Stray Voltage Solutions Guide for Electrical Contractors

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1.0 SCOPE

This document provides application guidelines for the resolution of stray voltage, also known as tingle voltage, when the source of the problem is determined to be the inherent voltage of the primary or secondary multi-grounded distribution system. The test procedure for determining the source of the problem is described in the Hydro One publication entitled "Stray Voltage Test Procedure for Electrical Contractors", referred to as reference /1/ throughout this document. The Stray Voltage Test Procedure for Electrical Contractors is also available from the Hydro One website www.hydroonenetworks.com/strayvoltage.

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 is developed 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. 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, for safety reasons. As a result of these bonds, all of the structure, etc., becomes 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 which is uncomfortable although it is well below the level considered a hazard. Similarly, livestock which come in contact with stabling, water bowls, etc., can receive a shock, as they become 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, the literature suggests 1 mA. The adult female and children are more sensitive, 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 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 reference /1/ for instruction on making voltage measurements.

Earlier studies, which 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 Ministry of Agriculture, Food and Rural Affairs (OMAFRA) are recommending a level of 1 volt as the safe exposure limit. 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, www.omafra.gov.on.ca/english/livestock/dairy/facts/strayvol.html.

3 0 MITIGATION TECHNIQUES

Hydro One will perform tests on the primary or utility distribution system to eliminate any problems on it prior to the customer making expenditures on mitigation devices. In addition, the tests outlined in the "Stray Voltage Test Procedure for Electrical Contractors" document (available on www.hydroonenetworks.com/strayvoltage) should be completed to ensure there are no faults or deficiencies on the secondary or customer distribution system. Ignoring this step jeopardizes the safety of humans and livestock served by the customer distribution system. Furthermore, the mitigation devices are designed to work on a fault free system and may not function if faults exist.

Stray Voltage solutions fall into one of the following three categories:

1) Bonding. All the conductive components of any structure are electrically connected together or bonded thereby reducing the step and touch potentials to minute values below the level of concern, or in most cases, the level of perception. The equipotential grid falls into this category.

2) Isolation. A device is installed at the supply transformer or at the service panel to reduce the flow of ground current into the problem area under normal operating conditions while allowing high levels of current to flow under fault conditions. The Dairyland Neutral Isolator (VT/NI), the Hammond Tingle Voltage Filter and the Ronk Blocker all fall into this category. An isolation transformer also falls into this category. It is a very effective solution shielding the service from both the primary and secondary components of stray voltage. However, it is an expensive option with ongoing costs due to losses and a high up front installed cost of $4,000-$5000 for a 50kVA unit suitable for buildings housing livestock. Therefore, it is not recommended and will not be discussed.

3) Current Balancing Transformer. This device is installed on the primary line between utility supply and the customer's supply transformer. It is a two winding transformer with one winding in series with the phase conductor and the other winding in series with the neutral conductor. The transformer action forces the load current flowing in the phase conductor to return via the neutral conductor rather than through the grounding system. It presents a high impedance path for any neutral current from off-farm sources that attempts to flow through the farm grounding system. The installed cost of this device is approximately $5,000. It is not recommended because of its high cost and will not be discussed.

4) Active Suppression. These active systems operate on the principle of measuring the neutral-to-earth voltage and injecting a ground current into the barn grounding system to negate the ground current from the primary or secondary distribution system sources.. These solutions have an installed cost $10,000 and up. They are not recommended due to their high cost and will not be discussed.

4.0 SELECTING THE STRAY VOLTAGE SOLUTION

Selecting the most appropriate solution depends on the situation. Is the problem in a residence, a recreational facility, or a livestock facility? Does it involve humans or only animals? Is a solution being considered for a new installation as an insurance measure to avoid a stray voltage problem? The objective is to select the most economic approach to prevent or resolve the problem.

Stray voltage complaints involving humans are most often reports of people getting shocks in showers or around swimming pools. In these cases, the individual's body resistance is lowered because their body is wet. Contact is made with a metal object that is bonded to the multi-grounded neutral resulting in a current flow through the body high enough to produce discomfort.

In the case of the shower, the voltage flows between the floor/shower drain and the shower head and taps. Possible solutions are:

a) If the shower drain is metallic, bond the drain to the shower head and taps.
b) Insert a 0.5 metre piece of non-metallic pipe in the water supply to isolate the shower head and taps from the multi-grounded neutral.
c) If the floor is concrete and contains steel reinforcing bars, access the bars and bond them to the shower head and taps.

d) Install an isolation device on the service or the supply transformer. See Section 5.0 below for installation instructions.

In the case of the swimming pool, the voltage usually flows between a metal object such as the pool ladder and the pool interior or deck. Possible solutions are:

a) Where reinforcing steel is used in the construction of the pool, bond the steel to all metal components that a person could contact, and bond the steel to the multi-grounded neutral to create an equipotential plane. See the Ontario Electrical Safety Code, 23rd Edition/2002, Rules 68-058(4) and 68-058(8) for more details.
b) Install an isolation device on the service or the supply transformer. See Section 5.0 below for instructions on installing these devices.

For buildings housing livestock, the solution depends on the age of the building structure (i.e. new-build or old). For a new milking parlour in a dairy barn, the Ontario Electrical Safety Code requires the installation of an equipotential grid (see rule 75-412). The equipotential grid may also be an economic approach for tie stall or free stall barns at the time of construction. Although techniques have been developed to install a grid in an existing barn, it is often impractical because the installation of the grid will require the animals to be housed elsewhere during the construction phase. For more information on the installation techniques for equipotential grids, see "Equipotential Planes for Stray Voltage Reduction". This document is produced by the Midwest Rural Energy Council and is available on their website, www.mrec.org/sv-info.html.

For existing barns, the most economic solution is an isolating device. The three devices currently available and approved for use in Ontario are:

1. Hammond Tingle Voltage Filter (TVF). This devise is installed by a qualified electrical contractor. The TVF is installed at the service panel on the service where the stray voltage problem persists. It separates that service panel neutral from the ground at that point. Because it is installed at this point on the secondary electrical system, it mitigates all off-site sources, on-site sources from other service panels, and secondary neutral voltage. It is rated for a service size of 200A. For a 400 A service, two units connected in parallel are required. The TVF is no longer manufactured by Hammond but is available in the after market. One supplier is:

Sussex Farm Supplies
3292 Route 121st
Sussex, NB
E4E 5L2
Phone: (506) 433-1699
E-mail: sussexfarm@nb.aibn.com

The current price as of January 2007 is $500.

2. Dairyland Neutral Isolator (VT/NI). This device is installed by Hydro One personnel at the transformer pole between the primary (utility) distribution system neutral and the secondary (customer) distribution system neutral. Because it is installed at this point, it

mitigates all off-site sources for the entire site. This can be ordered directly from the manufacturer at:

Dairyland Electrical Industries, Inc.
P.O. Box 187
Stoughton, WI. 53589
USA
Phone: (608) 877-9900
Fax: (608) 877-9920
Website: www.dairyland.com/index.php?page=products_vtni.html

The current price as of January 2007 is $900 CDN.

3. Ronk Blocker. This device is installed by Hydro One personnel at the transformer pole between the primary (utility) distribution system neutral and the secondary (customer) distribution system neutral. Because it is installed at this point, it mitigates all off-site sources for the entire site. One supplier is:

L & B Stray Voltage Services
17 Edward
Drayton Moorefield, ON
N0G 1P0
(519) 638-3680

The current price as of January 2007 is $1700.

5.0 INSTALLATION INSTRUCTIONS FOR ISOLATING DEVICES

Prior to installing any of the isolating mitigation devices, it is necessary to eliminate any sources that could bypass the mitigation device by re-connecting the primary and secondary neutrals. The two most common sources are Bell Canada and the Cable TV Company. On some installations, Bell Canada uses a shielded cable to provide the telephone circuit. The shield of this cable is connected to the utility primary distribution neutral for safety and operational reasons. The cable runs from the Bell Canada pedestal to the lightning protector, which is normally mounted outside the building which is to be served. The ground on this protector is often connected to the service entrance ground in the building. This will bypass the isolating device mounted at the transformer or the Hammond TVF in the service panel. Cable TV suppliers have similar practices. Contact these service providers for a solution.

Another potential bypass is the water supply. If metallic pipe is used throughout, it will be bonded to the secondary neutral at the service panels on the site. If for example, the house and the livestock barn have a common water supply, and a Hammond TVF was installed in the livestock barn, then the TVF would be bypassed. This can be remedied by installing a 0.5 metres section of non-metallic pipe in the line between the house and the barn.

5.1 HAMMOND TINGLE VOLTAGE FILTER (TVF)

The TVF is installed at the service panel which is to be isolated. The installation should be performed by a qualified electrical contractor, familiar with the Hydro One test procedure for the secondary or customer system. This procedure is available on www.hydroonenetworks.com/strayvoltage.

Figure 2 below shows the installation in a livestock barn, the most common application. The bonding screw must be removed from the neutral bar. The neutral terminal of the TVF is connected to the neutral bar of the service panel, and the ground terminal of the TVF is connected to the ground bar of the service panel. In order for the TVF to function correctly, all bonding sub-panels supplied by the main panel must be removed and all neutral-to-ground faults and all line-to-ground faults must be located and repaired.

The effectiveness of the TVF also depends on the value of the service grounding as the unit acts as a voltage divider (see Figure 3 and 4 below). For example, if the neutral-to-remote earth voltage is 5 volts, the ground-to-remote earth voltage will be approximately 0.06 volts if the ground resistance is 10 ohms. If the ground resistance measured 100 ohms, then the ground-to-remote earth voltage would be 0.68 volts. The ground resistance of a typical livestock facility is under 10 ohms. If the ground resistance is measured to be greater than 10 ohms, then improvements should be made.

5.2 DAIRYLAND NEUTRAL ISOLATOR (VT/NI)

Hydro One will install the VT/NI on the transformer pole. The customer is expected to coordinate with Bell Canada or the Cable TV Company, if required, and to have his or her electrical contractor on site at the same time to perform the in-service tests. The contractor should be qualified and have completed the Hydro One test procedure for the secondary or customer system (document is available on www.hydroonenetworks.com/strayvoltage). For more information on installation requirements, contact Dairyland Industries. The performance of the VT/NI in reducing stray voltage does not depend on the value of ground resistance.

5.3 RONK BLOCKER

Hydro One will install the Blocker on the transformer pole The customer is expected to coordinate with Bell Canada or the Cable TV Company, if required, and to have his or her electrical contractor on site at the same time to perform the in-service tests. The contractor should be qualified and have completed the Hydro One test procedure for the secondary or customer system (document is available on www.hydroonenetworks.com/strayvoltage). For more information on installation requirements, contact L & B Stray Voltage Services (see Section 4.0 above). The performance of the Blocker is less sensitive to ground resistance than the TVF.

5.4 TESTS FOR ISOLATING DEVICES

Any of the isolating devices referred to above, can be tested with a resistor to simulate the ground resistance, a variac, and a multi-meter. Connect the resistor in series with

the unit under test. Using the variac, apply a voltage to the series combination (see Figure 5 below). Measure the applied voltage, $V_{in,}$ and the voltage across the resistor, $V_{OUT.}$ With 10 volts applied, the voltage across the resistor should be < 0.15 volts for the Hammond TVF, <0.07 for the Ronk Blocker and <0.05 for the Dairyland VT/NI.

6.0 IN SERVICE TESTS FOR ISOLATING DEVICES

Refer to the Stray Voltage Test Procedure for Electrical Contractors (document available on www.hydroonenetworks.com/strayvoltage) for instructions on measuring Neutral-to-Earth Voltage (NEV) and Stray Voltage (SV).

6.1 TESTS FOR THE HAMMOND TVF

With the power off at the site, measure the secondary NEV and the ground-to-remote earth voltage at the service entrance panel where the TVF is installed. The ratio secondary NEV/ ground-to-remote earth voltage should be ≥ 20 and the ground-to-remote earth voltage should be < 0.25 V. If either of these tests fails, this indicates a bypass, neutral-to-ground fault on the service where the unit is installed, incorrect installation, deficient grounding, or a defective unit. To correct the situation, refer to /1/ for troubleshooting faults or deficiencies, re-check that the unit has been installed correctly, check for bypasses, and lastly, check the TVF as described in 5.4 above.

If the “power-off” tests are successful, turn on the power at all service entrances except the service where the unit is installed. Measure the secondary NEV, the ground-to-remote earth voltage and the SV. The secondary NEV should be < 5.0 V. If not, this indicates a primary neutral problem, a secondary neutral problem, or a ground fault on another service on the site. The ground-to-remote earth voltage should be <0.5 V and the SV should be < 0.25 V. To correct the situation, refer to /1/ for troubleshooting faults or deficiencies. If no problems are found on the secondary or customer system, contact Hydro One.

If all the tests above are successful, turn the power on at the service where the TVF is installed. Measure the secondary NEV, the ground-to-remote earth voltage, and the SV. The secondary NEV should be < 5.0 V. If not, this indicates a secondary neutral problem on the service where the unit is installed. The ground-to-remote earth voltage should be <0.5 V and the SV should be < 0.25 V. If not this indicates a fault in the service where the unit is installed. Refer to /1/ for troubleshooting.

6.2 TESTS FOR THE VT/NI OR THE RONK BLOCKER:

With the power off at the entire site, measure the primary NEV and the secondary NEV at the transformer pole. The ratio primary NEV/ secondary NEV should be ≥ 40 and the secondary NEV should be < 0.25 V. If either of these tests fails, this indicates a bypass, incorrect installation or a defective unit. To correct the situation, re-check that the unit has been installed correctly, check for bypasses, and lastly, check the isolating device as described in 5.4 above.

If the “power-off” tests are successful, turn on the power at all service entrances. Measure the secondary NEV at the service entrance of the building with the SV problem. Measure the SV in the problem area. The secondary NEV should be < 0.5 V and the SV should be < 0.25 V. If either of these tests fails, this indicates a secondary neutral problem or a ground fault on one of the services. Refer to /1/ for tests to locate and correct the problem.

6.3 RECORDING VOLTMETER TESTS

When all tests are complete, install a recording voltmeter (RVM) to measure the ground-to-remote earth voltage at the service entrance in the problem area. Hydro One will provide this service upon request. 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.

7.0 MAINTENANCE TESTS FOR ISOLATING DEVICES

The isolating devices are highly reliable passive devices. Failures are possible due to lightning but the most likely problem is the device being bypassed. Therefore, anytime that electrical improvements or changes are made on the property, it is recommended that the stray voltage be measured after the work is complete. Similarly, if changes are made to the telephone or cable TV service on the property, the stray voltage should be measured upon completion of the work. As an insurance measure, periodic checking is recommended. The level of stray voltage measured should be within 20% of the highest value recorded during the in-service tests. If this level is exceeded, the in-service test should be repeated to determine the problem.

REFERENCES

/1/ Hydro One Document, "*Stray Voltage Test Procedures for Electrical Contractors*", October 2007.

/2/ Ontario Hydro, "*Tingle Voltage, Customer Service Reference Manual*", Section 10, May 7, 1987.

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

SUPPLEMENTARY FIGURES

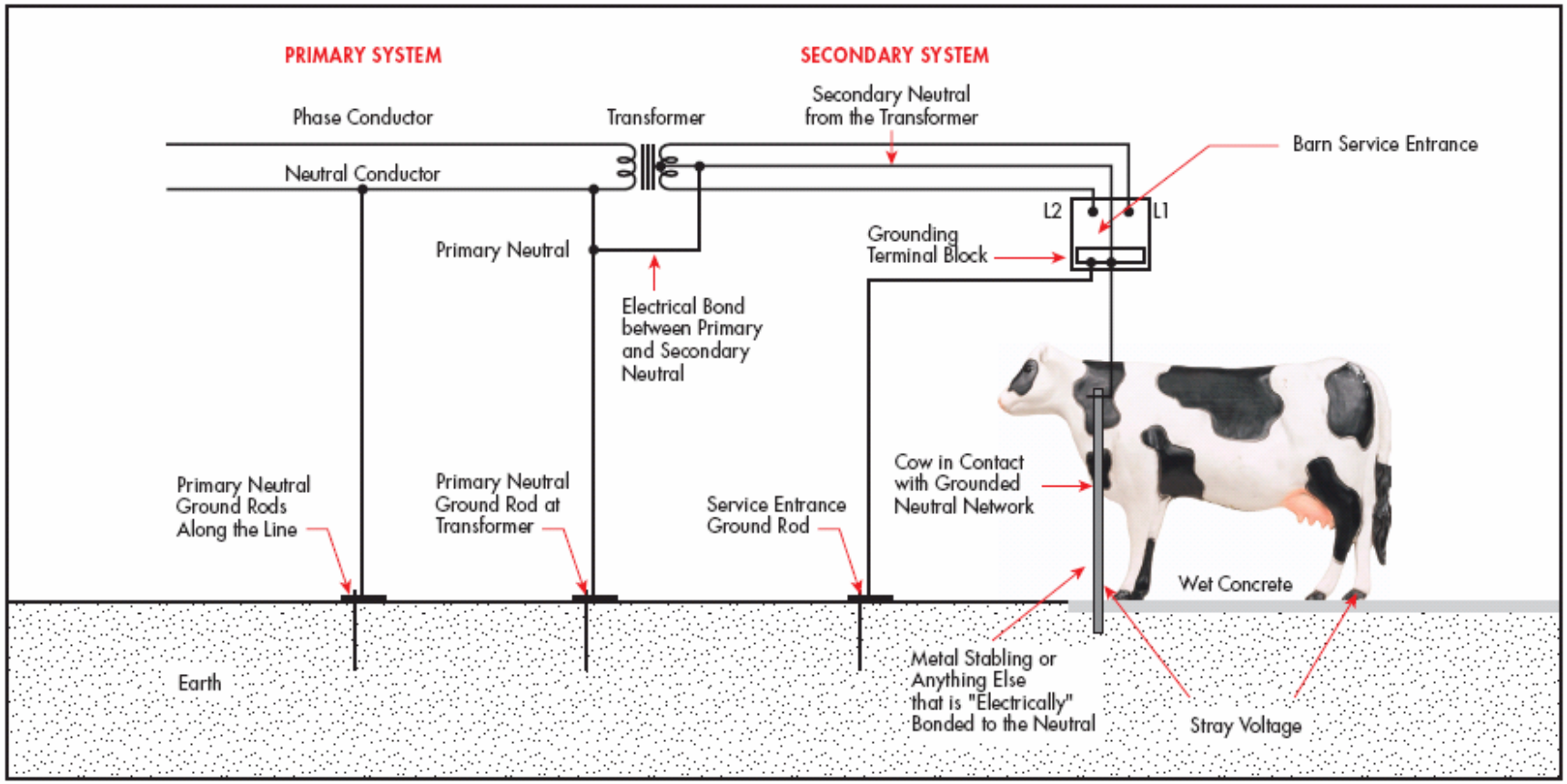

FIGURE 1: DAIRY COW SUBJECTED TO NEUTRAL-TO-EARTH VOLTAGE

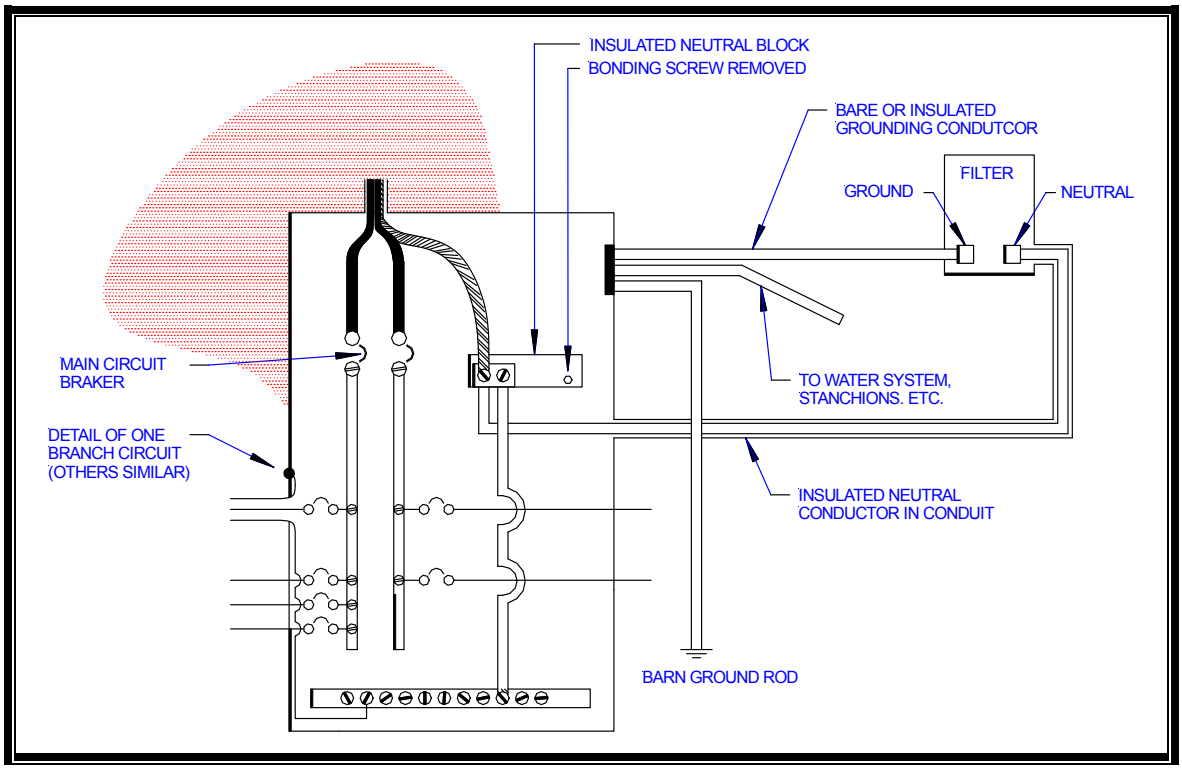

FIGURE 2: HAMMOND TINGLE VOLTAGE FILTER INSTALLATION

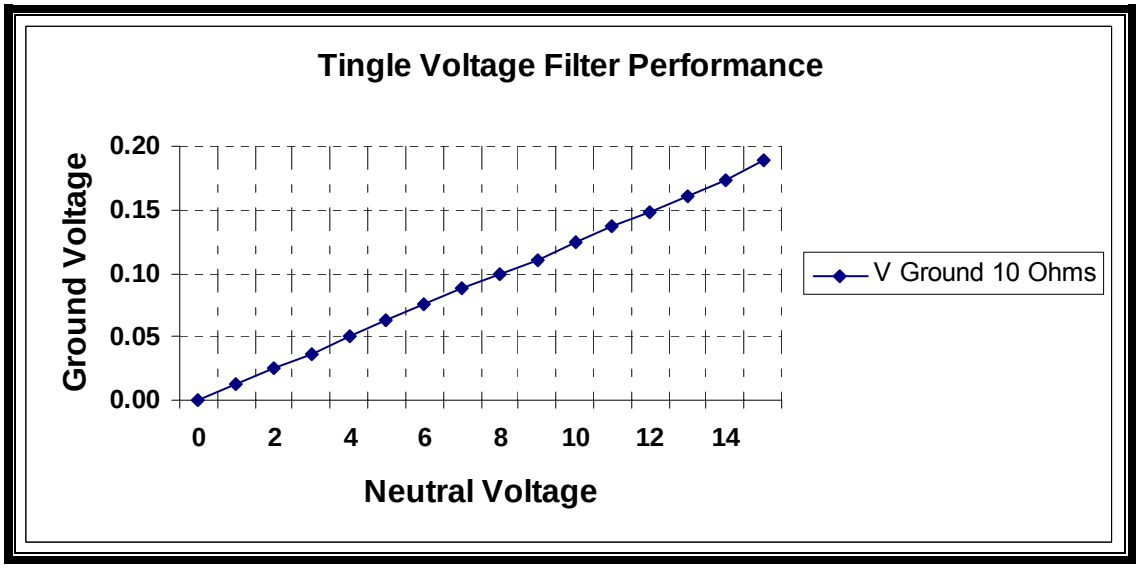

FIGURE 3: HAMMOND TINGLE VOLTAGE FILTER PERFORMANCE 10 OHM GROUND

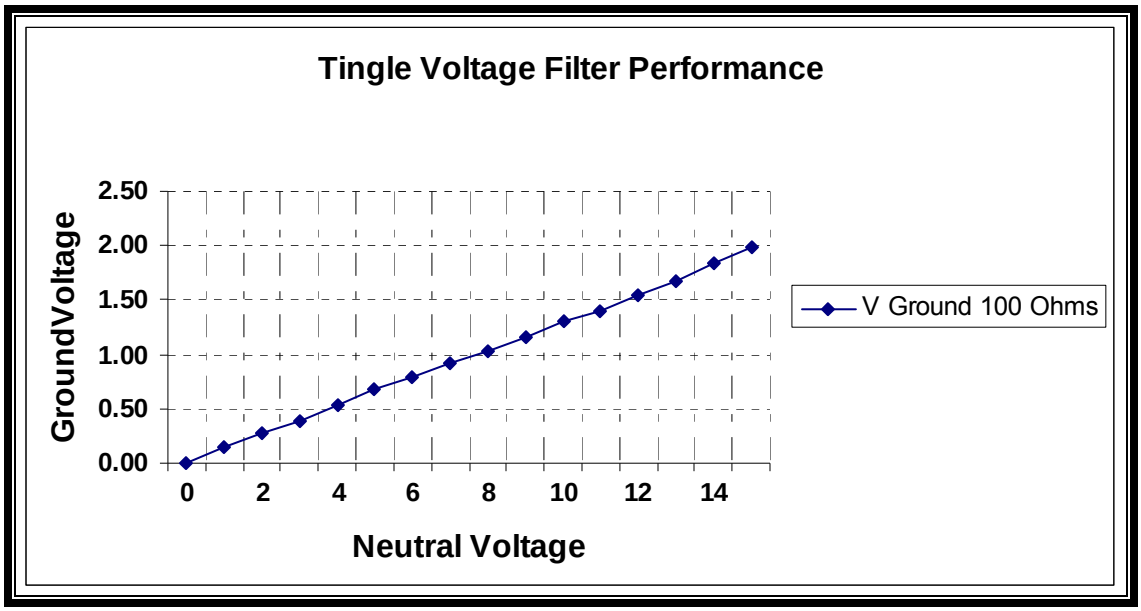

FIGURE 4: HAMMOND TINGLE VOLTAGE FILTER PERFORMANCE 100 OHM GROUND

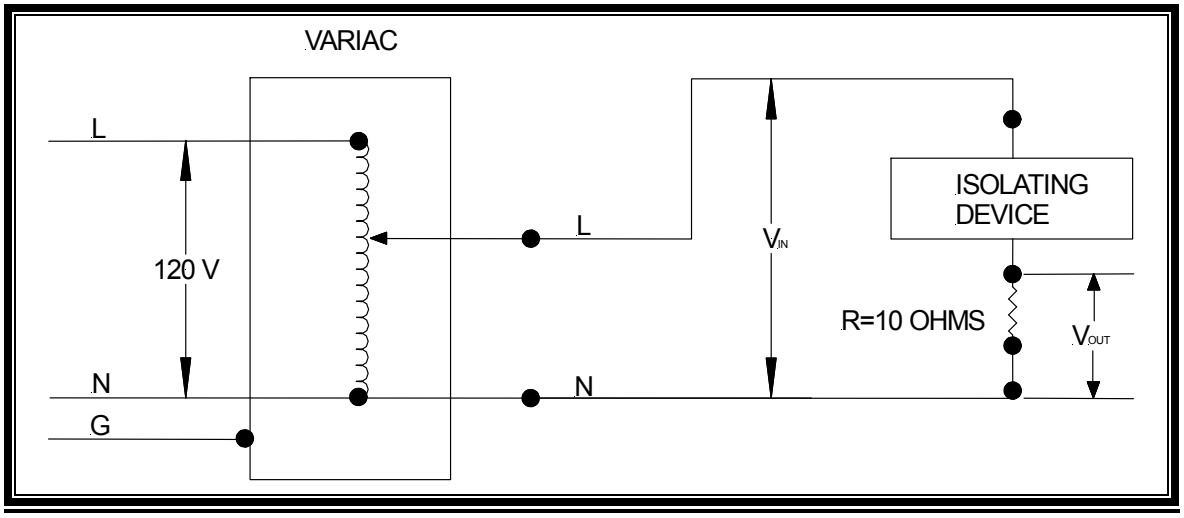

FIGURE 5: ISOLATING DEVICE TESTS

APPENDIX 1: SOLUTIONS MODULE

Customer Name				
Address				
Contractor's Name				
	Year	Month	Date	Comments
Investigation				
Previous Investigations				

6.0 In Service Tests for Isolating Devices

Hammond TVF

	Time of Tests		
Site Power Off Tests			
6.1 Neutral-to-Earth Voltage (NEV) @ Transformer			
Ground-to-Earth Voltage (GEV) @ Service Entrance			
Calculated NEV/GEV Ratio			
NEV/GEV Ratio ≥ 20 ? (Yes/No)			
GEV < 0.5 V? (Yes/No)			
Service Power Off Tests			
NEV at Transformer			
GEV at Service Entrance			
Stray Voltage (SV)			
NEV < 5.0 ? (Yes/No)			
GEV < 0.5 V? (Yes/No)			
SV < 0.25 V? (Yes/No)			
Service Power On Tests			
NEV at Transformer			
GEV at Service Entrance			
Stray Voltage (SV)			
NEV < 5.0 ? (Yes/No)			
GEV < 0.5 V? (Yes/No)			
SV < 0.25 V? (Yes/No)			

Dairyland (VT/NI) or Ronk Blocker

Site Power On Tests			
6.2 Primary NEV at Transformer			
Secondary NEV at Transformer			
Calculated Primary NEV/Secondary NEV Ratio			
Primary NEV/Secondary NEV Ratio ≥ 40? (Yes/No)			
Secondary NEV < 0.25 V? (Yes/No)			
Site Power Off Tests			
6.2 Secondary NEV at Tranformer			
Stray Voltage (SV)			
NEV < 0.5 ? (Yes/No) SV < 0.25 V? (Yes/No)			