White Paper **WP027026EN** Effective January 2025

Calib Burk, P.E.
Protection and Controls Engineer
Eaton Electrical Engineering Services and Systems

System Grounding with DER's

Introduction

An important consideration when designing an electrical system is the type of system grounding employed. System grounding falls into 3 general categories: solidly grounded, ungrounded, or resistance grounded, with there being different subcategories of resistance grounding. It is acknowledged that there are other types of grounding methods beyond these 3, but they are rare and beyond the scope of this document.

The main intent of this white paper is to discuss the concerns that arise when a system is designed for a specific system grounding type and the system grounding changes due to different operating scenarios with distributed energy resources (DER). A summary of common system grounding types is discussed to present the reader with a brief understanding of system grounding. This white paper does not provide an in-depth review of system grounding types, nor is it intended to suggest one type of grounding method over another. There are many other resources available that provide in-depth discussion of system grounding types and the advantages or disadvantages with each type. This white paper presents a discussion of problems that can arise when system grounding changes from the originally designed system grounding type so the reader is aware of potential issues and can properly design the system. Several example system configurations with multiple energy sources and the scenarios that can lead to changes in system grounding type are provided for reference.

System Grounding Types

In a solidly grounded system, there is an intentional connection between the system conductors and ground. This connection is typically made from the neutral point of the equipment (generator, transformer, etc…) directly to ground with no intentional impedance inserted between the neutral point and ground. Since a source or the connections between the neutral point and ground inherently have impedance, IEEE Std. 3003.1-2019 refers to solidly grounded systems using the term effectively grounded. For a system to behave like a solidly grounded system (theoretical zero-impedance between neutral point and ground) the system line-to-ground short circuit current should be at least 60% of the three-phase short-circuit current to be considered an effectively grounded system.

Equation 1. Assessing Effectively Grounded System

$$I\_SLG \geq 0.6\ I\_3ph$$

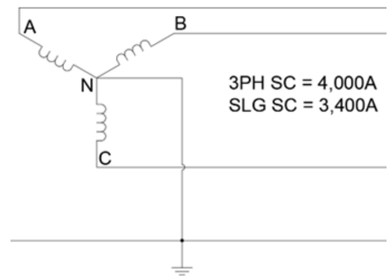

Figure 1. Solidly Grounded System

In an ungrounded system, there is no intentional connection between the system conductors and ground. However, the phase conductors in the system have capacitive coupling to ground and the distributed capacitance creates a capacitively grounded system.

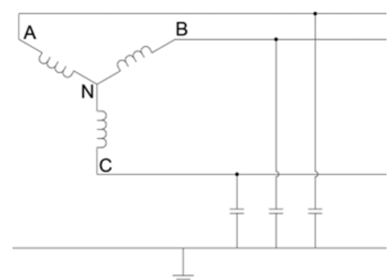

Figure 2. Ungrounded System (with distributed capacitive grounding)

In a resistance grounded system, a resistor is inserted between the neutral point and ground. Depending on the value of the resistor, the grounding can either be considered low-resistance grounding or high-resistance grounding.

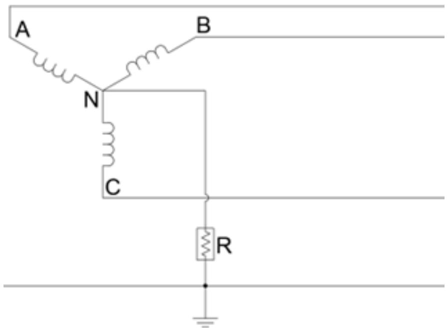

Figure 3. Resistance Grounded System

When equipment is directly served from the utility, the utility service dictates the system grounding type. The utility service grounding type is typically provided by the utility as part of the initial design process. If the utility does not specifically indicate the service grounding type, comparing the utility single-line-to-ground fault short-circuit current to the 3-phase short-circuit current can help determine the utility service grounding type. For most new utility services, it is common for the utility source to be solidly grounded. If the customer has step-down transformers, it is common for the secondary of the step down transformer to be connected in a wye configuration with the Xo terminal directly connected to ground to provide a solidly grounded system. In this case, when the utility is the single source to the system, the designer knows that the system will always be solidly grounded and can design and specify equipment for a solidly grounded system.

Historically, many commercial and industrial facilities installed diesel generators and ATS to provide emergency power during a utility outage to specific facility loads. However, many facilities are now installing a mix of energy resources, such as photo-voltaic (PV), battery-energy storage systems (BESS), Fuel Cells, and diesel or natural gas generators. When connected with the utility, the customer energy sources operate to offset the power provided by the utility. In many systems, if the utility fails, the customer can disconnect from the utility source and operate the energy resources as a localized system to maintain facility operations until the utility source returns. With multiple power sources that may be connected at different locations in the electrical system, it is critical to evaluate the type of system grounding that may occur as the system is reconfigured to operate with the different energy resources. Failure to carefully consider the system grounding can lead to equipment failure or mis-operation, leading to costly outages and expensive system modifications.

Specific Concerns Related to System Grounding Types

The following sections discuss issues that may arise when a system is reconfigured to operate from different sources (i.e. disconnecting from the utility and providing localized power sources) and the system grounding type changes. It is not intended to provide an exhaustive list of all issues that may occur based on different system grounding types.

Ground Fault Detection

When the system is solidly grounded, the line-to-ground fault current is high enough to operate an overcurrent device. This allows the system ground fault protection to be current based and the ground fault overcurrent elements can be coordinated so the device closest to the ground fault operates first and limits the system outage.

When the system is ungrounded, the line-to-ground fault current is limited by the system capacitive charging current and is not high enough to operate an overcurrent device.

In ungrounded medium voltage systems, ground fault detection requires a zero-sequence overvoltage relay element. To be able to measure zero-sequence voltage, the PT's need to be either Wye-Wye connected or broken Delta PT needs to be provided. Open Delta-Open Delta PT's do not provide a zero-sequence voltage to the relay and cannot be used for zero-sequence voltage protection.

NEC 250.21(B) requires ground fault detection in low voltage systems less than 1,000V. In ungrounded low voltage systems, it is common to see ground fault indicating lamps used to provide indication. There are also protection relays designed for detecting ground faults and providing an output signal to indicate an alarm.

If a zero-sequence voltage element is used to open a circuit breaker to isolate the system from a ground fault, all sources must be disconnected and the entire system de-energized. The zero-sequence overvoltage element cannot provide selectivity like the ground overcurrent protection does to limit the outage to the faulted circuits. The first ground fault in an ungrounded system is normally not a major concern and the facility can perform an orderly shutdown to identify and correct the ground fault. However, if the electrical system grounding type changes based on the system configuration, having a ground fault present in an ungrounded system that is reconfigured and becomes solidly grounded now presents a concern of closing into a fault condition.

The system designer and protection engineer must take into consideration the implementation and protection settings for ground fault protection or ground fault detection. If the system is designed to be solidly grounded and ground fault protection is provided by overcurrent devices, when the system is reconfigured and becomes ungrounded, the overcurrent ground fault protection is no longer providing the protection intended and an alternate ground fault protection scheme may be required. In Medium Voltage systems, adding zero-sequence overvoltage protection may not be possible if only Open Delta-Open Delta PTs are provided. Adding broken-delta PT's may be required to implement zero-sequence overvoltage protection. In multiple source systems that can have sources potentially segmented, creating several systems, this quickly becomes an issue with the number of PT's required.

Surge Arrester Ratings

Surge or lightning arrester maximum continuous overvoltage ratings are selected based on the system voltage and system grounding type. The surge arresters are connected from each phase to ground.

Figure 4 is an excerpt from Eaton Application Paper AP083011EN, Surge protection guidelines for VacClad-W metal-clad switchgear. The table shows the difference in Nominal and MCOV arrester ratings when applied on Solidly Grounded/Low Resistance Grounded Systems versus application on an ungrounded system.

	Distribution class arresters-kV ratings					
Service voltage line-to-line kV	Solidly grounded system		Low resistance grounded system		High resistance or ungrounded system	
	Normal	MCOV	Normal	MCOV	Normal	MCOV
2.30	3	2.55	3	2.55	3	2.55
2.40	3	2.55	3	2.55	6	5.10
3.30	3	2.55	3	2.55	6	5.10
4.00	3	2.55	6	5.10	6	5.10
4.16	6	5.10	6	5.10	6	5.10
4.76	6	5.10	6	5.10	9	7.65
4.80	6	5.10	6	5.10	9	7.65
6.60	6	5.10	6	5.10	9	7.65
6.90	6	5.10	6	5.10	9	7.65
7.20	6	5.10	6	5.10	10	8.40
8.32	9	7.65	9	7.65	12	10.20
8.40	9	7.65	9	7.65	12	10.20
11.00	9	7.65	9	7.65	15	12.70
11.50	9	7.65	10	8.40	18	15.30
12.00	10	8.40	10	8.40	18	15.30
12.47	10	8.40	12	10.20	18	15.30
13.20	12	10.20	12	10.20	18	15.30

Figure 4. AP083011EN Surge Protection Guidelines

In solidly grounded systems, the arresters are selected to have an MCOV rating slightly higher than the phase-to-neutral voltage of the system. During a ground fault, the phase-to-ground voltage across each arrester remains relatively close to phase-to-neutral voltage and there are no concerns with the arrester MCOV rating being exceeded.

In ungrounded systems, the arresters are selected to have an MCOV rating slightly higher than the phase-to-phase voltage. In an ungrounded system, the system cable capacitance from each phase to ground creates a neutral reference that keeps the voltage across each arrester relatively close to an equivalent phase-to-neutral voltage of the system. However, when one phase experiences a ground fault, the line-to-ground capacitance of the faulted phase is now at the same voltage as the faulted phase and the voltage across the other two phase's capacitance is line-to-line voltage. Similarly, the two arresters on the unfaulted phases experience line-to-line voltage across the arrester.

If the system is originally designed to be solidly grounded and the arresters selected based on a solidly grounded system, when the system is reconfigured and becomes ungrounded, the arresters will fail when the system experiences a ground fault.

Overvoltages

Ungrounded systems can experience overvoltage during certain ground fault conditions. During an arcing ground fault the system can be subjected to overvoltages up to 550% of nominal. These overvoltage events can lead to failure of surge arresters or insulation stress of equipment. The resultant insulation stress can lead to premature failure of equipment or machines in the system.

Circuit Breaker Interrupting Ratings

NEC 240.85 limits low voltage circuit breaker ratings that have a slash voltage rating (e.g. 480/277) to be used only on solidly grounded systems. On ungrounded systems, the circuit breaker must have a single-pole interrupting capability appropriate for available fault current. If the system was designed to be solidly grounded and the circuit breaker interrupting ratings are based on a solidly grounded system, when the system is reconfigured and becomes ungrounded, the circuit breakers may no longer be appropriately rated to interrupt fault currents.

PT Concerns

In Medium Voltage systems, the use of Wye-Wye PT's on an ungrounded system can result in erroneous voltage readings or possibly create a ferroresonant condition.

When PT's are connected phase-to-ground in an ungrounded system, there is an increased possibility that ferroresonace will occur. The ferroresonace results in system voltages much higher than rated and can lead to failure of the PT.

Wye-Wye PT's are typically provided with line-to-neutral voltage insulation ratings. Using PT's with line-to-line voltage insulation ratings can provide an additional margin of protection for the PT in the event of an overvoltage condition.

Wye-Wye PT's connected phase-to-ground in an ungrounded system can also present erroneous phase-to-ground voltage readings. As previously discussed, an ungrounded system has each phase capacitively coupled to ground. This coupling provides the ground reference for the PT's, but the reference is not perfectly balanced between each phase as seen with a solidly grounded system. This leads to phase-to-ground voltage readings that are not balanced. Figure 5 shows voltage measurements from Wye-Wye PT's installed in an ungrounded 12.47kV system. The line-to-line voltages are very closely balanced. However, the line-to-neutral voltages show some imbalance. In this case, the imbalance is relatively small, but this system did experience greater imbalances that prevented the system from synchronizing back to the utility when line-to-neutral voltages were used as the voltage reference.

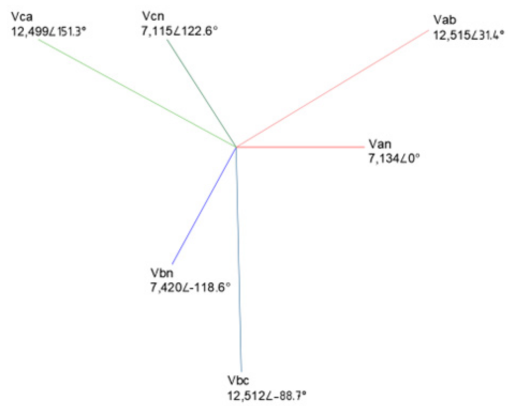

Figure 5. Wye-Wye PT Voltages on Ungrounded System

In solidly grounded systems, it is common practice to install Wye-Wye PT's to be able to measure line-to-neutral voltages. In ungrounded systems, Open Delta – Open Delta PT's are recommended for voltage measurements. If the system is reconfigured and becomes ungrounded, the Wye-Wye PT's may lead to the previously mentioned concerns. To overcome this , if MV equipment was originally supplied with Wye-Wye PT's, the PT's may be changed to Open Delta-Open Delta. However, this change eliminates the ability to measure zero-sequence voltage to detect ground fault conditions on an ungrounded system or to measure line-to-neutral voltages when the system is connected to the utility source. IEEE 1547 sets limits for system overvoltage and undervoltage detection. When the interconnection is solidly grounded, the limits apply to line-to-neutral and line-to-line voltages. With Open Delta-Open Delta, it is not possible to measure line-to-neutral voltages to take corrective action as required.

Examples

The following section provides two examples of systems where the system ground type changed based on the operating scenario. A brief summary is provided, the concerns noted and then some general recommendations and considerations to correct the issue. The recommendations are provided as generalizations and may not be suitable for all systems or circumstances. The reader is referred to the references section for more in-depth discussion and guidance on designing systems with distributed energy resources.

System Example #1

Figure 6 shows a system where utility service is provided at 480V from a utility owned transformer with a solidly grounded wye secondary. A diesel generator, BESS and PV are connected directly to the 480V service entrance switchgear. When the switchgear main breaker is closed and the PV and BESS are providing power, the system is solidly grounded.

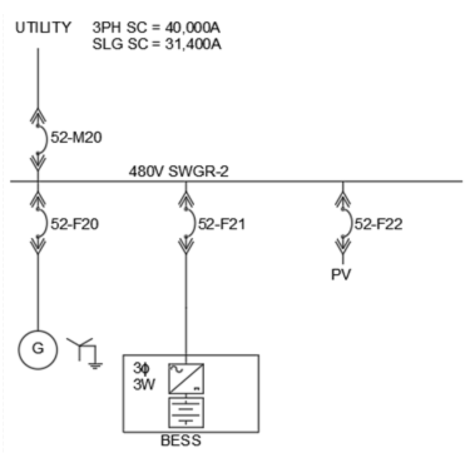

Figure 6. Unground BESS System

When the utility source fails, the utility main breaker is opened and the generator and BESS are used as the grid-forming resources. The generator is solidly grounded, so when the generator circuit breaker is closed and the generator connected to the switchgear, the system is solidly grounded. When the generator circuit breaker is open and the BESS is operating as the sole grid-forming resource, system grounding is dependent on the BESS inverter. In Figure 6, the BESS inverter is a 3-wire inverter with no neutral, resulting in an ungrounded system and leading to the previously discussed problems. To prevent this, the BESS source needs to be a solidly grounded 4-wire source. It is not common for a BESS inverter to inherently provide a solidly grounded 4-wire connection. More commonly, to create a solidly grounded BESS source, a transformer is installed between the inverter and system. This transformer may be supplied as part of the BESS supplier's unit package or it may need to be specified and ordered separately from the BESS. Figure 7 shows a transformer, TB, installed between the BESS and SWGR-2 to create a solidly grounded system when the BESS is the sole power source. It is important to note that the system between the BESS and transformer TB is still ungrounded and needs to take this into consideration during the design process. In some situations, instead of installing transformer TB, a zig-zag or wye-delta grounding transformer may provide the needed ground reference when operating on the BESS.

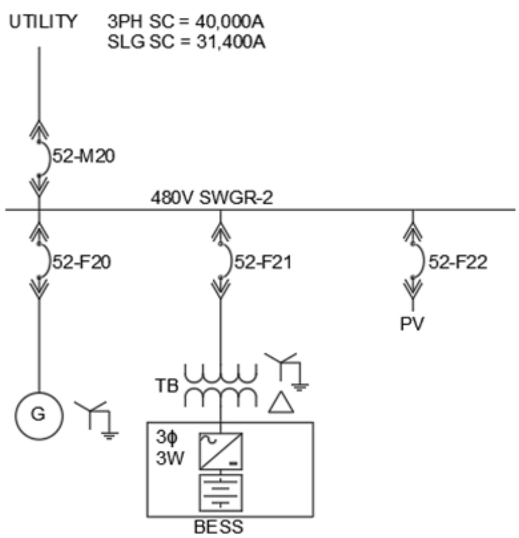

Figure 7. Solidly Grounded BESS Source

System Example #2

Figure 8 shows a system where utility service is provided directly at medium voltage. The utility service is solidly grounded and the utility has a recloser close to the customer's facility. The ratio of utility line-to-ground short-circuit current is greater than 60% of the utility three-phase short circuit current, indicating the utility service provides a good degree of system grounding.

The customer owns the medium voltage switchgear (SWGR-1) with a main circuit breaker and several feeder circuit breakers. The feeders provide power to the medium voltage distribution system with several step-down transformers to lower the voltage to utilization voltage (480V). The transformers have a primary winding connected in Delta and the secondary is Wye connected with Xo directly connected to ground. There are energy resources connected to the low voltage secondary side of the step-down distribution transformer.

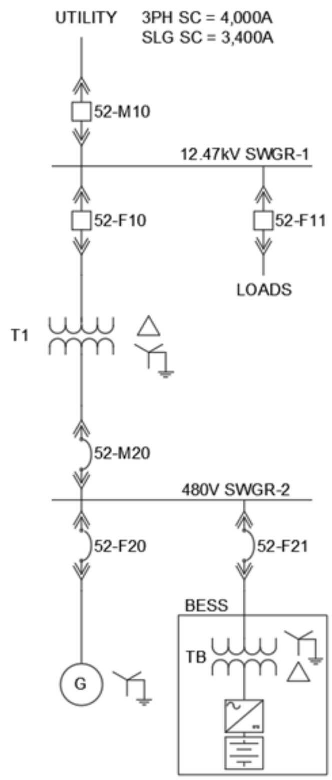

Figure 8. Example MV Distribution System with Low-Voltage Energy Resources

When a utility failure occurs, the main breaker 52-M10 will open to separate the facility from the utility system. The BESS or generator on the 480V system becomes the grid-forming resource. The 480V generated power is stepped-up to 12.47kV voltage through T1 to provide power through SWGR-1 to the other loads on the system. In this example, the primary side of the transformer is connected in Delta, blocking zero-sequence current from flowing to a ground-fault in the 12.47kV system. When a 12.47kV ground fault occurs, the ground fault current will be very low (limited by the system distributed capacitance). The 12.47kV system now operates as an ungrounded medium voltage system and is subjected to the previously discussed problems.

Another similar scenario of concern occurs if the utility line experiences a line-to-ground fault between the utility line recloser and the main circuit breaker 52-M10. The recloser will likely open before the main circuit breaker 52-M10, creating an island that energizes the faulted utility line from the customer's energy sources. The 12.47kV island operates as an ungrounded system, so any ground overcurrent relaying on 52-M10 is not going to detect the ground fault. If there are sufficient loads on the utility line segment between the recloser and 52-M10, then the energy resources may shut down on overload. However, if there are no or limited loads on the utility line segment, the line will likely remain energized. This situation presents a severe hazard to utility workers who may be trying to repair the line. Additionally, the utility recloser may try to close back to the energized line and close out of sync. Finally, there is a potential for utility or other utility customer's equipment to be damaged during islanded operation as an ungrounded system. IEEE 1547 requires unintentionally created islands to be detected and cease to energize the island within 2 seconds of formation. For this scenario, careful coordination with the utility system must be considered to prevent creating an unintentionally islanded system. The system design, protection and energy source settings must be considered and coordinated to be able to detect abnormal operations for all scenarios.

To prevent the creation of an ungrounded system when 52-M10 opens, transformer T1 should be connected in a Grounded Wye-Grounded Wye (GY-GY) configuration, with H0 and X0 solidly grounded, as shown in Figure 9. In this system, when 52-M10 is open, the solidly grounded connection of the generator or BESS provides a solid ground reference for the entire system through both windings of transformer T1. For a ground fault in the 12.47kV system, ground fault current will flow from the generator through T1 to the fault, allowing ground overcurrent protection to operate.

While the GY-GY transformer connection is necessary for providing a solidly grounded system, it does create a challenge for coordinating ground overcurrent protection. When transformer T1 has a delta primary winding connection as shown in Figure 8, the ground fault protection of 52-F10 does not need to be coordinated with the SWGR-2 ground overcurrent protection. However, with the GY-GY transformer connection, the 52-F10 and SWGR-2 ground overcurrent protection does require coordination so that a ground fault on a 480V feeder does not trip the 12.47kV equipment and de-energize the entire system. Further complicating the ground fault coordination is that coordination also needs to be considered when the SWGR-2 sources are feeding the 12.47kV switchgear (looking from SWGR-2 towards SGWR-1). Different ground fault magnitudes from each source may necessitate different setting groups in protection relays to detect and coordinate ground fault overcurrent settings depending on system configurations.

An important distinction must be made with the GY-GY transformer shown in Figure 9. The GY-GY connection itself does not create a solidly grounded system. Unlike a delta-wye transformer, the GY-GY transformer is not a source of zero-sequence current, it only allows zero-sequence current to flow through the transformer. There must be another source of zero-sequence current in the system. When disconnected from the utility, the zero-sequence current source must be either the generator or BESS. In other words, both must be solidly grounded as depicted in Figure 9. If either source is not solidly grounded, a grounding transformer will be required at SWGR-2 to create a solidly grounded system when the generator or BESS are the grid-forming source. With solidly grounded equipment or installation of a grounding transformer at the low-voltage equipment, careful attention must be paid to overcurrent ground fault protection. When connecting interconnected power production equipment to the load side of equipment with ground fault protection (as SWGR-2 is depicted), NEC 705.32 requires there to be ground fault protection from all ground current sources. In low-voltage 4-wire systems, it is important to design the ground fault protection so that the multiple sources do not result in the desensitization of the ground fault protection system or nuisance tripping.

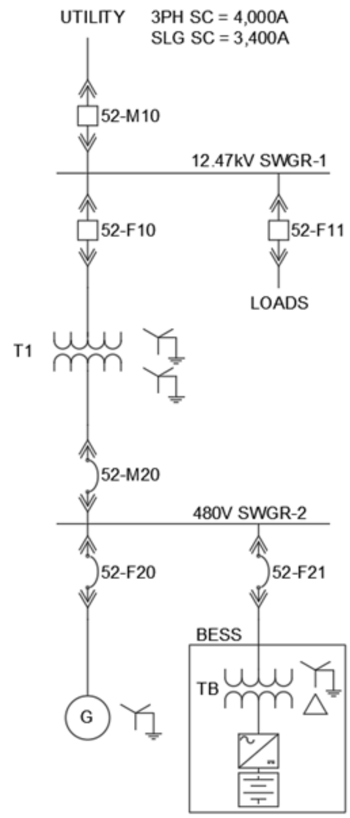

Figure 9. Recommend Transformer T1 Connection to Maintain a Solidly Grounded System

In instances where the transformer T1 is already installed, the cost of a new transformer or lead-times may be prohibitively high. A zig-zag or wye-delta grounding transformer is an alternate solution at the medium voltage level to derive a ground, but careful attention must be paid to the varying system configurations that may occur to ensure that no part of the system will become ungrounded if the system is segmented. In many instances, the decision is made to not install a GY-GY transformer or a grounding transformer. Instead, the customer will replace surge arresters installed for a solidly grounded system with surge arresters rated for an ungrounded system. Additionally, the customer may replace the Wye-Wye PTs with Open Delta-Open Delta PTs to limit the risk of ferroresonance and prevent erroneous line-to-neutral voltage readings in the relays. While this may provide an immediate lower cost solution that allows the system to operate, it presents the potential to shorten the useful life of the system or equipment. With this approach, there is now the problem of detecting ground faults with the Open Delta-Open Delta PTs on an ungrounded system. When operating as an isolated ungrounded system, a ground fault could occur in the Medium Voltage system and there is no way to detect this condition. The system could experience overvoltage, stressing equipment insulation and shortening equipment life. Additionally, when the utility returns and the system transfers back to utility, the main breaker will be closing into a ground fault and high magnitude ground fault currents will be flowing through the closing main breaker.

Additional Considerations

The following provides some additional discussion and points of consideration regarding system grounding with multiple sources and selection of transformer winding connections. The reader is referred to the references section for more in-depth discussion of these topics.

1) Coefficient of Grounding - When discussing solidly grounded systems, providing a solid connection from a neutral point of the equipment ground does not guarantee that the system will behave like a solidly grounded system. The effectiveness of the grounding in the system must be evaluated. In simple systems, the magnitude of the ground-fault current to system three-phase current is a good guide (Equation 1) to determine if the system is effectively grounded.
In complex systems with multiple transformers, multiple sources or installation of grounding transformers, a more comprehensive analysis may be required to determine the system Coefficient of Grounding. This analysis considers the ratios of the system zero-sequence reactance to positive sequence reactance and zero-sequence resistance to positive sequence resistance. Eaton's Power Systems Engineering Team can provide a PSCAD system grounding analysis to determine the system Coefficient of Grounding.

2) GY-GY Transformer Considerations - When installing GY-GY transformers, there are several considerations that must be considered when designing the system.

- **Harmonics -** With a GY-GY transformer, the effect of harmonics on the system needs to be considered. When a transformer has a delta connected winding, the delta winding traps triplen harmonics so they do not flow from the low-voltage to medium-voltage system. With no delta winding, if triplen harmonics are present in the low voltage system, they may impact the medium voltage system.
- **Zero Sequence Current -** The GY-GY transformer does not create a solidly grounded system. Unlike a delta-wye transformer, the GY-GY transformer is not a source of zero-sequence current, it only allows zero-sequence current to flow through the transformer. There must be a source of zero-sequence current in the system and a neutral path must exist on both sides of the transformer for zero-sequence currents to flow through the transformer.
- **Voltage Unbalance -** When using a Y-Y transformer, any voltage unbalance on the primary side will be reflected to the secondary side. If unbalance is severe enough, it can cause problems for equipment supplied from the system. Including voltage phase balance protection may be necessary to ensure equipment is not damaged by significant voltage unbalance.

3) Wye-Delta Transformers - In Figure 9, occasionally the designer may select T1 windings so that the 480V side is a delta connection and the 12.47kV side is a grounded wye to avoid some of the concerns related to using a GY-GY transformer. However, this will create an ungrounded 480V system when SWGR-2 is being fed from the utility source and the generator and BESS are not operating. The designer must consider if the 480V system is suitable for operation as an ungrounded system. Additionally, the Wye-Delta transformer connection is a source of zero-sequence current to the 12.47kV and can de-sensitize the 12.47kV ground fault overcurrent protection.

4) Paralleling Generators with Dissimilar Alternator Winding Pitches - If multiple generators are paralleled in a system and all generators do not have the same winding pitch, harmonic currents can circulate in the system neutral. Eaton's Power Systems Engineering Team can analyze the effects of differing generator pitches and provide a solution to minimize the impact of harmonic currents to the system.

5) Current and Voltage Instrumentation - Some protection schemes implemented in a distributed energy resource system are dependent on measurement of zero-sequence currents and voltages. Where transformers are installed, the protection schemes may be dependent on continuity of the zero-sequence network. Additionally, certain transformer installations or winding configurations can reconstruct voltages during abnormal system conditions. This can prevent undervoltage protection from operating as intended. The system designer and protection engineer need to take into consideration the location of current and voltage instrumentation transformers to ensure the protection scheme operates as designed.

6) Protection Settings and Avoiding Nuisance Tripping - In DER systems where the transformer can be supplied from either the primary or secondary windings, the designer and protection engineer need to carefully consider equipment and system protection and coordination requirements.

- **Transformer Winding and Cable Protection -** Consult NEC Article 450 for protection of transformer windings and NEC Article 240 for protection of conductors connected directly to transformer windings.
- **Transformer Inrush Current -** Transformers designed as step-down can draw significantly more inrush current when energized as a step-up configuration, requiring careful consideration of overcurrent device settings to prevent nuisance tripping.
- **Continuous Neutral Bus Grounding Challenges (3ph-4wire) -** If the transformer provides zero-sequence continuity, the design of the grounding and protection system need to be evaluated. Coordination of the transformer primary and secondary ground fault protection systems is necessary. In solidly grounded systems, the grounded neutral conductor can be carried throughout the system (a 3-phase 4-wire system) to serve line-to-neutral loads. Having multiple neutral to ground bonds in the system creates challenges for traditional residual sensing ground fault protection schemes and may de-sensitize or cause nuisance operation of ground fault overcurrent protection. These types of systems require the design and use of specialized ground fault protection schemes that may consist of differential ground fault sensing, the use of 4 pole breakers, source ground sensing or a hybrid grounding scheme. Some of the challenges to ground fault overcurrent protection related to the installation of a 4-wire system can be eliminated or simplified using a solidly grounded 3-phase 3-wire system. In this system, the neutral to ground bond is still present at the source, but the grounded neutral conductor is not carried throughout the system and tied together at each source. This design precludes line-to-neutral loads being served directly from the system and requires D-GY isolation transformers to serve line-to-neutral loads.

References

IEEE Recommended Practice for System Grounding of Industrial and Commercial Power System, IEEE 3003.1-2019

IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces, IEEE Standard 1547-2018

IEEE Application Guide for IEEE Std 1547-2018, IEEE 1547.2-2023

IEEE Guide for Application of Transformer Connections in Three-Phase Electrical Systems, IEEE Std C57.105-2019

National Electrical Code, NFPA 70-2023

Changes to the 2002 NEC® clarify requirements for the use of slash rated circuit breakers and application of individual pole interrupting capabilities for various grounding schemes, Cooper-Bussmann-2001. [Online]. Available: https://www.eaton.com/content/dam/eaton/products/electrical-circuit-protection/fuses/protective-device-ratings/bus-ele-slash-rated-devices-2.pdf

Application Paper, Surge protection guidelines for VacClad-W metal-clad switchgear, Eaton AP083011EN-2018. [Online]. Available: https://www.eaton.com/content/dam/eaton/products/medium-voltage-power-distribution-control-systems/vacclad-w-pages/surge-protection-guidelines-for-vac-clad-w-metal-clad-switchgear-ap083011en.pdf

Application Paper, Grounding methods in mission critical facilities, Eaton AP083008EN-2018. [Online]. Available: https://www.eaton.com/content/dam/eaton/products/medium-voltage-power-distribution-control-systems/vacclad-w-pages/grounded-systems-in-mission-critical-installations-ap083008enpdf.pdf

White Paper, Ground Fault isolation with loads fed from separately derived grounded sources, Eaton WP027003EN-2013. [Online]. Available: https://www.eaton.com/content/dam/eaton/products/low-voltage-power-distribution-controls-systems/switchgear/low-voltage-switchgear-documents/white-paper-groud-fault-isolation-wp027003en.pdf

PV and Inverter-based DER Ground Referencing Requirements and Sample Calculations, Xcel Energy AE-DG-2-2015 Ver: 1.4. [Online]. Available: https://www.xcelenergy.com/staticfiles/xe/PDF/MN-SRC-Invertor-Based-Ground-Refrencing-Requirements-and-Sample-Calculations.pdf

D.L. Swindler; R. Snider, "A case study of medium voltage power system failures as a result of the loss of system grounding," *in Conference Record of 1995 Annual Pulp and Paper Industry Technical Conference*, 1995, doi: 10.1109/PAPCON.1995.404832

J. Mohammadi; F. Badrkhani Ajaei, G. Stevens. "AC Microgrid Grounding Strategies," in *2018 IEEE/IAS 54th Industrial and Commercial Power Systems Technical Conference (I&CPS),* 2018, doi: 10.1109/ICPS.2018.8369994

Instrument Transformers Technical Information and Application Guide, ABB 1VAP420003-TG-2004-Rev-A. [Online]. Available: https://library.e.abb.com/public/e2462bd7f816437ac1256f9a007629cf/ITTechInfoAppGuide.pdf

Eaton
1000 Eaton Boulevard
Cleveland, OH 44122
United States
Eaton.com

Printed in USA
Publication No. WP027026EN
January 2025

Powering Business Worldwide