

**ELECTRICAL SERVICE TO AGRICULTURAL BUILDINGS:
FOUR- WIRE AND THREE-WIRE SYSTEMS**

by

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Summary:

This paper provides a description of the four wire systems, a test to determine if it has been installed correctly and recommendations on its application to reduce stray voltage.

Keywords: Measurements, Wiring, Four Wire Systems, Code

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INTRODUCTION

It is important to install wiring so that it will fail safely. Wiring in agricultural buildings should also be installed and maintained so it does not contribute to a stray voltage problem. On farms with three-wire single-phase supply there will always be some current on the neutral system resulting in secondary-neutral voltage drop. This voltage can be measured as neutral to earth (NEV) voltage from the neutral to remote earth. The four-wire system does not prevent NEV, but if properly installed, it will greatly reduce the potential for stray voltage affecting animals. Confusion regarding National Electrical Code (NEC) requirements for four-wire systems has resulted in improper installation and unsafe conditions on many farms. When inspecting agricultural electrical systems, a determination must first be made as to the type of wiring system. Only then can an evaluation be made if it has been installed properly.

Secondary Neutral Voltage Drop

The stray voltage issue has brought agricultural wiring from the farm to the court room. There is confusion about sources of secondary neutral voltage drop and how to identify it as a stray voltage source. We know that farm wiring systems will always create some neutral-to-earth on farm voltages. If the farm has ten services to ten different buildings or structures, then there will be ten neutral voltage sources. Each NEV source must be measured to determine the most effective method to reduce animal contact voltages. The following four parameters:

- Isn** Current on the secondary neutral from unbalanced 120-V loads and other sources (A)
- Rsn** Resistance of the neutral conductor due to its material, diameter, length, and connections (Ohms)
- Vs** Voltage measured from the building service equipment neutral to remote earth, commonly called secondary neutral voltage (V)
- Vp** Voltage measured from the transformer secondary neutral at the transformer to remote earth, if the farm is not isolated this will be the primary neutral voltage (V)

are required to evaluate secondary-neutral voltage drop.

V_{ps} Voltage drop on the secondary neutral conductor measured from the transformer to building service equipment (V).

V_{ps} can be measured from V_p to V_s in volts across R_{sn}.

$$V_{ps} = R_{sn} I_{sn}$$

Figure 2 Neutral current flow on a three-wire service

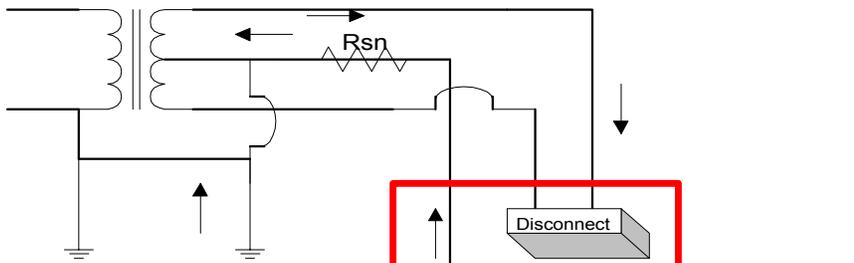
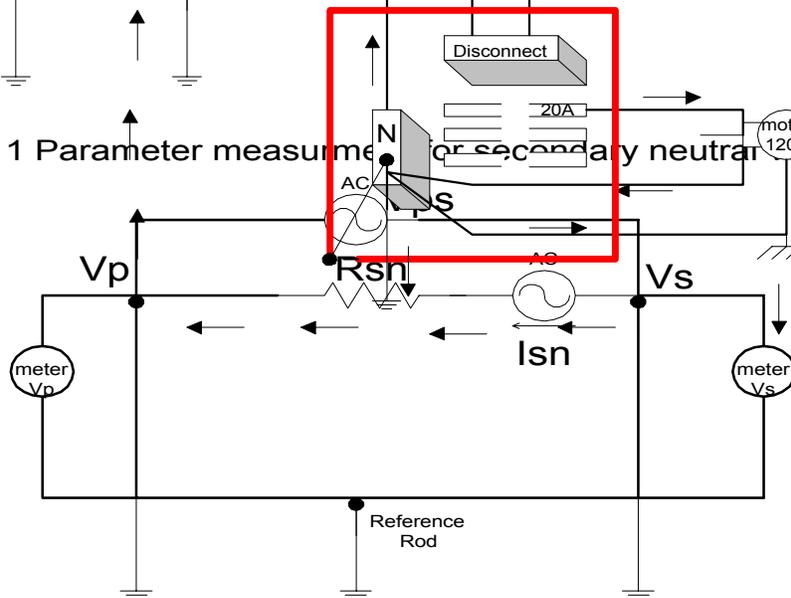


Figure 1 Parameter measurement for secondary neutral voltage drop



$$R_{sn} = V_{ps} / I_{sn}$$

Figure 1 shows a typical circuit used for analysis of V_{ps}. The measured value of V_{ps} should be compared to expected value. The expected value is calculated based on the load (I_{sn}), conductor material and length. If V_{ps} is higher than expected, further inspection for bad connections is necessary. If V_{ps} is within the expected range but there is still a desire to reduce animal contact voltages, then an evaluation can be made to determine whether a four-wire service would be appropriate.

Three-Wire Systems

Fig. 2 shows a three-wire system. Some current can be measured on all farm and utility grounded neutral systems. The resistance of the secondary neutral (R_{sn}) relative to other

paths to the transformer will determine the proportion of the return current to flow on the secondary neutral conductor. This secondary neutral current will result in some voltage drop (V_{ps}) across the secondary neutral due to this current (I_{sn}) and its resistance (R_{sn}). Secondary neutral voltage drop (V_{ps}) is the most common cause of stray voltage. There are several ways to correct or minimize the effects of V_{ps} on three-wire services:

1. Balance the loads at the service equipment. This common technique will reduce I_{sn} and the voltage across R_{sn} . This is sometimes difficult due to seasonal loads and intermittent 120-V loads operating in a cyclical manner. While the load may be balanced for one set of operating characteristics, there is no way to control all the loads all of the time to balance the neutral current.
2. An effective and low cost way to reduce secondary neutral resistance and voltage drop is to increase the secondary neutral conductor size. If you design the electrical system on the farm to maintain less than 2% voltage drop for each major segment, it is unlikely that you will experience significant secondary-neutral voltage drop problems. By designing for 2% per segment, the total voltage drop from the meter to the farthest load should be about 5%. For feeder circuits the NEC (NFPA, 1993) recommends limiting the voltage drop to 5% (215-2 FPN-2).
3. Reduce V_{ps} on other building services neutrals which connect at a common point at the farm transformer. Test to determine if V_{ps} is within expected values for each neutral conductor. Replace high resistance connections and/or undersized conductors to reduce V_{ps} .

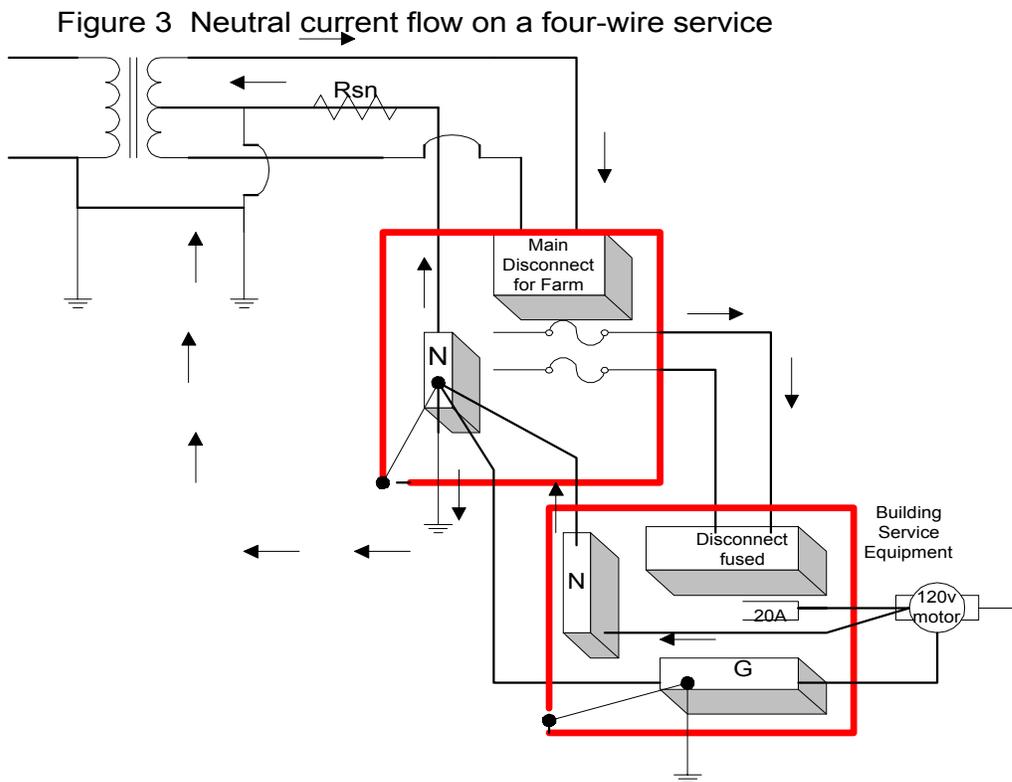
Four-Wire Systems

A fourth alternative is to install a four-wire system (Figure 3). A properly installed four-wire system will reduce animal contact voltages formerly generated by **secondary neutral voltage drop on that individual 3-wire service equipment**. Animal contact voltage generated from secondary neutral voltage drop on **other services will not be affected**.

Figure 3 shows that all of the current due to 120-V loads returns on the secondary neutral conductor to the disconnect at the service center near the transformer. The paths by which the neutral current returns to the transformer are the short length of neutral conductor, various paths through grounding conductors, and the earth. With a properly sized neutral conductor and good connections, the majority of the neutral current uses the neutral conductor path. This reduces the amount of neutral current returning through the earth and the contribution to stray voltage from the building with a four-wire service.

The neutral is not bonded to the grounding bar at the building service equipment panel. Voltage on the neutral does not contribute to voltages on other grounded structures such as the waterline that may be bonded at this panel. The only connection between the grounded conductor and the grounding conductor for a building supplied by a four-wire service is at the main disconnecting means on the farm.

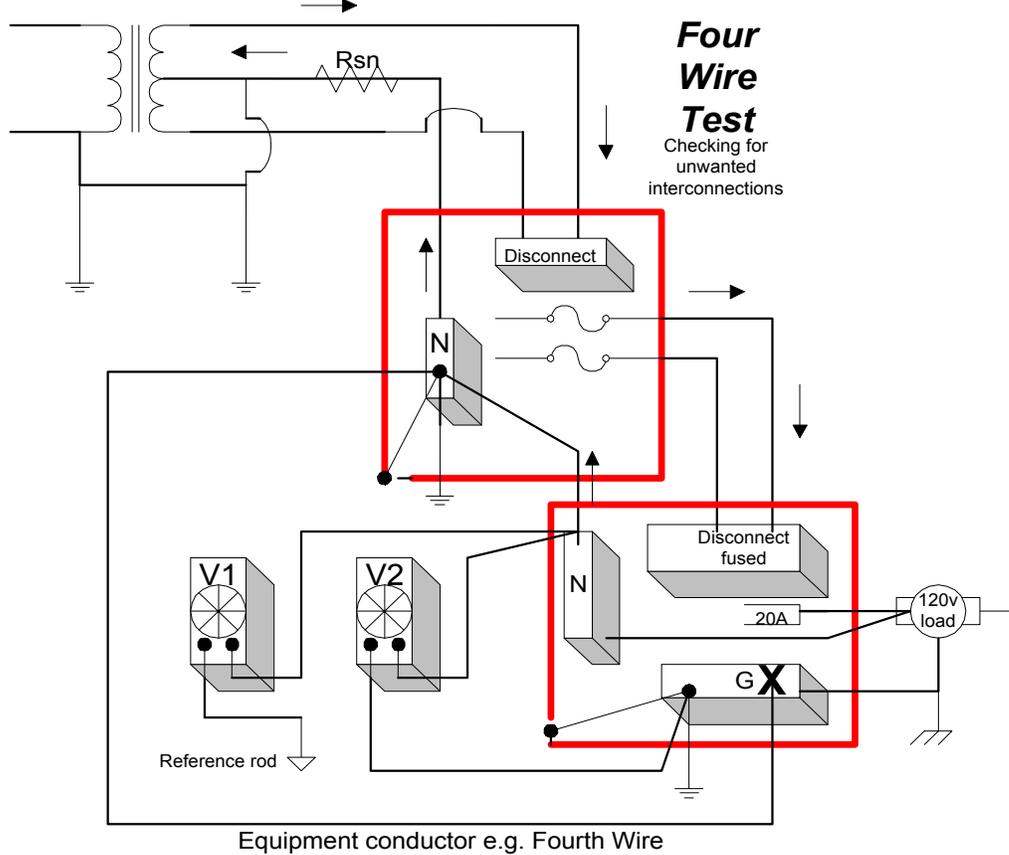
The Code rules for a four-wire service can be found in NEC sections 547-8(a) Ex. No. 1 and 250-24 Ex. No. 2. The Code requires a service disconnecting means at the source and an equipment grounding conductor (fourth-wire) which must be copper if underground. Service equipment bonding and grounding electrodes are shown in Fig. 3. Neutral voltages from other three-wire services on the premises can still cause stray voltages as the grounded surfaces in an animal confinement building are still connected to



the premises neutral system. Note that Fig. 3 shows a service to only one building for simplicity. In practice there are usually several buildings supplied from this main disconnecting means.

Code Panel 19 of the National Electrical Code Committee notes that the present wording in article 547-8 (a) Exception No. 1 for a service disconnecting means requires a *main control and means for disconnect of the supply and is adequate*. This satisfies 547-8 (a) Ex. No. 1 which requires that all the elements of service equipment include over-current protection (NFPA 70-A95ROP and NFPA-A95ROC). The purpose of the service

Figure 4 Setup for testing four-wire systems



disconnect is to provide both a disconnecting means and a bus bar for bonding the grounded and grounding conductors in an enclosure. A pole-top disconnect with provision for such bonding would meet the intent of the NEC.

The Code rules for a four-wire system to agricultural buildings were added in the 1987 NEC. Since that time changes in 250-24- Ex. No. 2 (NFPA 70-1993) now permit either three-wire or four-wire services with rules for each where several buildings are supplied from a common service. If the building is served as a "feeder" with properly sized over-current devices, disconnecting means and grounding at the supply end as specified in NEC Articles 225 and 250 then the special provisions of 547-8 (a) Ex. No. 1 would not be needed. A standard four-wire feeder would be appropriate.

A concern with the four-wire system is that it depends on a single connection between the grounded and grounding conductors at the main disconnect. If the neutral circuit opens, you would know because none of the 120-V loads in the facility would function. However, if the grounding conductor (fourth wire) opened, the only way you would know is after the damage was done and something or someone is hurt.

Another concern with the four-wire system is that it is rarely installed properly. Unsafe installation results from poor understanding of the code and basic electrical theory. If there are ground and neutral interconnections in the four-wire system, it will not work as intended. Sometimes the grounding conductor (fourth wire) is not connected to the neutral at the main disconnect and the system will not fail safely. NEC 250-51 and 250-91 both state that the earth shall not be the sole path for current flow. The earth is not a good conductor and over-current devices will not operate in the event of a fault condition when the connection between the grounded and grounding system is corroded or becomes open. When an electrical system faults to ground and the only return path is the earth, the grounding system will be energized at 120 V. It is imperative that the bond between the grounded and grounding system be kept intact and made inside of an approved enclosure. This will ensure that the system will operate properly and fail safely when required.

Testing Four-Wire Systems

The circuit diagram for testing four-wire systems for ground and neutral interconnections is presented in Fig. 4. Tests to determine if the fourth wire is improperly joined to the neutral beyond the main service involve the following procedures.

1. Remove all loads from the service equipment except one 120-V load (e.g., a hair dryer remote from the service equipment.)
2. Connect two meters, each with one lead to the neutral bar. (V1 & V2)
3. On one meter connect the second lead to a remote reference rod. (V1)
4. On the second meter connect the second lead to the grounding bar marked G. (V2)
5. Remove the grounding conductor (fourth-wire) from the grounding bar at point X in Figure 4.

Evaluate the separation of the grounded (neutral) and grounding (fourth-wire) conductors by the following analyses:

- A. If V1 is much greater than V2 there is probably an unwanted interconnection between the neutral and grounding wires. V2 will be near zero if grounded & grounding conductors are connected.
- B. Remove one outgoing grounding wire at a time until V1 and V2 read essentially the same.

- C. Find and separate the identified grounding wire-neutral interconnection.
- D. Continue to remove other grounding wires (one at a time) from the grounding bus and verify that the two meters continue to read essentially the same.
- E. Reconnect the 'fourth-wire' at 'X' to the grounding bus.

DISCUSSION

A four-wire service meeting all the requirements of the NEC is difficult to achieve. In practice it is rarely done correctly. The authors suggest upgrading three-wire service to reduce neutral voltage drop particularly in existing situations where there are other three-wire services. If a four-wire service is desired, install the new supply to the selected building as a four-wire feeder. The most appropriate use of a four-wire service is for a new facility which has its own electrical service. This eliminates interactions with other three-wire services.

A four-wire system will not prevent neutral voltage developed on one service from affecting other services or the primary neutral voltage from appearing on the grounding conductor ('fourth-wire'). It will only prevent neutral voltage due to the secondary neutral voltage drop on the service **with** the four-wire system from causing voltages at animal contact locations.

DEFINITIONS

EARTH RESISTANCE. The resistance of soil to the passage of electrical current. The larger the area, the smaller the resistance.

TRUE EARTH. A location sufficiently distant from an electrode so that the area of earth available for passage of current is large enough to result in little or no resistance.

NEUTRAL-TO-EARTH RESISTANCE. The resistance to current along the parallel paths between various electrodes connected to the neutral conductor and the surrounding earth.

REMOTE REFERENCE ROD. An electrode driven at a location sufficiently distant from other electrodes so as not to be significantly impacted by the current flowing through them to earth.

NEUTRAL-TO-EARTH VOLTAGE (NEV). Voltage measured between the neutral conductor and remote reference rod representative of true earth.

NORMAL NEUTRAL RETURN CURRENT. Normal system load current which returns to its source by way of the neutral conductor and all connections between the neutral conductor and earth.

GROUND CURRENT. Current that flows on the conductive paths between the neutral and earth.

EARTH CURRENT. System return current, either normal or abnormal, that flows in the earth between electrodes.

STRAY VOLTAGE. Stray voltage is a small voltage (less than 10V) that can be measured between two points animals can contact simultaneously.

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