

Stray Voltage Test Procedure for Electrical Contractors

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1.0 SCOPE

This document is the standard test procedure for resolving stray voltage, also known as tingle voltage, when the source of the problem is believed to be on the secondary or customer's electrical system. The objective of the procedure is to isolate any faults or deficiencies on the customer's electrical system. This procedure has been developed by Hydro One to assist a qualified electrical contractor in troubleshooting stray voltage problems on the customer's electrical system.

2.0 INTRODUCTION

Neutral-to-earth voltage (NEV) is the voltage measured between the primary distribution system neutral, or the customer's system neutral, and remote earth. Stray voltage is the voltage measured between contact points in a residence, commercial building or a building housing livestock. Stray voltage is typically 40-60% of the NEV. Hydro One designs its primary distribution system so that the NEV does not exceed 10 volts under normal operating conditions.

Small electrical potentials or voltages between any metal structure or equipment and floor surfaces, are natural, explainable and expected phenomena in buildings served by grounded neutral electrical systems. The voltage develops as a result of current returning to the source through the grounded neutral conductors. The neutral conductors on both the primary distribution system and the secondary customer system are connected to earth through ground electrodes or rods. It is the flow of current through these connections to earth that generates NEV and stray voltage. For safety reasons, any metal structure in a building, water lines and case grounds on electrical equipment, are all bonded back to the neutral of the system at the service entrance panel. As a result of these bonds, the metal structures become an integral part of the return path of electrical current to the transformer from which it originates. A human coming in contact with this structure, for example a showerhead, may receive a mild shock. Although this shock may be uncomfortable, it is well below the level considered a hazard. Similarly, livestock that come in to contact with stabling, water bowls, etc., can receive a shock, as the livestock becomes part of this complex configuration of electrical pathways for current flow. See Figure 1 below.

The "threshold of perception" for humans is defined in terms of current. For the adult male, research suggests a perception of current to take place at a measure of 1 mA. The adult female and children are more sensitive, perceiving current at 0.6 mA and 0.5 mA respectively. The "threshold of perception" should not be confused with hazard levels, which are an order of magnitude higher. To translate the "threshold of perception" from levels of current into levels of voltage, it is necessary to consider the total resistance of the pathway from the electrical source, through the body and back to the source. Skin resistance is the largest component of the total body resistance. Skin resistance varies widely and depends on skin condition and the path through the human body. The most frequent complaints originate from individuals receiving shocks in the shower or in the area of swimming pools where the pathway through the body is from the hands to the feet. In these wet environments, a skin resistance as low as 10,000 ohms is possible. At that body resistance, and a threshold of perception of 1 mA, the

voltage that would be required to initiate a response would be 10 volts. Lower resistances are possible but only under abnormal skin conditions such as a cut where the flesh is exposed. **Experience has shown complaints involving humans originate from customer sites where the voltage between contact points exceeded 3 volts.**

The body resistance of livestock is substantially lower than humans. According to one study, the average body resistance of a dairy cow is 359 ohms from the mouth to the all-hooves pathway. It is 738 ohms from the front to rear hooves pathway (see reference /3/). For the purpose of testing, a value of 500 ohms has emerged as a standard in Canada and the US to simulate the body resistance of an animal when making stray voltage measurements (see section 5.0 below for instruction on making voltage measurements).

Earlier studies focused on defining the sensitivity of livestock resulted in recommendations for corrective action at very low voltage levels. A further understanding of tolerance levels resulting from more recent trials indicates that there is little cause for concern in the 0.5–2 volt range commonly found between surfaces contacted by livestock. The Ontario Energy Board 'Appendix H' recommends a level of 1 volt as the safe exposure limit. For more information on 'Appendix H' please visit OEB site,

http://www.ontarioenergyboard.ca/oeb/Documents/Regulatory/Distribution_System_Code_AppH.pdf. The vast majority of research to date supports this limit. **In many cases, this level can only be achieved and maintained by the addition of mitigating devices installed on the customer's secondary system or at the supply transformer.** For additional information on the effects of stray voltage on livestock see the OMAFRA site, <http://www.omafra.gov.on.ca/english/livestock/dairy/facts/strayvol.htm>.

3.0 NORMAL LEVELS OF NEV AND STRAY VOLTAGE

The design limit for NEV on the primary distribution system for all electrical utilities in the province of Ontario is 10 volts. This limit is established by the Ontario Electrical Safety Code (see reference /8/, Rule 75-814). On most lines the NEV peaks at less than 5 volts. Whatever the level, the primary NEV will be transferred into all electrical service panels on the site via the secondary neutral. There will also be contributions from the secondary or customer's system even with a fault free system. Levels of stray voltage above 5 volts may be an indication of a fault on the secondary customer system or the Hydro One primary distribution system.

4.0 TEST EQUIPMENT REQUIREMENTS

The following test equipment is required:

- 2 x true RMS responding multi-meters, such as the HIOKI 3805 multi-meter or equivalent. One meter should be equipped with a current clamp to measure current.
- 2 x 10,000 ohm resistors, 2 watts, $\leq 5\%$ accuracy. Each resistor must be mounted on a dual banana plug such as a Pomona MDP-O/P or equivalent. This is referred to as a bridging resistor in the procedure. It is used when taking neutral-to-earth voltage measurements and stray voltage measurements where humans are concerned.
- 1 x 500 ohm resistors, 2 watts, $\leq 5\%$ accuracy. The resistor must be mounted on a dual banana plug such as a Pomona MDP-O/P or equivalent. This bridging resistor is used for the stray voltage measurements where livestock is concerned.
- 1 x stainless steel portable ground rod. The rod must be at least 1 meter in length and 1.5 cm in diameter. It should be sharpened at one end to ease the insertion into the earth. The 0.5 meter point from the sharpened point should be marked. The rod should be equipped with an appropriate terminal that permits connection to it via an alligator clip.
- 2 rolls of insulated #18 stranded wire, 50 meters in length. One end should be equipped with an alligator clip of suitable size to connect to the ground rod. The other end should be equipped with a banana plug to connect to the multi-meter.
- Insulation Tester, HIOKI 3454-10 or equivalent.
- Floor contact plate for measuring stray voltage. Plate must be copper or stainless steel 15 cm x 15 cm x 1.5 cm. The plate should be equipped with an appropriate terminal that permits connection to it via an alligator clip.
- Pocket calculator.

5.0 NEV AND STRAY VOLTAGE MEASUREMENTS

Throughout this procedure, the following voltage measurements are required:

- Measure Neutral-to-Earth Voltage (NEV). Refer to the manufacturer's manual for instruction on the use of the multi-meter to measure voltage. Connect one lead of the voltmeter to the ground wire that connects the neutral to the ground rod at the service entrance that serves the problem area. Insert a portable ground rod

- 0.5 meter into the earth 15 meters from the ground rod under test. This becomes the remote ground reference point. Using the #18 test lead wire to extend the second voltmeter lead, connect it to the portable ground rod. Install a 10,000 ohm resistor across the input of the meter. Note the reading. Install a second 10,000 ohm resistor across the input of the meter. The reading should not decrease by more than 10%. A reading of more than 10% indicates the portable ground rod is a high resistance. Move the rod to another location to reduce the resistance. When a good connection to earth has been established, remove the second 10,000 ohm resistor from the meter. Read and record the NEV.
- Measure Stray Voltage (SV). Refer to the manufacturer's manual for instruction on the use of the multi-meter to measure voltage. To measure SV for humans, insert a 10,000 ohm bridging resistor across the input of the multi-meter. To measure SV for animals, use a 500 ohm bridging resistor. Connect one lead of the multi-meter to one contact point. This could be a shower head for a complaint involving humans, or a water bowl for a complaint involving livestock. Connect the second lead of the meter to the floor contact plate placed where the human or animal would stand. Move the plate around the site to obtain the highest reading and record. Measure the NEV again and calculate the ratio between the stray voltage and NEV. These two readings should be taken simultaneously to achieve maximum accuracy which requires two multi-meters. The stray voltage should always be less than the NEV. If it is not, this is an indication of a secondary ground fault.

Note: The bridging resistor must be removed when making line-neutral or line-line voltage measurements. The resistor does not have a high enough wattage rating to withstand this level of voltage.

6.0 INITIAL MEASUREMENTS

Test results may be recorded on the form provided in Appendix 1.

6.1 AS FOUND NEV & STRAY VOLTAGE MEASUREMENTS

6.1.1 Measure the NEV at the service entrance with the problem.

6.1.2 Measure the stray voltage in the problem area.

6.1.3 Calculate stray voltage /NEV ratio.

7.0 SERVICE ENTRANCE TESTS

The tests below are performed on the service entrance of the building where the stray voltage problem exists. If there is reason to suspect a problem on one of the other service entrances on the site, these entrances should also be tested.

7.1 BONDING TEST

Bonding all the metal structures in the building to the neutral at the service panel provides a low impedance path for sufficient current to flow to operate the fuse or circuit breaker if a fault occurs. It also prevents stray voltage from developing on an un-bonded

piece of equipment when a low level, high resistance, fault is present. It also lowers the barn grounding resistance.

7.1.1 Open the service entrance main breaker.

7.1.2 Connect one terminal of the multi-meter to the service entrance panel ground. Connect the second terminal of the meter to a test lead long enough to reach throughout the building. This lead should have a sharp probe on the end to penetrate the rust and dirt commonly found in buildings.

7.1.3 Touch the sharp probe to the service entrance panel and measure the lead resistance. This should be less than 5 ohms.

7.1.4 Move around the building and contact each metal part. The readings should be no greater than 1 ohm above the lead resistance measured in 6.3.4 above. Note and repair any improperly bonded equipment.

7.2 SERVICE GROUNDING RESISTANCE TEST

Lowering the service ground resistance will lower the stray voltage. Other benefits are improved electrical safety by reducing voltage rise on faulted equipment, and improved lightning protection by providing a low resistance path for lightning to discharge. Experience has shown that 10 ohms or less is readily attainable in most locations in Ontario on a well bonded system.

7.2.1 Remove all the load on the service panel by opening the main service entrance circuit breaker or disconnect.

7.2.2 Remove the service panel cover to access the two line buses and the neutral bus.

7.2.3 Verify that the panel is de-energized by checking the voltage on the line buses with the multi-meter.

7.2.4 Remove the supply side (transformer side) neutral conductor from the panel and connect the multi-meter between the conductor and the panel. Select milliamps on the multi-meter. Measure and record the current.

7.2.5 With the second multi-meter, measure the NEV.

Note: The readings for voltage and current must be taken simultaneously to be accurate. If only one multi-meter is available, then the readings should be repeated 3 times and the average taken for better accuracy.

7.2.6 Calculate the service grounding resistance (NEV divided by the neutral (ground) current). This number should be less than 10 ohms. If the number is greater than 10 ohms, improvements are recommended.

7.3 SECONDARY NEUTRAL TEST

Voltage drop on the secondary neutral will be split between the grounding of the service under test and the composite value of all the other grounding connected to the neutral, both primary and secondary. For example, if the voltage drop on the secondary neutral was 3 volts, the service grounding measured 10 ohms, the composite value of all other

grounds measured 5 ohms, then the NEV at the service under test would measure 2 volts, ignoring any contribution from the primary system. The voltage drop can be due to a poor connection, an undersized neutral or excessive unbalance.

To test for stray voltage caused by secondary neutral drop:

7.3.1 Remove the entire load from all service entrances except the service under test.

7.3.2 Determine what equipment is likely to be operating during peak use in the service under test. Operate the equipment.

7.3.3 Measure the neutral current with the multi-meter and a current clamp.

7.3.4 Turn off all branch circuit breakers on the distribution panel.

7.3.5 While measuring the neutral current, turn on the branch circuits on one leg of the distribution panel until the neutral current is within $\pm 10\%$ of the value measured in 7.4.3.

7.3.6 Measure the stray voltage.

7.3.7 Remove the entire load and note the change. If the voltage change is 0.25 volts or less, proceed to section 8 below.

If the voltage change measured is greater than 0.25 volts:

7.3.8 Refer to Figure 2. Connect the voltmeter and ammeter as shown.

7.3.9 Create the same unbalanced condition as in 7.4.5 above.

7.3.10 Measure the neutral voltage and current.

7.3.11 Determine the approximate length of the secondary neutral conductor and conductor size. Refer to the table in Appendix 1 for conductor impedances. Calculate the voltage as shown. If the measured voltage is greater than the calculated value by 5%, this indicates a poor connection. Check connections and repair as required.

7.3.12 If the measured voltage is equal to or less than the calculated value, the problem is an undersized neutral for the amount of neutral current and the length of run. The solutions are:

- Improve the load balancing on the service. A level of 20% of the service rating should be achievable by rearranging circuits in the panel, or by converting some of the 120 volts equipment to 240 volts equipment.
- If the secondary neutral drop exceeds 3 volts after the load balancing has been improved, the secondary neutral size should be increased.
- If the secondary neutral drop is less than 3 volts, some solutions such as the Hammond Tingle Voltage Filter may be used to reduce the stray voltage to acceptable levels.

7.4 ADDITIONAL TESTING

The testing that follows will allow for further troubleshooting if the preceding tests have identified there is likely problems deeper in the customer's electrical system. These additional tests will require wires to be removed from breakers as well as other temporary wiring changes. Due to the age of some panels it might be prudent to have sourced some spare breakers and other materials prior to attempting these tests. The ESA will also require a permit on any changes you are making to your system. An inspection will be required once testing and repairs are complete if your electrician is not on the ESA's Approved Contractors List.

If the stray voltage measured is above acceptable levels, contact Hydro One. If the stray voltage measured is between 50% and 100% of the acceptable level, it is recommended that a recording voltmeter (RVM) be installed to measure the NEV and stray voltage. The RVM should be left on for a period of 72 hours minimum to ensure all load cycles on both the primary and secondary systems are recorded.

7.5 INSULATION TEST

Insulation failure that results in a fault current level below the operating point of the circuit breaker or fuse will cause stray voltage if the fault results in a flow of ground current. Faults can be from line-to-neutral, line-to-ground, neutral-to-ground or line-to-line for 240 volt equipment. The test below will not detect line-to-neutral or line-to-line faults, which do not cause stray voltage because they do not result in a flow of ground current.

Refer to Figure 3.

7.5.1 Open the service entrance main breaker and leave the branch circuit breakers closed.

7.5.2 Close all switches at the equipment including lights.

7.5.3 Remove the distribution panel cover.

7.5.4 Check with a voltmeter to ensure the panel is completely de-energized.

7.5.5 Remove the supply side (transformer side) neutral conductor. Remove the bonding screw from the neutral bar. Remove any other ground connections on the neutral bar such as connections to the water system or ground rod. Temporarily connect these to the ground bar in the panel.

7.5.6 Refer to the instruction manual of the tester for directions on performing tests. Connect one lead of the insulation tester to the service entrance ground bus and the second lead to the neutral bar. Perform the insulation test on the 500 volt range. The readings should be 50,000 ohms or greater.

7.5.7 Test each bus (line) of the distribution panel. The reading should be 50,000 ohms or greater.

7.5.8 Any 240 volt equipment which is turned on and off by magnetic contactor or motor starter, or any other equipment which is not connected to the distribution panel bus at the time of the test, must be tested separately. To perform this test, remove the cover of the contactor and connect the insulation tester on the load side of the contactor. The reading should be 100,000 ohms or greater.

7.5.9 If the insulation measured is less than 50,000 ohms in 7.3.6 or 7.3.7 above, it is necessary to test each branch circuit individually (see Figure 4). All readings should be 100,000 ohms or greater.

7.6 INTERPRETATION OF THE 72 HOUR RECORD

Retrieve the records from the RVM. Convert the NEV readings to stray voltage readings by using the ratio obtained in 6.1.3 above. If the highest stray voltage is less than the acceptable limit, then there is no stray voltage problem. If the limit is exceeded, contact Hydro One. Hydro One will perform tests on the primary distribution system to determine if there are any faults or deficiencies on the utility system. If Hydro One does not uncover any problems or make improvements that lower the stray voltage, proceed with the tests in section 7.0 below.

8.0 STRAY VOLTAGE SOLUTIONS

The tests outlined in this procedure, and those performed by Hydro One on the distribution system, are designed to uncover faults or deficiencies on either the customer's system or the Hydro One system. If stray voltage still measures above acceptable levels after the sources described in this document are eliminated by improvements, then the stray voltage must be reduced by employing one of the mitigation techniques. This includes bonding, special isolation procedures or the use of an isolating device.

REFERENCES

/1/ PSC White Paper Series, "On distinguishing various contributors to Stray Voltage"
M. Cook, D. Dasho, R. Reines, D. Reineman, Mar. 1994.

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/3/ Review of Literature on the Effect of the Electrical Environment on Farm Animals, 6 November 2003 Draft, Douglas J. Reinemann, Ph. D., University of Wisconsin-Madison

/4/ Hydro One Document, "Resolution of Tingle Voltage Complaints", PR 0273 R0, Oct.2002

/5/ Ontario Hydro, "Tingle Voltage, Customer Service Reference Manual", Section 10, May 7, 1987.

/6/ OMAFRA Publication, "Stray Voltage Problems in Livestock Production", Jack Rodenburg, Fall Seminar, 1998.

/7/ Ontario Hydro, "The Resolution of Tingle Voltage Complaints" Line Trade Reference and Work Methods Manual, Section 14, January 30, 1984.

/8/ Ontario Electrical Safety Code, 25th Edition/2012.

SUPPLEMENTARY FIGURES

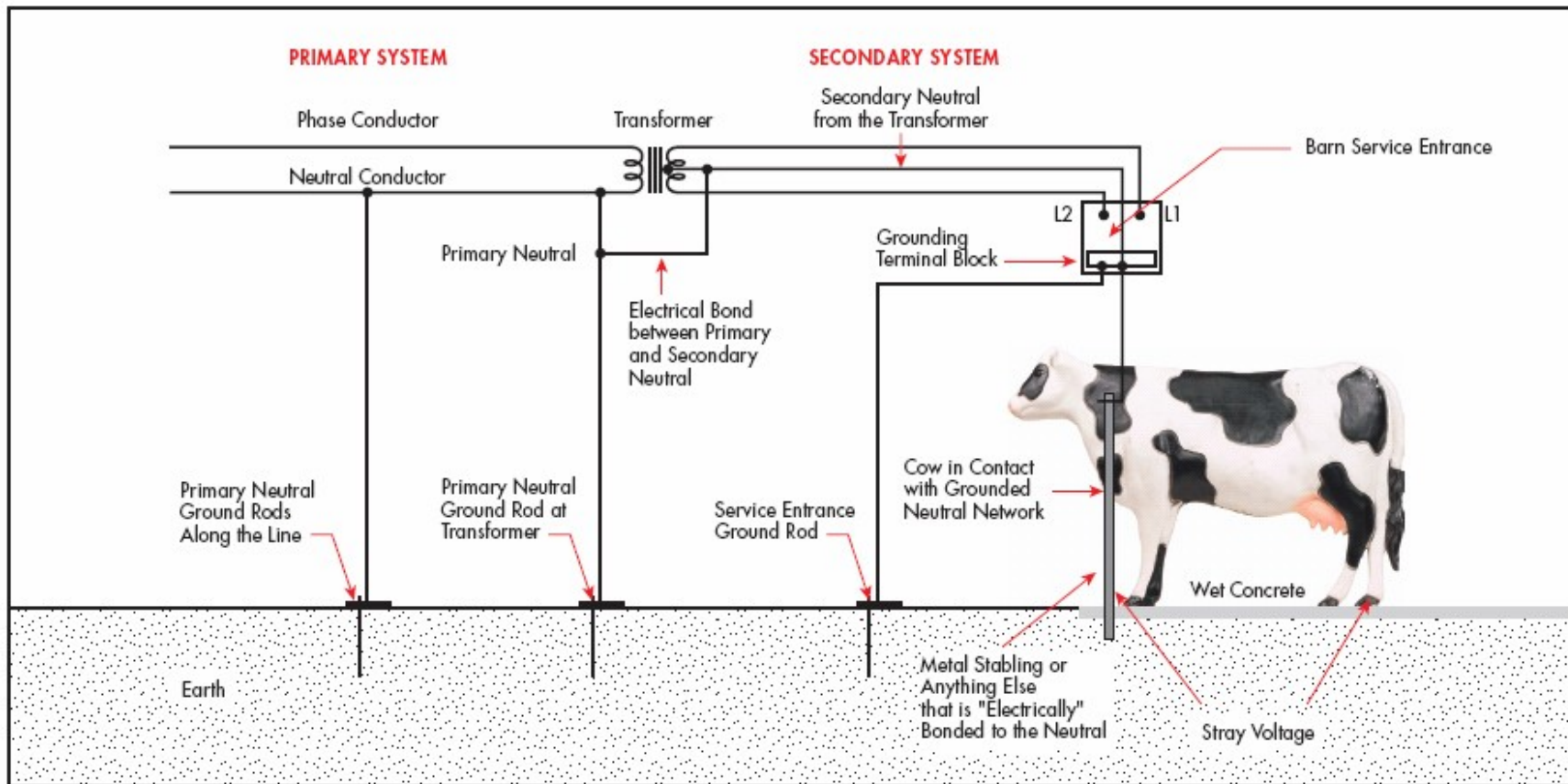


FIGURE 1: DAIRY COW SUBJECTED TO NEUTRAL-TO-EARTH VOLTAGE

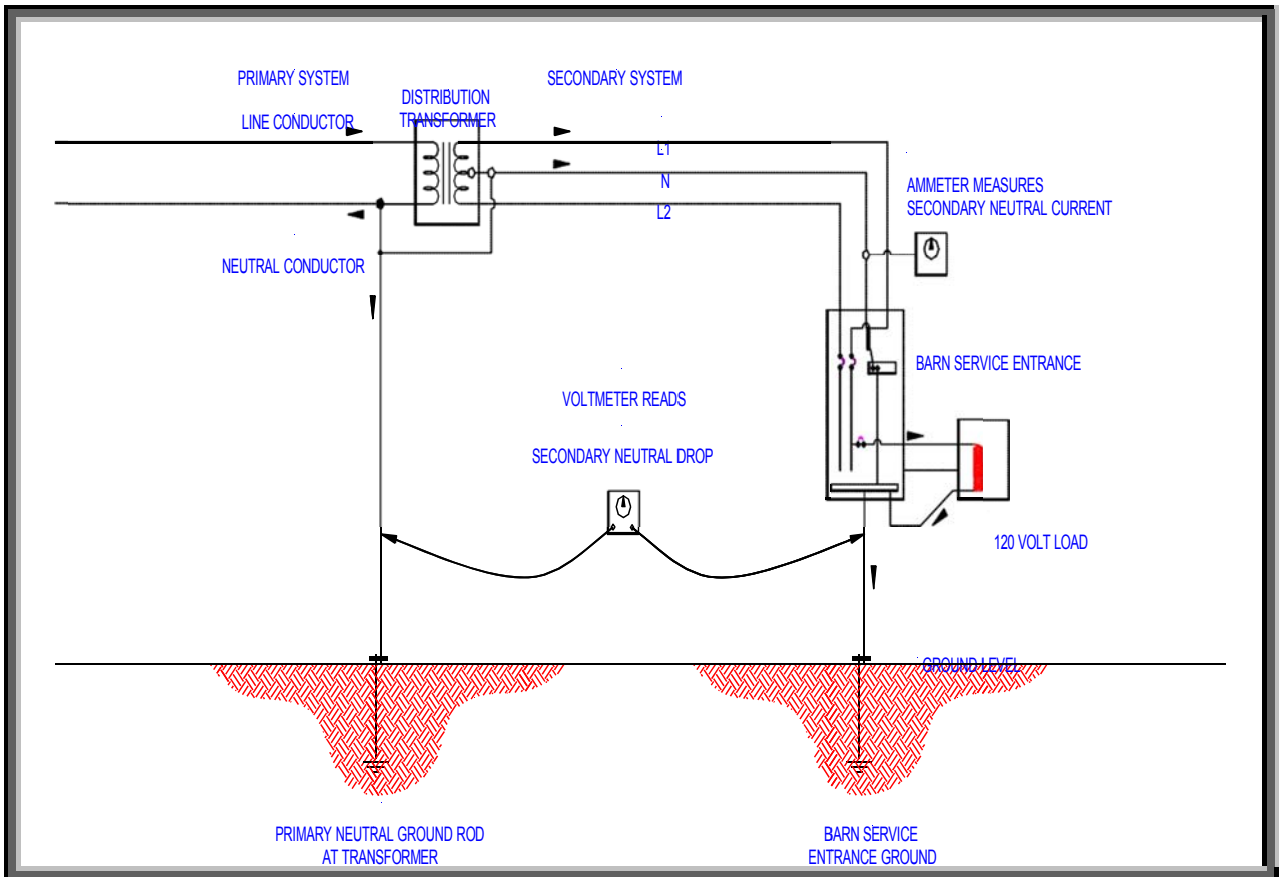


FIGURE 2: SECONDARY NEUTRAL TEST

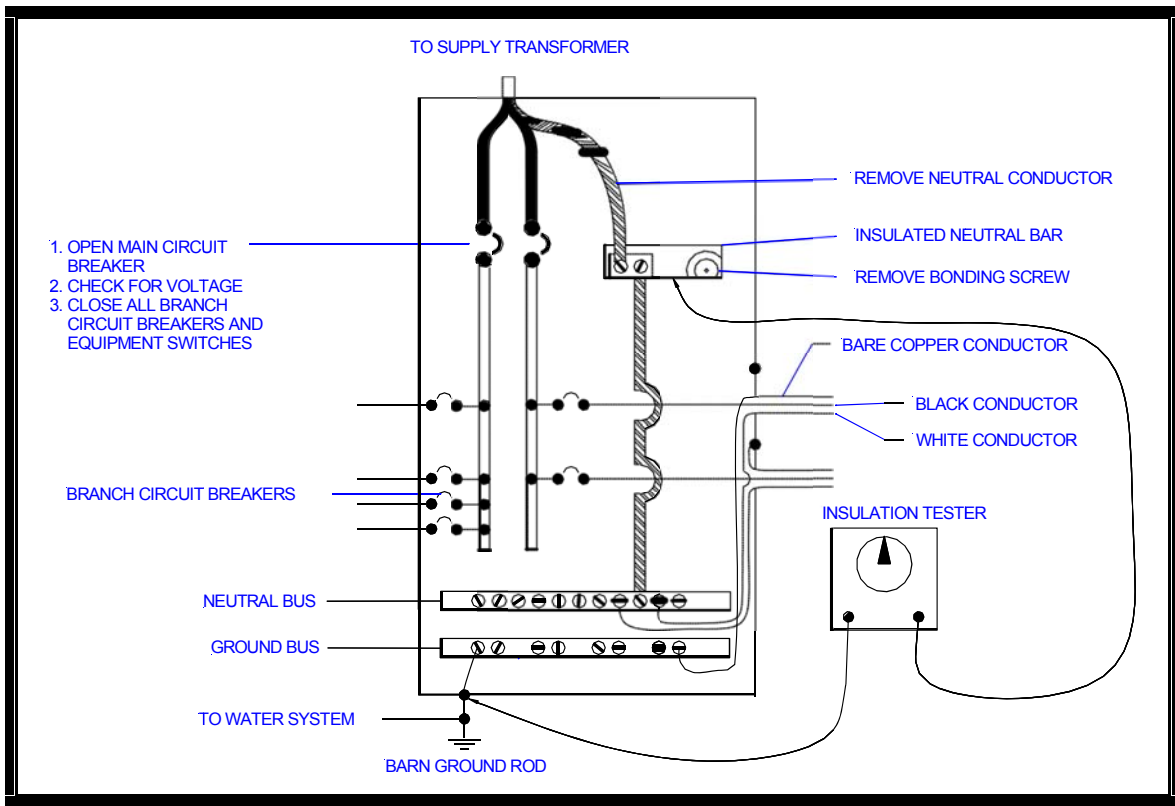


FIGURE 3: INSULATION TEST COMPLETE SYSTEM

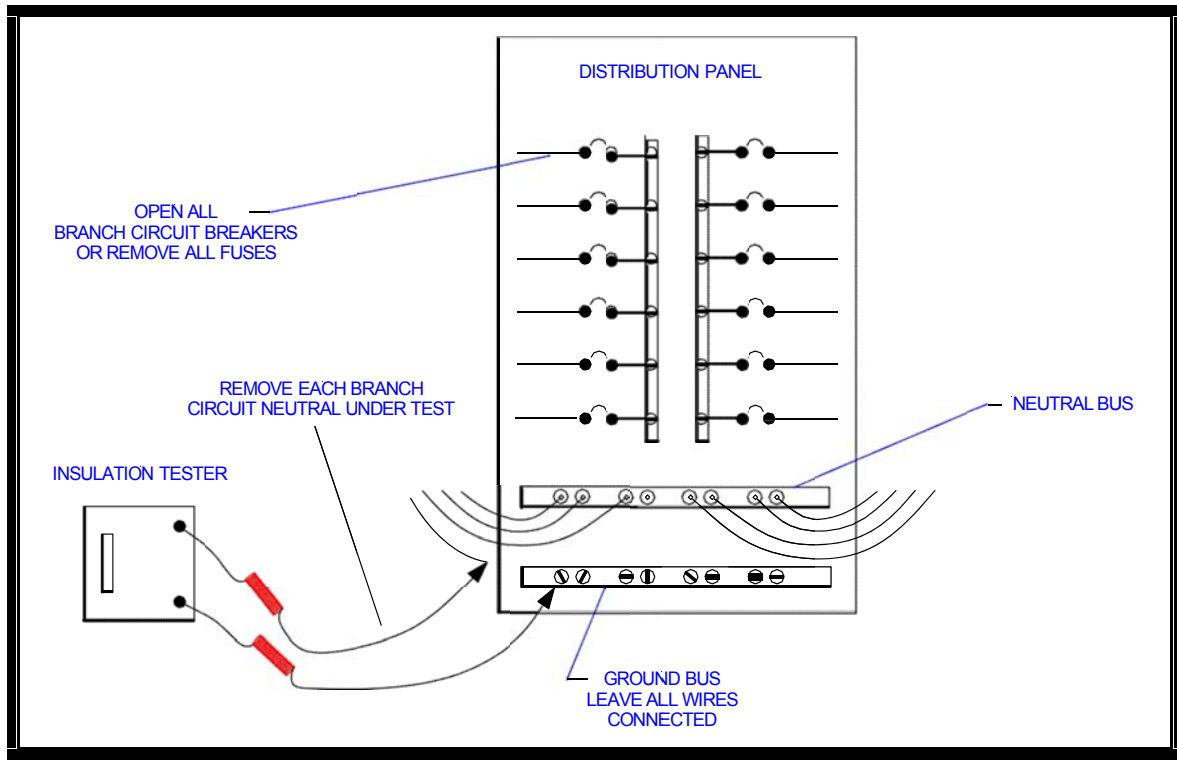



FIGURE 4: INSULATION TEST INDIVIDUAL CIRCUITS

TESTING SHEETS

	
Customer Name	
Address	
Contractor/Electrician	
	Date & Comments
Investigation	
Previous Investigations	

6.1 AS FOUND NEV & STRAY VOLTAGE TESTS

On-load Tests (conduct tests with normal service load)

Time of Tests		
6.1.1 Neutral to Earth (NEV)		
6.1.2 Stray Voltage (SV)		
6.1.3 Ration (SV/NEV)		

7.1 BONDING TEST

7.1.3 Lead Resistance	
7.1.4 Resistance Measurements to all bonded equipment and structures	
Location requiring improvement	
Location requiring improvement	
Location requiring improvement	
Location requiring improvement	
Location requiring improvement	
Location requiring improvement	

7.2 SERVICE GROUNDING RESISTANCE TEST

7.2.4 Service Neutral Current	
7.2.5 Neutral to Earth Voltage (NEV)	
7.2.6 Calculated Barn Ground Resistance	

7.3 Secondary Neutral Test

7.3.3 Neutral Current	
7.3.6 Stray Voltage	
7.3.10 Neutral Current	
7.3.10 Secondary Neutral Voltage at Transformer	

Impedance of Neutral Conductors

Size AWG	Bare Copper		Aluminum	
	milliohms/Ft	milliohms/Ft	milliohms/Ft	milliohms/Ft
#8	0.640	2.101	1.050	3.445
#6	0.410	1.345	0.674	2.211
#4	0.259	0.850	0.424	1.391
#2	0.162	0.531	0.286	0.873
1/0	0.102	0.335	0.168	0.551
2/0	0.081	0.286	0.133	0.436
3/0	0.064	0.211	0.105	0.344
4/0	0.051	0.167	0.084	0.274

7.3.11 Calculated Voltage Drop
 Eg. length = 35 M, #4 Alum, Current-23 A
 Voltage Drop = 35 x 1.391/1000 x 23 = 1.20 Volts

7.3.12 Secondary Neutral Acceptable (Yes/No)	
Implemented Improved Balancing (Yes/No)	
Increased Conductor Size (Yes/No)	
Other - Describe in Comments	

7.5 INSULATION TEST

7.5.6 Insulation Resistance of Neutral Bus	
7.5.7 Insulation Resistance of Line 1 Bus	
Insulation Resistance of Line 2 Bus	
7.5.8 Insulation Resistance of 240 V Equipment	
Insulation Resistance of 240 V Equipment	
Insulation Resistance of 240 V Equipment	
Insulation Resistance of 240 V Equipment	
Insulation Resistance of 240 V Equipment	
Insulation Resistance of 240 V Equipment	
7.5.9 Insulation Resistance of Circuits	
Insulation Resistance of Circuits	
Insulation Resistance of Circuits	
Insulation Resistance of Circuits	
Insulation Resistance of Circuits	
Insulation Resistance of Circuits	
Insulation Resistance of Circuits	
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Insulation Resistance of Circuits	
Insulation Resistance of Circuits	
Insulation Resistance of Circuits	
Insulation Resistance of Circuits	

7.6 INTERPRATION OF 72 HOUR RECORD

7.6.1 Max NEV	
7.6.2 Date of Max NEV	
7.6.3 Time of Max NEV	
7.6.4 Calculated Stray Voltage (Max NEV x Ratio)	(7.6.1 x 6.1.3)
7.6.5 Stray Voltage Problem (YES / NO)	
7.6.6 Hydro Contacted (YES / NO)	

Recommended Limits : 1 Volt for livestock & 3 Volts for Humans