used, turn on first half of load box, record time and 7 data points. If using a single load box, skip this step.
4	Turn on full load box, record time and 7 data points.
5	Turn all electrical service to farm back on. Record time and 7 data points and one additional data point of the net current on all three secondary wires from transformer (2 phase wires and the neutral wire grouped together).
6	Turn off load box and record time and 8 data points.
7	Transfer the appropriate numbers to the formula section and calculate the total system resistance, R_t , the primary system resistance, R_p , the farm resistance, R_f , the K-factor, and the primary current ratio, CR.
8	Care must be taken when performing this test. If the transformer is located on the distribution right-of-way, the phase and neutral currents must be measured both upstream (towards the substation) and downstream of the transformer.

* The primary phase current may be calculated using the measured secondary current of the load box and the known transformer ratio. (e.g for a 100 amp @ 240 volt secondary load box with a 30:1 transformer ratio, the primary phase current at 7,200 volts would be 3.3 amps.)

LOAD BOX TEST



Appendix A-2c

SECONDARY NEUTRAL VOLTAGE DROP TEST

Test performed by: _____ Date: _____

Customer name: _____

(All other farm loads must be off. Use only one load per circuit)

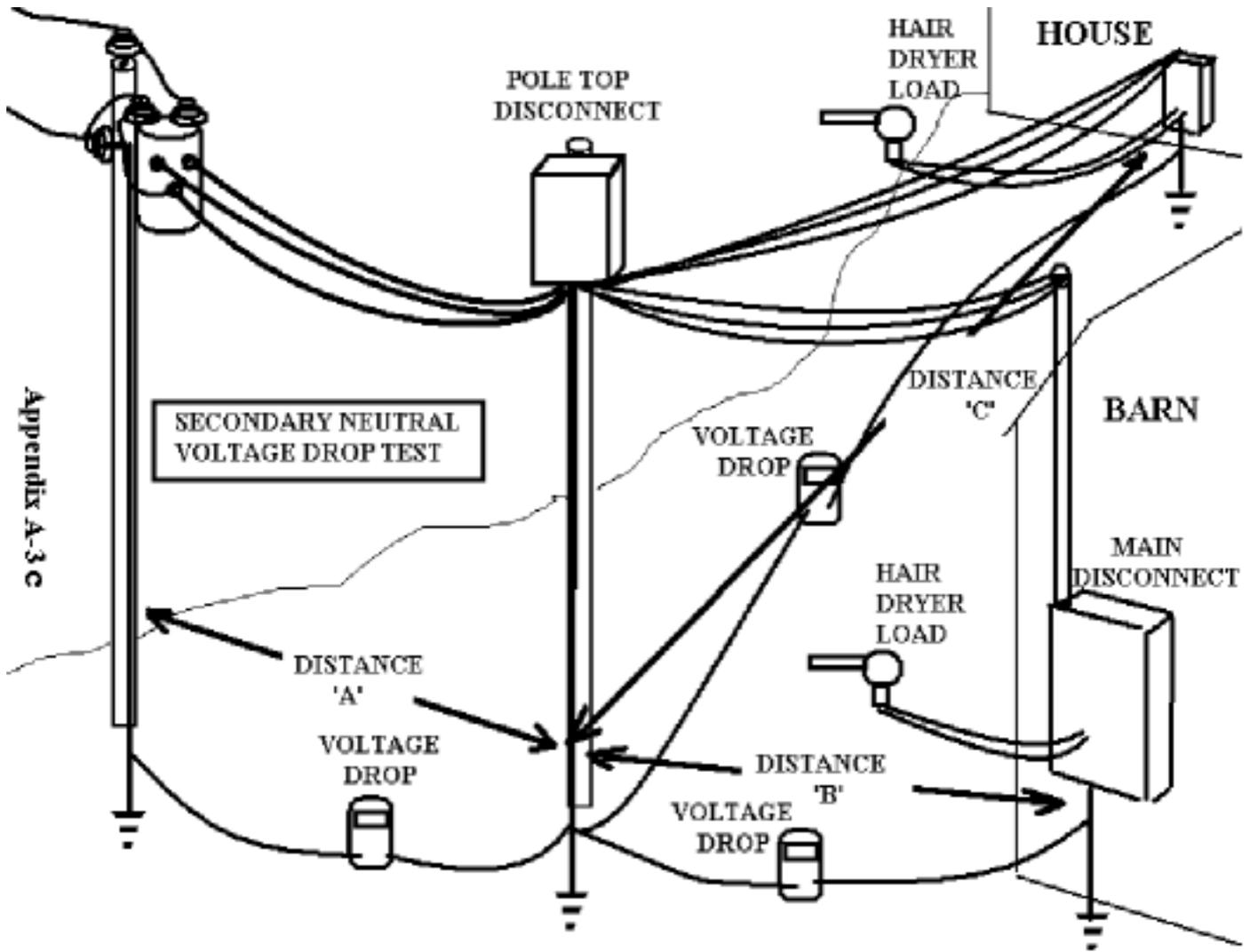
SITE:	1	2	3	4	5	
Site Location:						UNITS
A. Circuit neut. wire gauge						
B. Wire length (in 100's ft.)						100 ft
C. Ω/100ft.						Ω
D. Total Q (B times C)						Ω
E. Measured neut. Current						A
F. Calculated voltage drop (D times E)						V
G. Measured voltage drop						V
H Percent difference $(\{G-F\}/G * 100)$						%
Vp load off						V
Vs load off						V
Vcc load off						V
Vp load on						V
Vs load on						V
Vcc load on						V

SECONDARY NEUTRAL VOLTAGE DROP TEST INSTRUCTIONS

ITEM	EXPLANATION
1	Enter names of those performing test
2	Enter date test is performed
3	Enter customer name
4-8	Describe load site location, neutral wire gauge, neutral wire length (in 100's of feet), resistance per 100 feet (see table below), measured neutral current, measured voltage drop, Vp, Vs and Vcc for load off and load on.
9-13	Calculate the total circuit resistance. Calculate, using Ohm's Law, the expected neutral voltage drop. Calculate the absolute value of the difference and divide by the measured voltage drop. Express this as a percentage. If the two values (measured voltage drop and calculated voltage drop) do not agree, further investigation is warranted to discover the reason for the discrepancy. Prioritize your investigation to look at the largest percentage difference cases first.

Resistance Chart (Ohms per 100 feet)

MATERIAL			MATERIAL		
GAUGE	AL	CU	GAUGE	AL	CU
14	0.42	0.26	2	0.027	0.016
12	0.26	0.16	1	0.021	0.013
10	0.17	0.10	1/0	0.017	0.010
8	0.11	0.064	2/0	0.013	0.008
6	0.67	0.041	3/0	0.011	0.006
4	0.34	0.020	4/0	0.008	0.005



Appendix A-3 c

SIGNATURE TEST FORM

Customer Name: _____

Date: _____

	Type of Load	Location	Time On	Time Off	(*)
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					
26					
27					
28					
29					
30					
31					
32					
33					
34					
35					

SIGNATURE TEST FORM INSTRUCTIONS

ITEM	EXPLANATION
1	Enter the date the test is performed.
2	Enter the customer's name.
3	Enter the description of the load for which the signature will be recorded (If using a hair dryer, note it as HD).
4	Enter the location of the load.
5	Note the time of turn-on and time of turn-off. Equipment should be on for a period of not less than 10 seconds. If equipment is found in the on condition, turn it off then turn it back on and note the event with a star in the right column to make sense of the difference in on and off time events.
6	Repeat for all major circuits and pieces of equipment (both 120 volt and 240 volt). Some equipment may normally be operated in sequence. Start each piece at 15-second intervals until all are running, then turn off in reverse order in 15-second intervals.

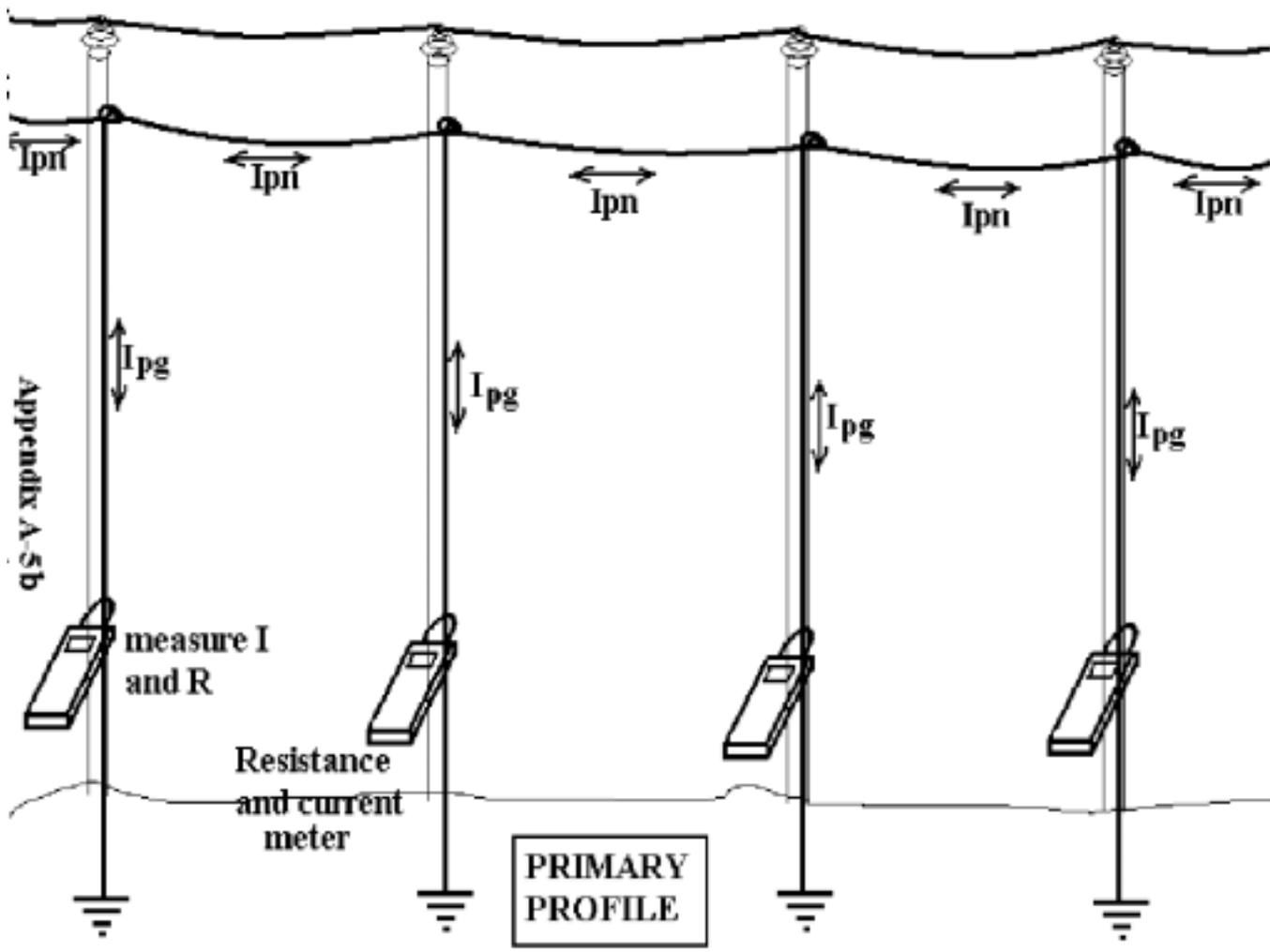
PRIMARY PROFILE DATA FORM

Customer name: _____ Date: _____

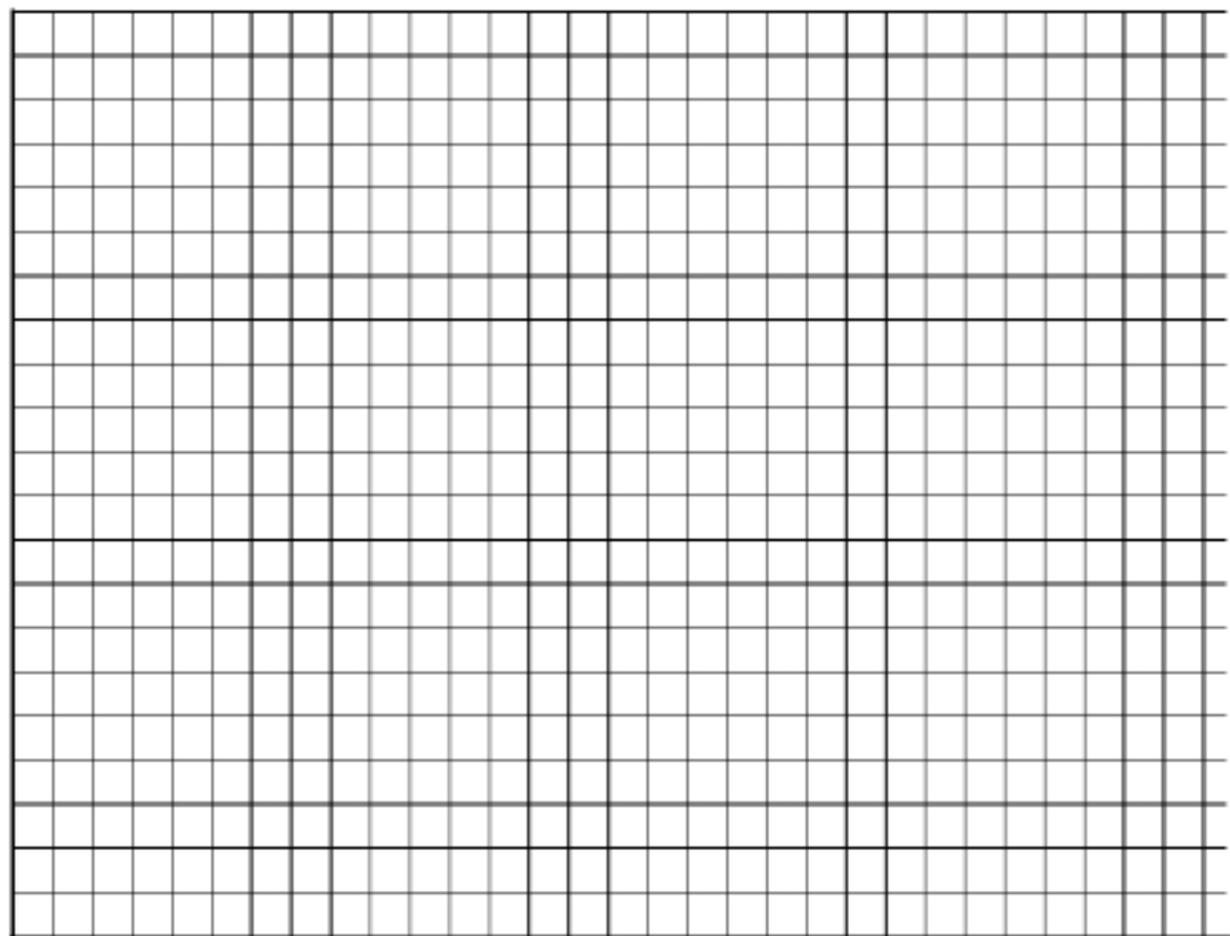
Test performed by: _____

Record the current (I_{pg}) and the resistance (R_{pg}) of each ground rod in a linear pattern $\frac{3}{4}$ ths of a mile on each side of the farm's tap/transformer pole. Calculate, using Ohm's Law, the primary neutral to earth voltage (V_{pne}) for each pole. Use the notes section to annotate the condition of each pole and if the pole has a transformer, capacitor bank, recloser, arrester, telephone pedestal or CATV device, etc. attached.

POLE #	POLE ID #	I_{pg} (mA)	R_{pg} (Ω)	Calc. V_{pne} (V)	Notes
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					
26					



PRIMARY PROFILE CURRENT (mA)

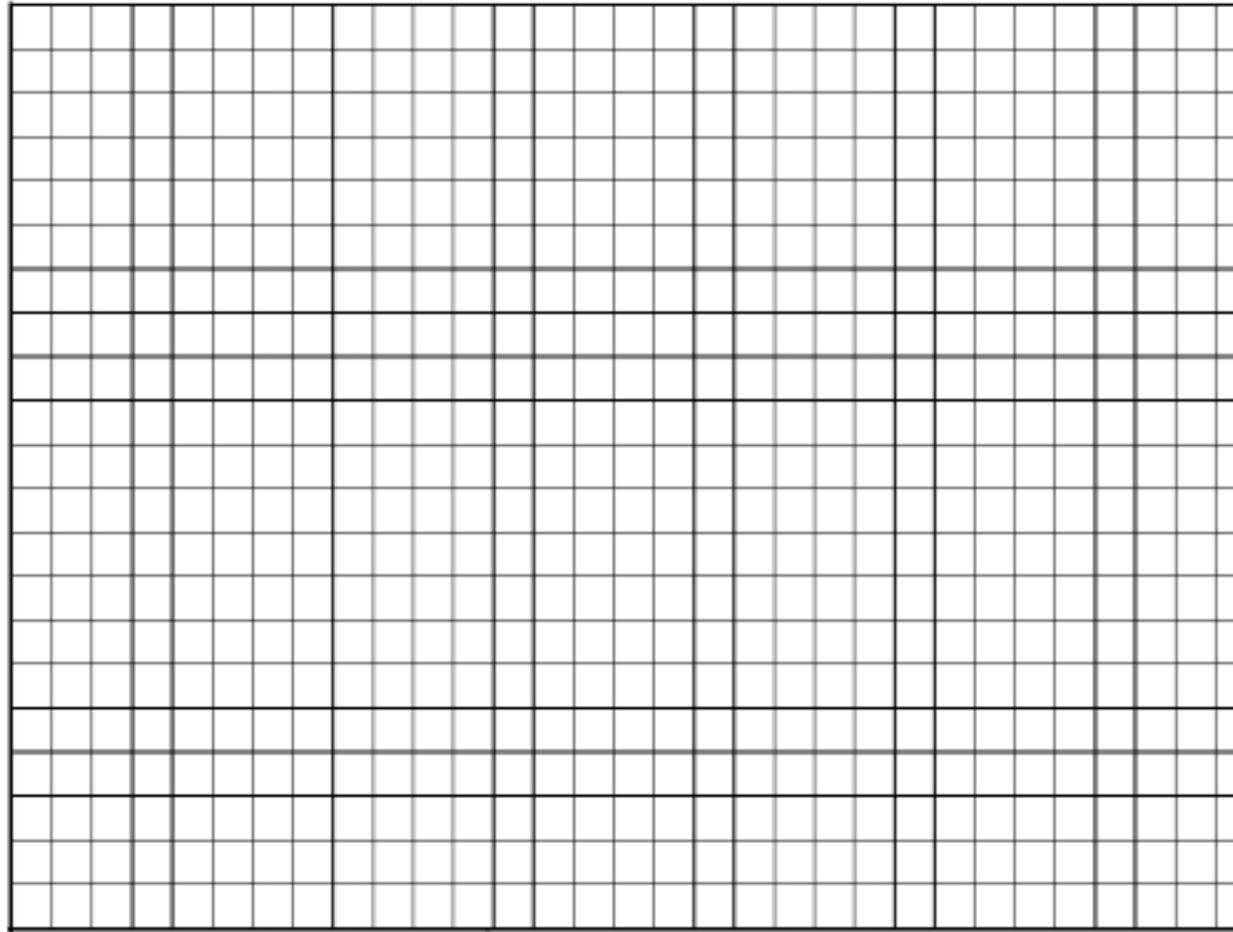


1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

POLE NUMBER

Appendix A-5 C

PRIMARY PROFILE RESISTANCE (ohms)

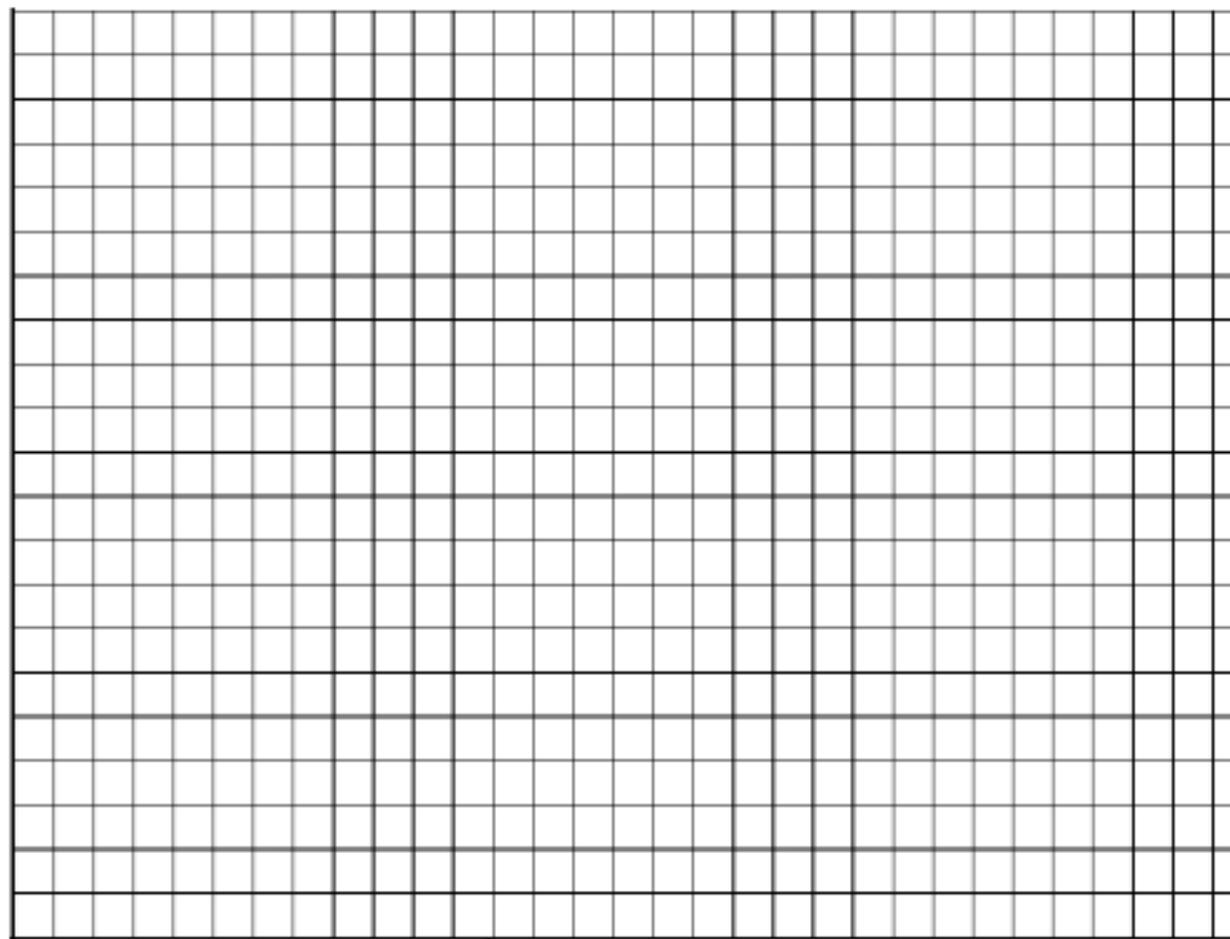


1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

POLE NUMBER

Appendix A-5d

PRIMARY PROFILE VOLTAGE (volts)



1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

POLE NUMBER

Appendix A-5e

"24-HOUR" TEST REPORT FORM

Customer name: _____ Date: _____

Start time: _____ Stop time: _____

Measure the following points with a long term digitizing data recorder: Vp from the primary pole ground rod to remote reference, Vs from the barn's main disconnect panel neutral/ground electrode, Vps between the previous two points, and Vcc, the cow contact voltage.

Data Recorder Settings and Assignments:

**Waveform capture: OFF, Impulse capture: ON, Record min RMS: NO,
Record RMS: YES, Record max RMS: YES, Record time: Maximum,
RMS Storage interval: 10 Sec.**

Channel	Variable	Inputs	Lower RMS	Upper RMS	Impulse
Red	Vp	ON	OFF	OFF	15 V.
Black	Vs	ON	OFF	OFF	15 V.
Blue	Vps	ON	OFF	OFF	15 V.
White	Vcc	ON	OFF	ON, 3V.	10 V.

After recording the data, analyze the reports section and record the following for the number of occurrences of each type of event. The first is from the exceedence report and the second two are from the out-of-limits report.

- | | | |
|----|--|---|
| 1. | VOLTAGE LEVEL: exceeding 1.0 v. RMS max. | Occurrences: <input style="width: 80px; height: 20px; border: 1px solid black;" type="text"/> |
| 2. | VOLTAGE LEVEL: exceeding 3.0 v. RMS max. | Occurrences: <input style="width: 80px; height: 20px; border: 1px solid black;" type="text"/> |
| 3. | IMPULSE VOLTAGE LEVEL:
exceeding 10.0 v. PEAK max.
(For a time duration of 130 microseconds
to 16.67 milliseconds.) | Occurrences: <input style="width: 80px; height: 20px; border: 1px solid black;" type="text"/> |

Additional comments: