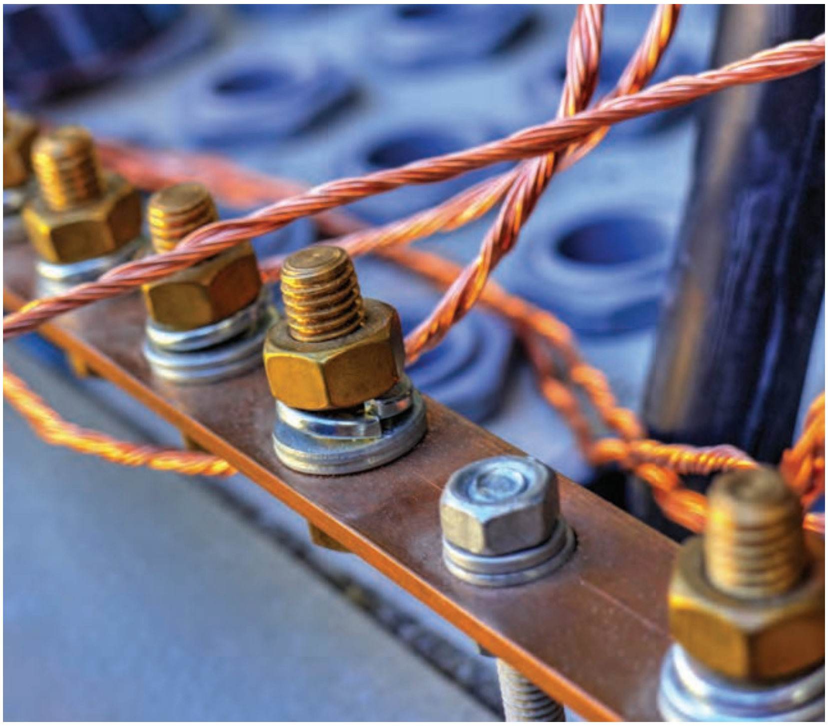
How to Eliminate Ground Loops in Building Electrical Systems

Easy to create and hard to detect, ground loops can only be prevented through proactive design and strict NEC compliance.



ID 134509719 © Phadventure | Dreamstime.com

By Hua Yan, P.E., Stantec

Ground loops are a common yet often overlooked issue in building electrical systems. While they may seem minor during design or construction, ground loops can significantly impact system performance and safety. They can introduce common-mode noise in electronic circuits, degrade power quality, hinder ground fault protection, damage equipment, and even pose shock or fire hazards. Understanding and addressing ground loops is essential for ensuring system safety and reliability.

WHAT IS A GROUND LOOP?

According to IEEE Std 1159-2019, *IEEE Recommended Practice for Monitoring Electric Power Quality*, a ground loop is "a potentially detrimental loop formed when

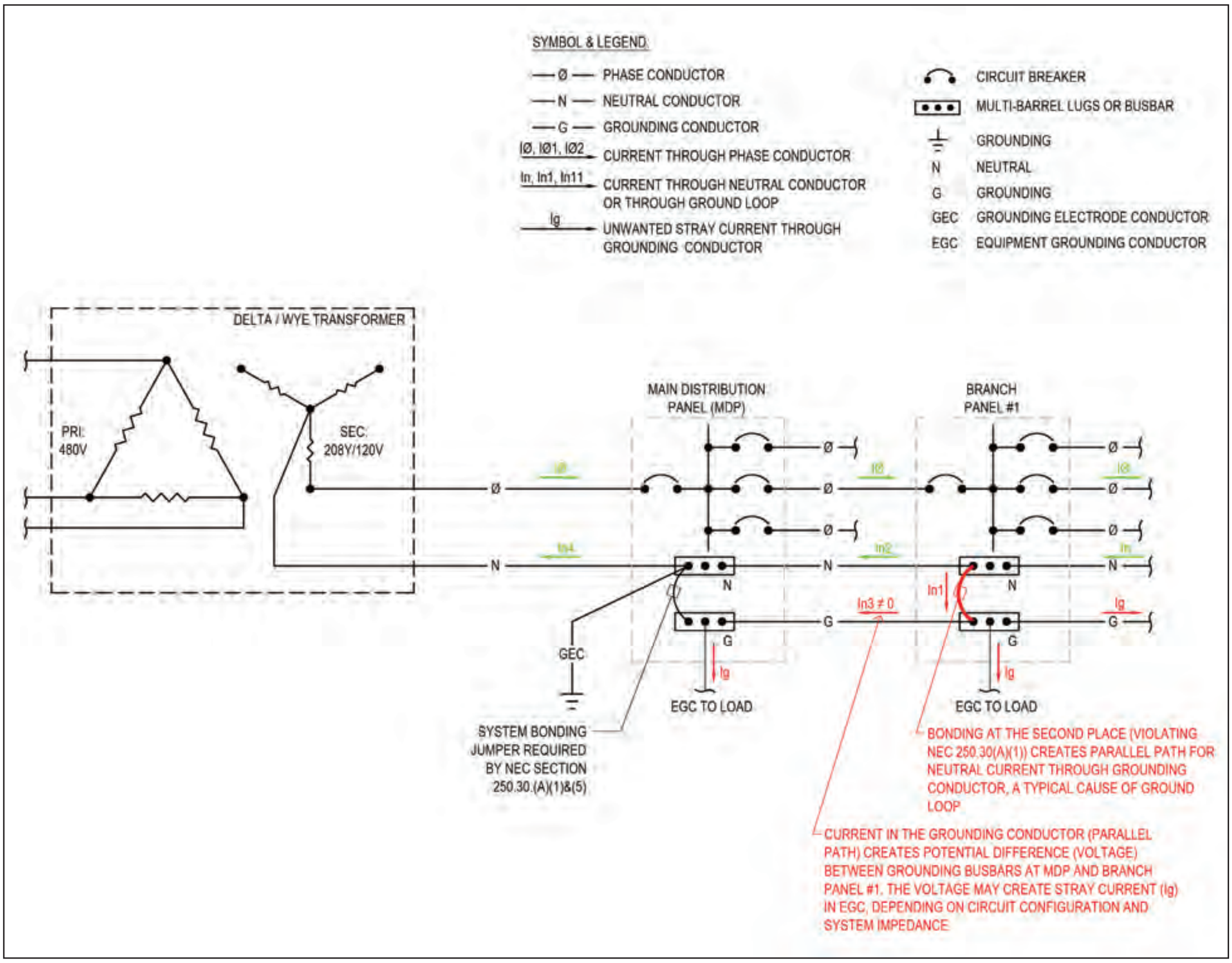


Fig. 1. The second bonding jumper at the branch panelboard creates a parallel path for neutral current on the grounding conductor. This connection is a typical source of a ground loop.

two or more points in an electrical system that are nominally at ground potential are connected by a conducting path such that either or both points are not at the same ground potential."

Under normal conditions, neutral current arises from load unbalance in 3-phase, 4-wire systems or from electrical circuit harmonics. While grounded (neutral) conductors are designed to carry current, grounding conductors are not. If a grounded conductor is improperly grounded at multiple points, neutral current may flow through unintended parallel paths, such as grounding conductors and the overall grounding system, creating a ground loop.

Figure 1 illustrates an example of a system with a ground loop problem. In the one-line diagram, neutral current is brought to the grounding system through a second bonding jumper, which violates National Electrical Code (NEC) Sec. 250.30(A)(1). Please note that all figures in this article use generic symbols to represent current and are based on the 2023 edition of the NEC. Refer to the symbol list in **Fig. 1** for clarification. Not all connections are depicted in the diagrams. None of the figures in the article should be used for any real project, which grounding system shall be designed and constructed per applicable code and standards. The primary intent is to identify potential ground loop problems within the systems rather than to analyze the exact flow or quantity of current in detail.

NEC GUIDELINES FOR GROUND LOOP PREVENTION

Although the 2023 NEC doesn't explicitly define ground loops, Art. 250 outlines methods to prevent them:

- **Section 250.6** mandates that "the grounding and bonding of electrical systems, circuit conductors, surge arresters, surge-protective devices, and conductive normally non-current-carrying metal parts of equipment shall be installed and arranged in a manner that will prevent objectionable current." Objectionable current refers to unwanted current, such as neutral current, flowing through grounding and bonding conductors, which are not designed for current-carrying under normal conditions. "Currents resulting from abnormal conditions such as ground faults, and from currents resulting from required grounding and bonding connections shall not be classified as objectionable current," as noted in Sec. 250.6(C).
- **Section 250.30(A)(1)** restricts grounding and bonding to a single point for separately derived systems to prevent parallel paths for neutral current.

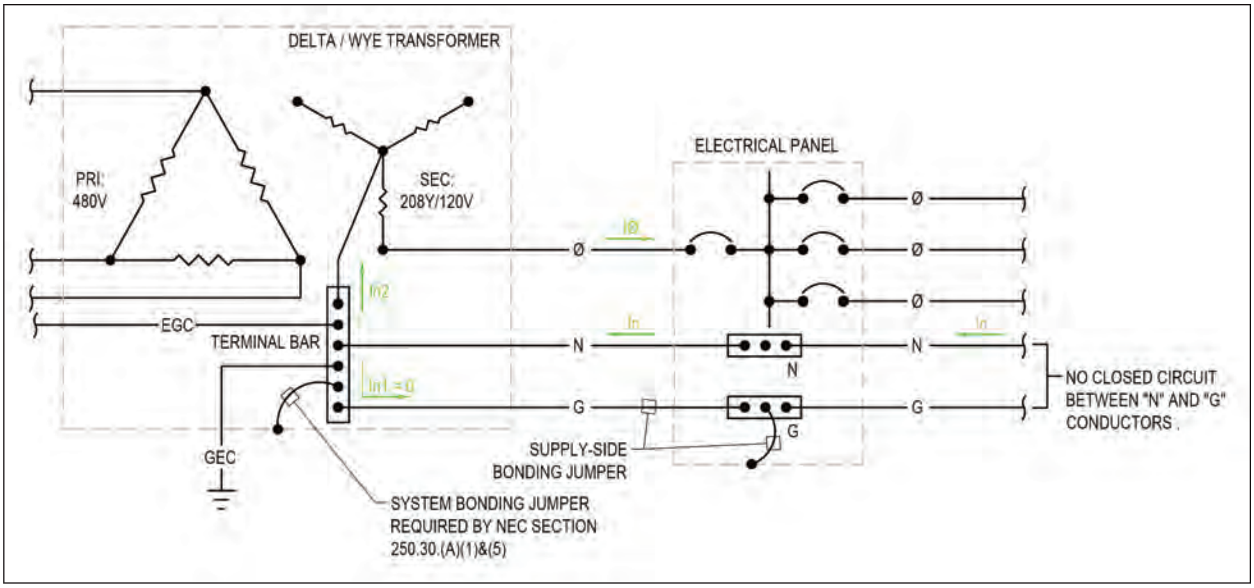


Fig. 2A. This one-line diagram with a grounding electrode connection at the source meets the Code requirements for a separately derived system. The figure is similar to NEC Exhibit 250.14.

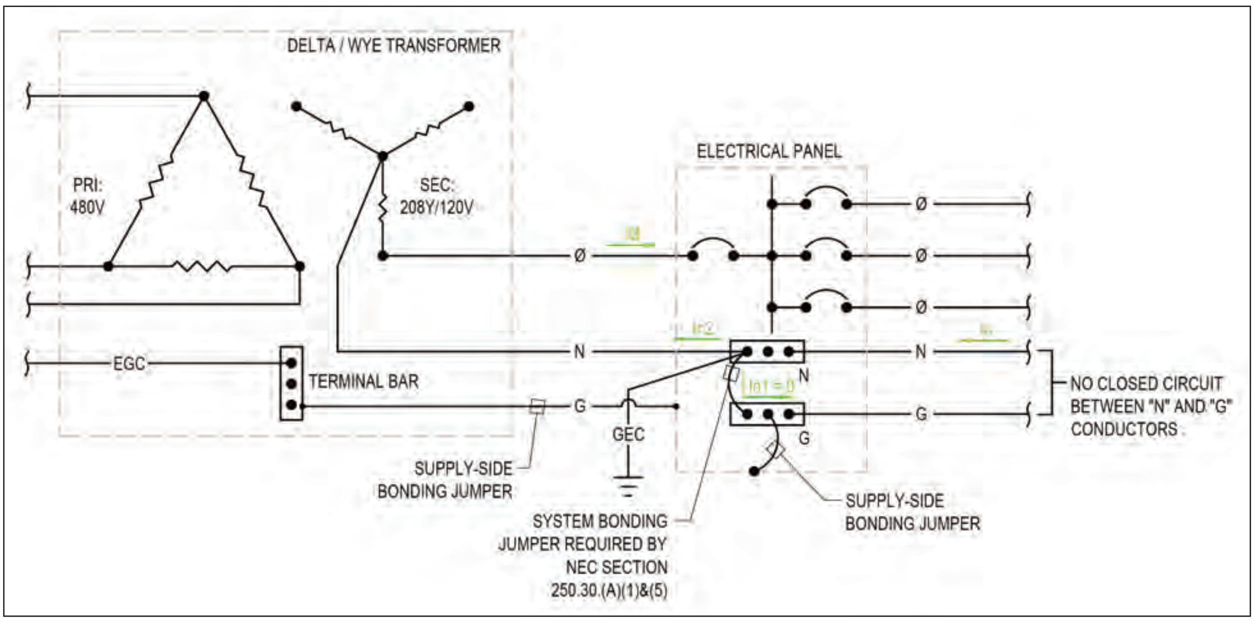


Fig. 2B. This one-line diagram with a grounding electrode connection at the first disconnect means meets the Code requirements for a separately derived system. The figure is similar to NEC Exhibit 250.15.

- **Section 250.142** prohibits using a grounded conductor for grounding load-side equipment to avoid creating objectionable current.

In the following paragraphs, several NEC-related scenarios will be reviewed where potential Code violations should be carefully considered during design and construction.

SCENARIO #1: SINGLE SEPARATELY DERIVED SYSTEM

Let's start with a single separately derived system, which is defined as "an electrical power supply output, other than a service, having no direct connection(s) to circuit conductors of any other electrical source other than those established by grounding and bonding connections," as noted in Art. 100.

Sections 250.30(A)(1) and (5) require the neutral conductor to be grounded and connected to the grounding electrode system at a common point between the source terminal and the first disconnect means. "A grounding electrode conductor connection for a single separately derived system shall be made at the same point where the system bonding jumper is connected," [Sec. 250.30(A)(5)]. This ensures that objectionable current does not flow through the grounding system.

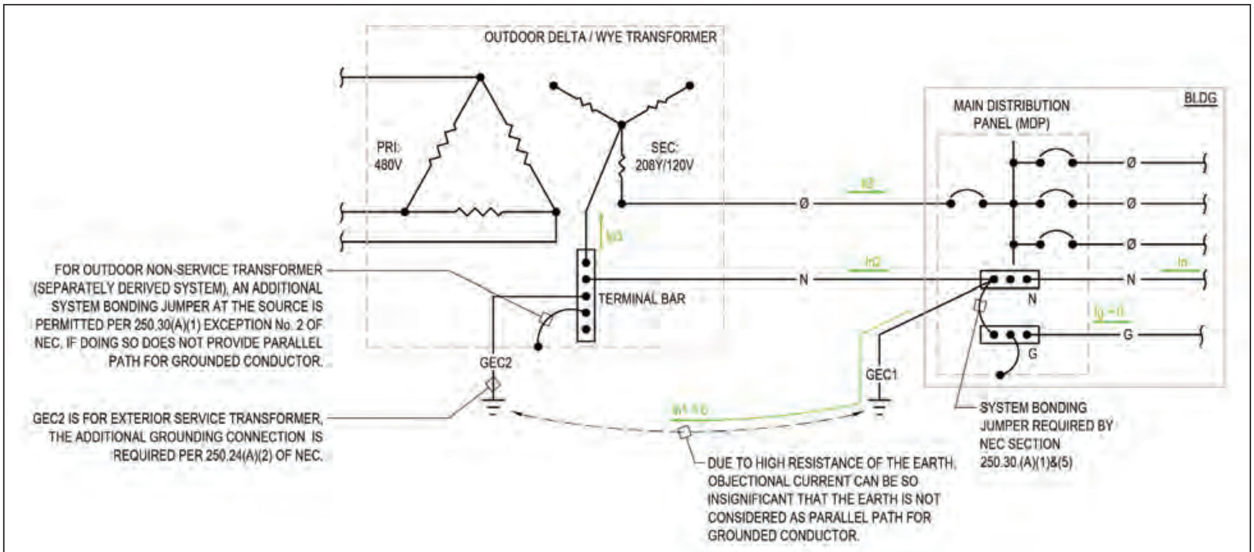


Fig. 3. This one-line diagram for an outdoor transformer (either service transformer or separately derived system) serving a single building shows a grounding electrode connection at the first disconnect means.

Exhibits 250.14 and 250.15 in the NEC illustrate these requirements. **Figures 2A** and **2B** (similar to NEC exhibits) show line current (Iø) and neutral current (In) flow under normal conditions. From the figures, no parallel path is created when the separately derived system is grounded and bonded at a single point. No closed circuit forms between the neutral and grounding conductors, so no neutral current (In) flows through the grounding system (In1 = 0A as indicated in the figures).

SCENARIO #2: OUTDOOR TRANSFORMERS

For outdoor service transformers, except those with impedance-grounded neutral systems, Sec. 250.24(A)(2) requires at least one additional connection from neutral to a grounding electrode at the transformer or elsewhere outside the building. This outdoor grounding connection helps mitigate the effects of lightning, line surges, or accidental primary-to-secondary crossovers on the interior portion of the premises wiring system. So, a bonding jumper is required and is typically installed at the exterior service transformer besides a main bonding jumper inside the building, usually at the indoor main switchboard.

For exterior transformers serving as separately derived systems but not as electrical services, Sec. 250.30(A)(1), Exception No. 2 allows "a system bonding jumper at both the source and the first disconnect means shall be permitted if doing so does not establish a parallel path for the grounding conductor."

Therefore, for exterior transformers, an additional grounding point at each service transformer is required [Sec. 250.24(A)(2)], or an additional system bonding jumper is permitted [Sec. 250.30(A)(1), Exception No. 2] for a separately derived system (**Fig. 3**). The electrical system is grounded and bonded at two different locations, which could potentially lead to a ground loop problem. However, the resistance of the earth between these two grounding and bonding points is typically high enough that any objectionable current flowing through it is insignificant, which mitigates ground loops in most cases. This is why Exception No. 2 of Sec. 250.30(A)(1) clarifies that "for the purposes of this exception, connection through the earth shall not be considered as providing a parallel path" for neutral current.

Here, two terms need to be clarified for their difference: main bonding jumper and system bonding jumper. Both serve a similar function — providing connections between a grounded circuit conductor and an equipment grounding conductor — to complete a ground fault current path back to the source. However, a main bonding jumper is used at the service entrance, while a system bonding jumper is used in a separately derived system.

SCENARIO #3: SINGLE OUTDOOR TRANSFORMER FEEDING MULTIPLE BUILDINGS

Figure 3 illustrates a scenario where an additional grounding connection is required at an outdoor service transformer feeding a single building. But what if it supplies multiple buildings? Can the neutrals still be grounded at both the outdoor transformer and each building's main disconnect? The answer varies by configuration. **Figure 4** on page 53 provides an example of an exterior transformer feeding two separate buildings, highlighting how grounding requirements can differ.

In this example, if there is no continuous metallic path between Building No. 1 and Building No. 2, the neutral-to-ground connection is allowed in each building. However, if the continuous metallic path exists and is bonded to the building grounding system, it may create a ground loop. Inter-building metallic connections, such as telecom outside plant copper backbone cable and metallic water/gas pipes, are common in multi-building facilities. In these cases, a system or main bonding jumper should not be installed at both buildings' main switchboards to prevent ground loops through the metallic paths.

With ground loops, neutrals can unintentionally serve as ground fault return paths — a condition recognized and generally prohibited by the NEC with limited exceptions. Section 250.32(B)(1), Exception No. 1 permits the

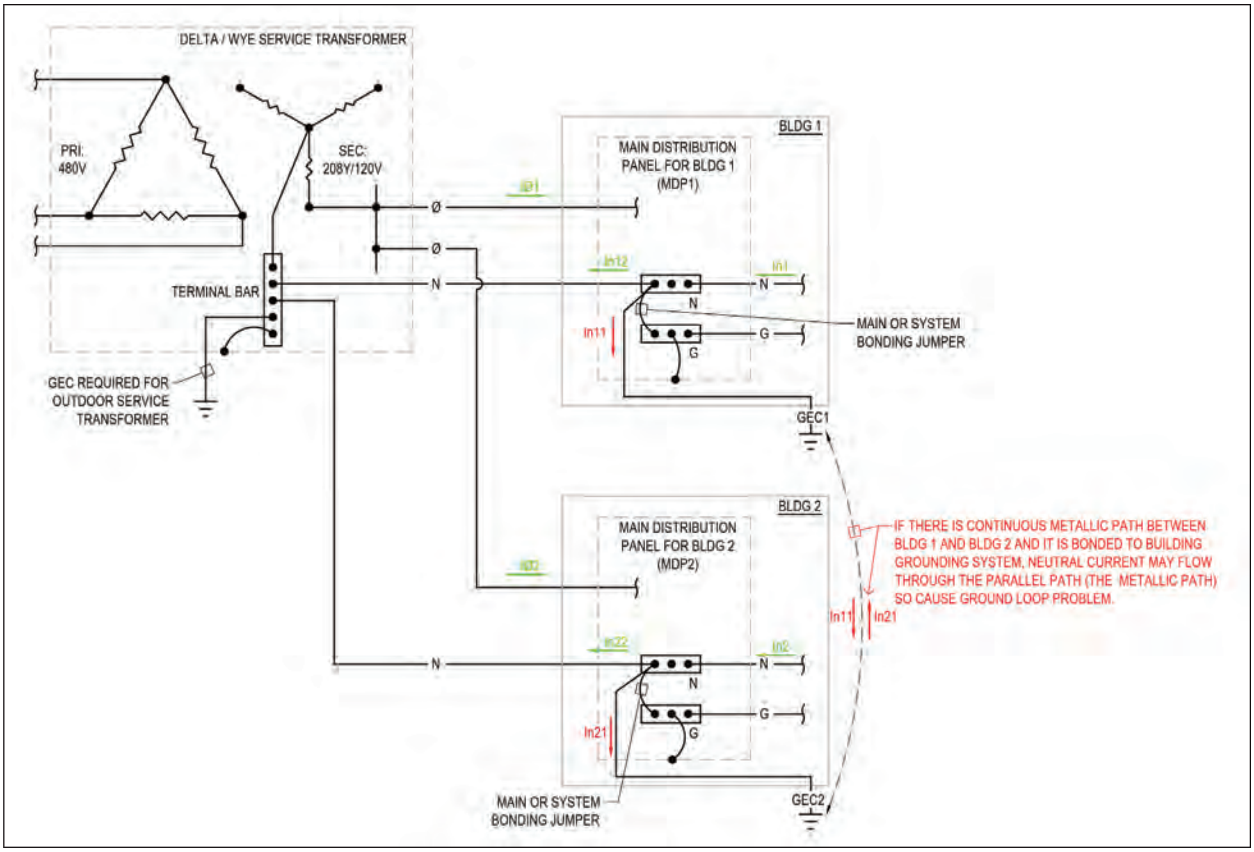


Fig. 4. This electrical schematic shows a typical bonding and grounding arrangement for an outdoor transformer serving multiple buildings.

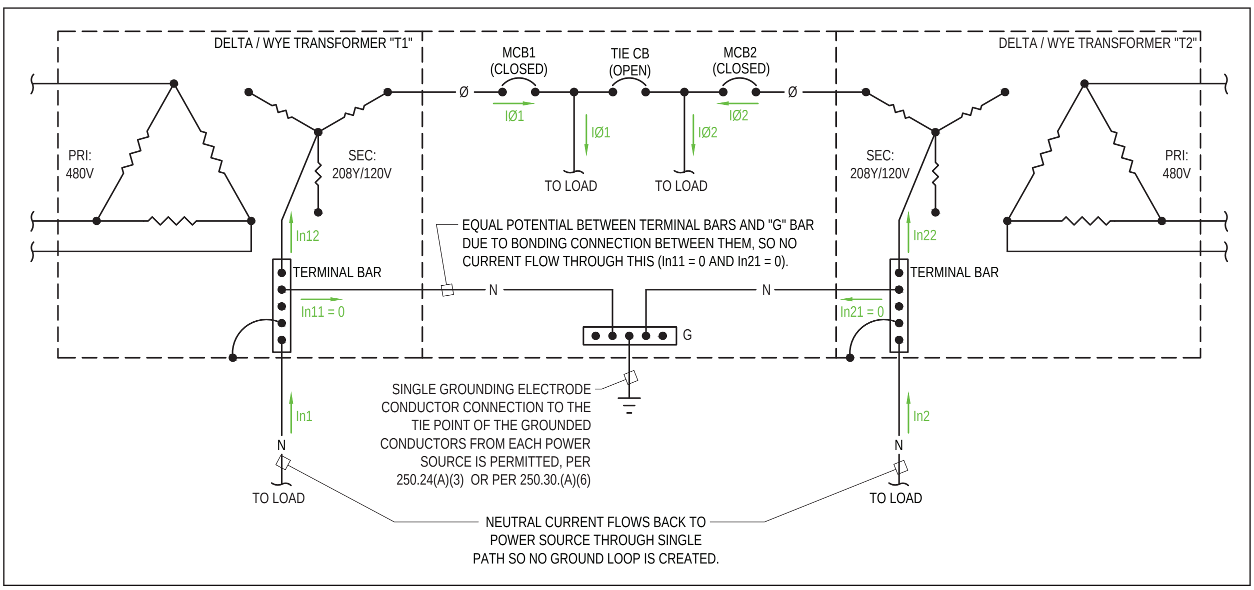


Fig. 5A. This one-line diagram shows a double-ended substation arrangement with a single grounding electrode connection.

grounded conductor to serve as the ground fault return path for a feeder to a separate building/structure, but only for existing installations that comply with the 2002 NEC or earlier, and that meets all three listed conditions, including "no continuous metallic paths bonded to the grounding system in each building or structure involved." In such cases, an equipment grounding conductor may not be permitted in the related feeder.

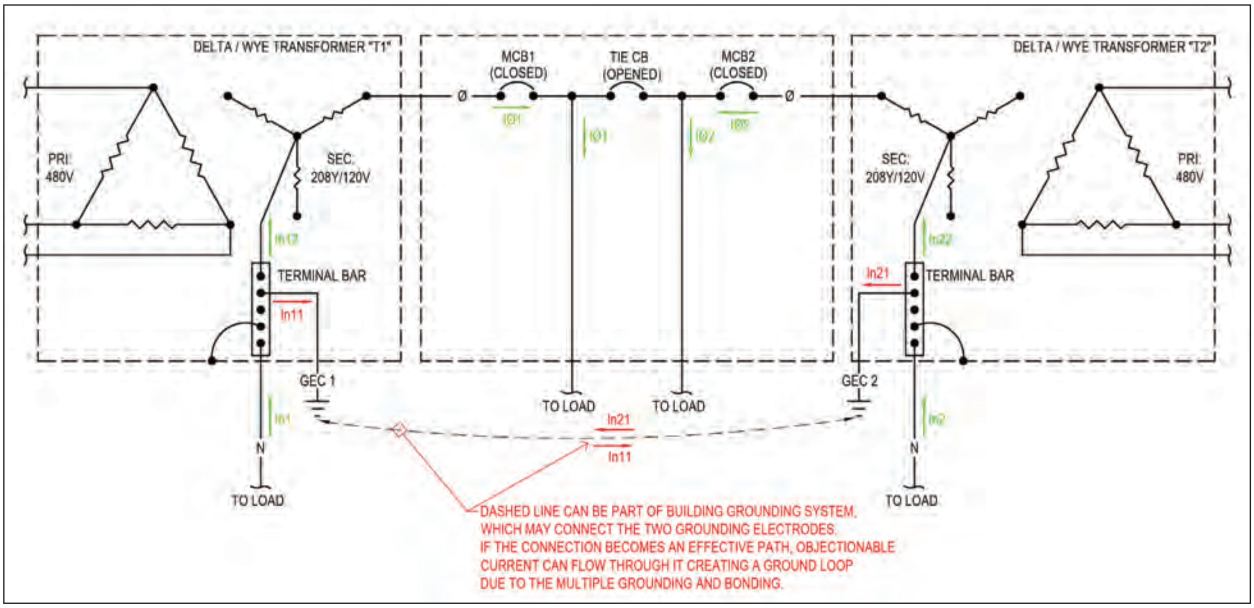


Fig. 5B. This one-line diagram shows a double-ended substation arrangement with multiple grounding electrode connections. Note: Transformers T1 and T2 are not in close proximity.

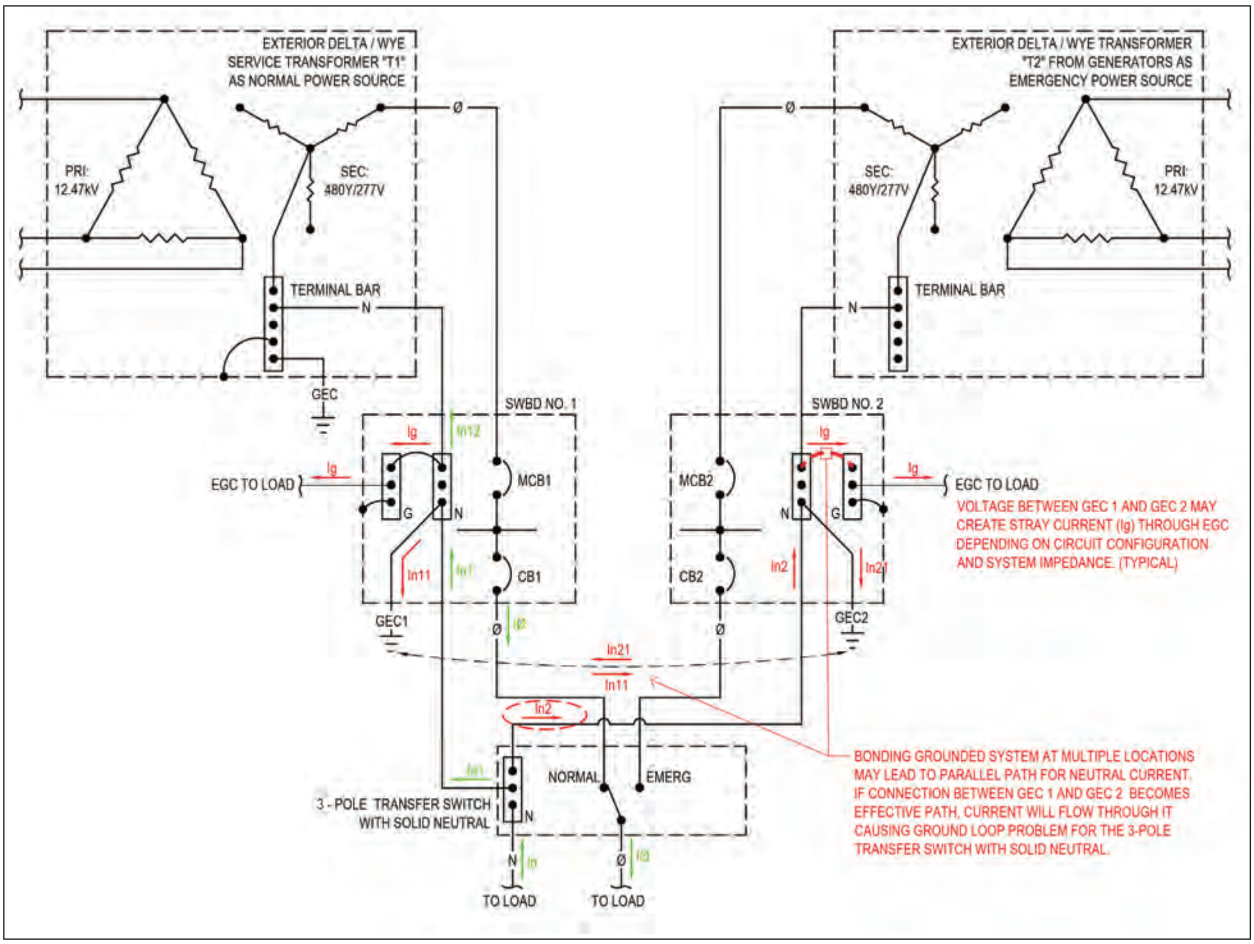


Fig. 6A. As this one-line diagram shows, a ground loop may form if both switchboards are connected to ground and feed a 3-pole transfer switch with a solid neutral. Note: Some bonding & grounding conductors are not shown.

Per UL 891, switchboards used as service equipment shall be marked "suitable for use as service equipment" and include a bonding jumper connecting the neutral to the enclosure and ground bus. NEC Sec. 408.3(C) also requires "each switchboard, switchgear, or panelboard, if used as service equipment, shall be provided with a main bonding jumper …". If the main bonding jumper is omitted, as in **Fig. 4** to avoid ground loops, the switchboard may no longer qualify as service entrance-rated equipment. In this case, coordination with the electric utility or local AHJ is required, and a field evaluation and UL recertification may be necessary.

SCENARIO #4: SINGLE BUILDING FED BY MULTIPLE FEEDERS/SERVICES (DOUBLE-ENDED SECONDARY SUBSTATION)

For multiple separately derived systems feeding a single building, "a common grounding electrode conductor for multiple separately derived systems shall be permitted. … This connection shall be made at the same point on the separately derived system where the system bonding jumper is connected." [Sec. 250.30(A)(6)] For dual-fed electrical services, the single grounding electrode conductor is also permitted to connect to the tie point of grounded conductors from each power source, if both services are "in a common enclosure or grouped together in separate enclosures, and employing a secondary tie," [Sec. 250.24(A)(3)]. A double-ended substation with main-tie-main configuration is a typical example. As shown in **Fig. 5A** on page 53, the switchboard is supplied by two power sources with two main breakers and a tie breaker, all grounded at a common point. In this setup, neutral current returns to the source through a single path, avoiding any ground loop.

However, "if the power sources are not in close proximity, a common ground point is not recommended. The impedance in the neutral bus connection may become large enough to prevent effectively grounding the neutral of the source at the remote location. The interconnect may inadvertently become open, allowing the transformer to operate ungrounded." [IEEE Standard 142-2007, Section 1.6.6] In dual-fed (double-ended) substations, where transformers are located remotely from the switchboard, each transformer must be individually grounded at its location (**Fig. 5B** on page 54). If the connection between GEC1 and GEC2 forms an effective path for current (indicated as dashed line in **Fig. 5B**), such as through the building grounding system, a parallel path for neutral current may be created, potentially resulting in a ground loop. When multiple grounding and bonding connections cause objectionable current, Sec. 250.6(B) lists four permitted alterations to eliminate or minimize such currents.

With **Fig. 5A**, a traditional ground fault sensing scheme, such as differential ground fault protection, can be used for a double-ended substation with a common permissible ground shared by multiple power sources. However, in **Fig. 5B**, where

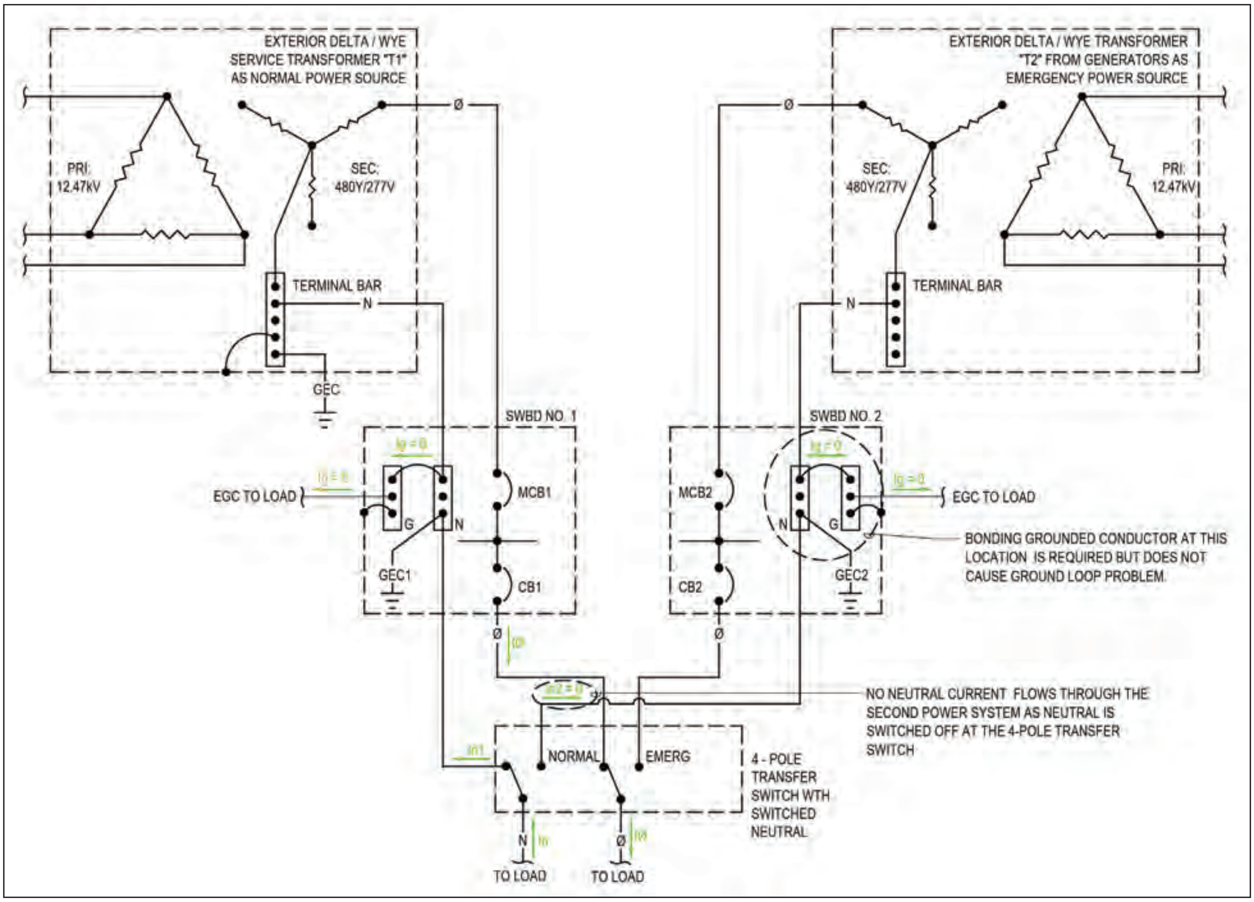


Fig. 6B. As this one-line diagram shows, no ground loop will form if both switchboards are connected to ground and feed a 4-pole transfer switch with a switched neutral. Note: Some bonding & grounding conductors are not shown.

neutrals are grounded at multiple locations, ground fault currents may return through various paths, depending on fault conditions. In this case, a modified differential ground fault protection scheme is recommended to capture and sum up ground fault current through all varied paths. This ensures reliable system protection, even when multiple ground-fault current paths exist during a fault, as noted in the whitepaper, "Modified Differential Ground Fault Protection for Systems Having Multiple Sources and Grounds," by David L. Swindler and Carl J. Fredericks.

SCENARIO #5: ELECTRICAL SYSTEM WITH TRANSFER SWITCHES

For buildings supplied by alternate power sources, such as generators in addition to electric utility power, transfer switches are used to transfer power between sources. Proper bonding of the grounded conductor is essential to avoid ground loops. **Figures 6A** (on page 54) and **6B** illustrate a system fed by two medium-voltage transformers — one from the electric utility and the other from generators. Main or system bonding jumpers are provided at both the normal and emergency power switchboards.

The system in **Fig. 6B**, using a 4-pole transfer switch with a switched neutral, is acceptable. However, if both switchboards feed a 3-pole transfer switch with a solid neutral, as shown in **Fig. 6A**, a ground loop may form.

In California, as noted in its *Electrical Guide for Health Facilities Review 2022*, the Department of Health Care Access and Information (HCAI) requires 4-pole transfer switches for separately derived Emergency Power Systems (EPSs) — that is, systems with generator-side grounding and neutral-to-ground bond — for hospital projects.

CONCLUSION

Ground loop issues often result from overlooked design flaws or improper installations. To minimize risk, it's essential to carefully follow NEC guidelines, ensure correct bonding, select appropriate grounding points, and remain aware of potential parallel current paths. While ground loops are easy to create, they can be extremely difficult to diagnose and fix, making proactive prevention vital for safe and reliable electrical systems. **EC&M**

Hua Yan, P.E., LC, RCDD is a Principal Electrical Engineer with Stantec, Irvine, Calif. He has 30 years of design experience across multiple sectors, including mission-critical facilities, aviation, industrial, commercial, and more. He can be reached at Hua.Yan@stantec.com.