DC DECOUPLING FROM UTILITY GROUNDING SYSTEMS

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INTRODUCTION

Within facilities such as pipeline stations and tank farms, cathodic protection (CP) is most easily achieved when the protected structure is electrically isolated from other structures and grounding systems. This allows for lower current requirements from CP current sources, such as rectifiers or galvanic anodes, and generally allows the operator to achieve the required voltage criteria for protection against corrosion.

However, electrical equipment connected to the structure, such as motor operated valves and instrumentation, must be electrically grounded to provide protection against AC faults and lightning or to provide a suitable ground reference for instrumentation. If such equipment and the associated grounding systems are properly isolated from the cathodically protected structure through the use of isolation joints and/or dielectric fittings, there is no impact on the CP system.

However, it is not uncommon for many cathodically-protected structures to be inadvertently bonded to other structures and grounding systems and this results in the CP system having to protect not only the coating defects on the intended structure, but also the other structures and grounding systems to which it is bonded.

In addition to the local facility grounding system, the power utility grounding system to which the facility is bonded presents a large and unknown amount of buried metallic surface area in the form of copper ground rods and other grounding electrodes, as illustrated in Figure 1. Moreover, the facility is also bonded to all the other utility customers' grounding systems. This vast bare surface area becomes part of the cathodically protected structure from a current-requirement perspective, overwhelming the CP design goals, and allowing unintended interaction to occur. High rectifier output to meet the current demand can also cause excessive voltage gradients in the soil that result in interference with other nearby structures, including both owned and foreign systems, affecting CP potentials, and possibly causing corrosion.

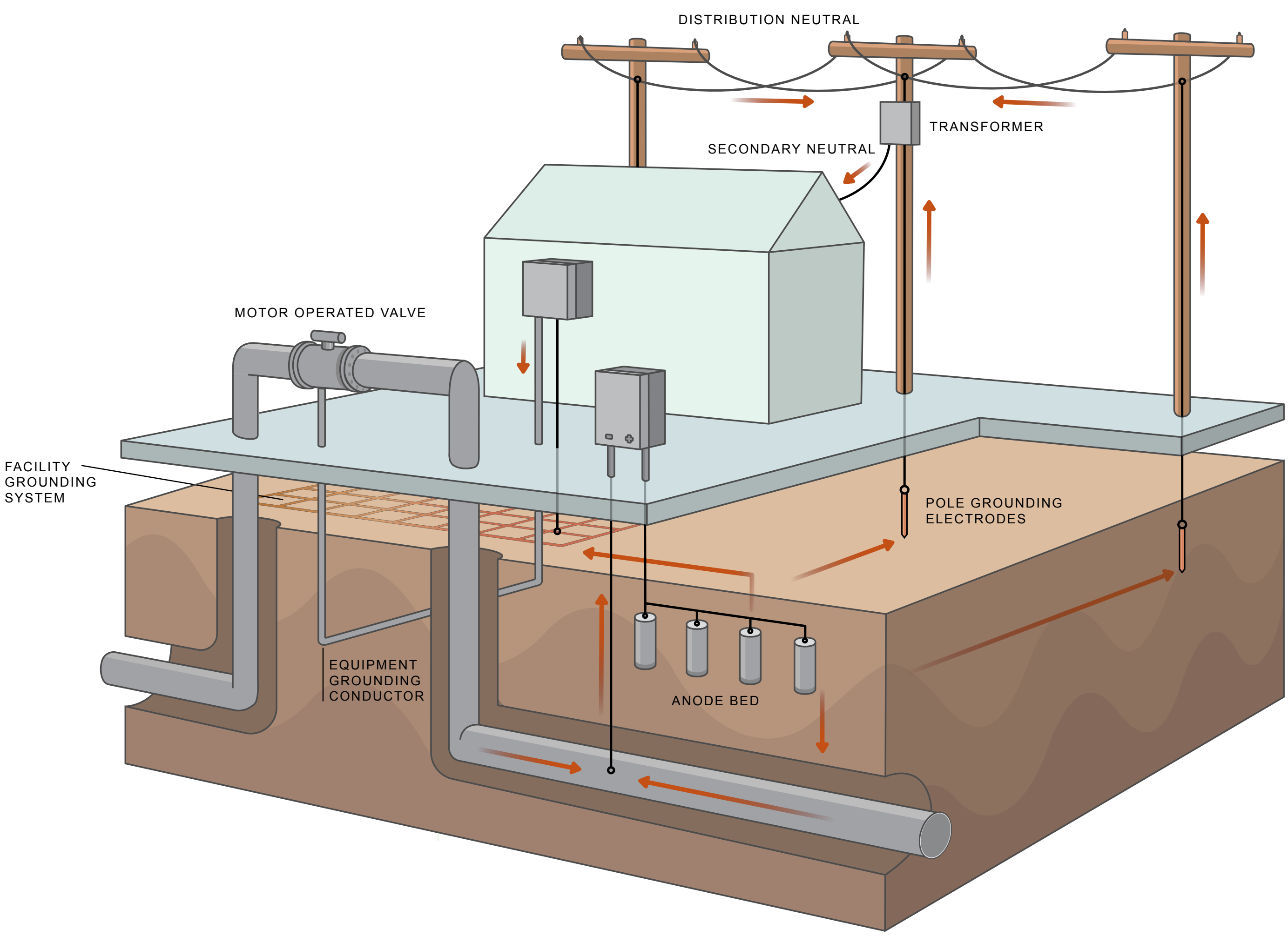


Figure 1. Facility cathodic protection interacts with power utility grounding system.

These negative effects can be prevented by judicious application of DC decouplers. Solid-state decouplers provide effective DC isolation while maintaining a safe grounding path for AC faults and lightning. Decouplers are bi-directional, two-terminal devices that feature power semiconductor-based isolation and switching. Fail-safe designs ensure that any exposure to conditions that exceed the device ratings result in an uneventful fail-shorted condition, hence the term “fail-safe”. Under normal operating conditions, the device blocks DC and conducts AC up to a predetermined voltage threshold of typically several volts. During an over-voltage event, upon reaching the voltage threshold, the decoupler instantly switches to the fully conducting mode, clamping voltages (AC and DC) to low and safe levels. After the event, the voltage drops below the threshold and the decoupler automatically switches back to the DC blocking/AC conducting mode.

Two accepted installation methods exist for applying decouplers to isolate CP protected facilities from grounding systems, each with its relative advantages: Installation in the grounding conductors of individual electrical devices and installation at the transformer feeding power to the facility.

Installation in Equipment Grounding Conductors

In smaller simple facilities, it is usually most efficient to install decouplers in series with the grounding conductors of individual electrical devices, being mindful to also isolate any associated conduit that bonds the CP protected structure to the grounding system. The main advantage of this approach is that it minimizes the additional surface area that the CP system must protect, especially if the decoupler is located close to the protected structure. Recommended practices for implementing this method are thoroughly described in reference 1 [1].

However, at larger, more complex facilities having multiple electrical devices with grounding connected to the protected structure or piping that is otherwise bonded to the grounding system at several points, locating and individually isolating every bond can be challenging and expensive.

Installation at the Transformer

At larger, more complex facilities, it may be more prudent to abandon trying to isolate at every individual bonding point and instead allow the CP system to protect the entire facility including underground piping, grounding grids, conduit, fencing, etc. Though the CP system may be sufficient to protect the facility, it will likely be overwhelmed by the current demand required to also protect the extensive surface area presented by the utility grounding system. So, to maintain the effectiveness and efficiency of the facility’s CP system, it is important to isolate the facility CP system from the utility grounding system.

The common tie between cathodically protected facilities and power utility grounding systems is the bond that exists at the electrical service. Specifically, the primary-to-secondary neutral bond enables cathodic protection current flow between the two facilities. However, this bond exists to meet safety requirements and cannot simply be separated for convenience.

The utility (primary) and customer (secondary) grounding systems are bonded together by default to facilitate safe operation, should either system attempt to rise in voltage, such as during an AC fault or lightning event. Bonding assures that both systems remain close in voltage. Permanent separation of the two systems is not an option, due to safety concerns. However, a suitably rated decoupler can be installed as the bond between primary and secondary neutrals (and/or grounding systems) to address cathodic protection issues along with safety bonding. This results in a great reduction of CP current required, limits interference with other structures, and helps CP potentials to achieve industry compliance. Figure 2 illustrates a decoupler installed at the transformer, resulting in CP current flow only to the intended facility.

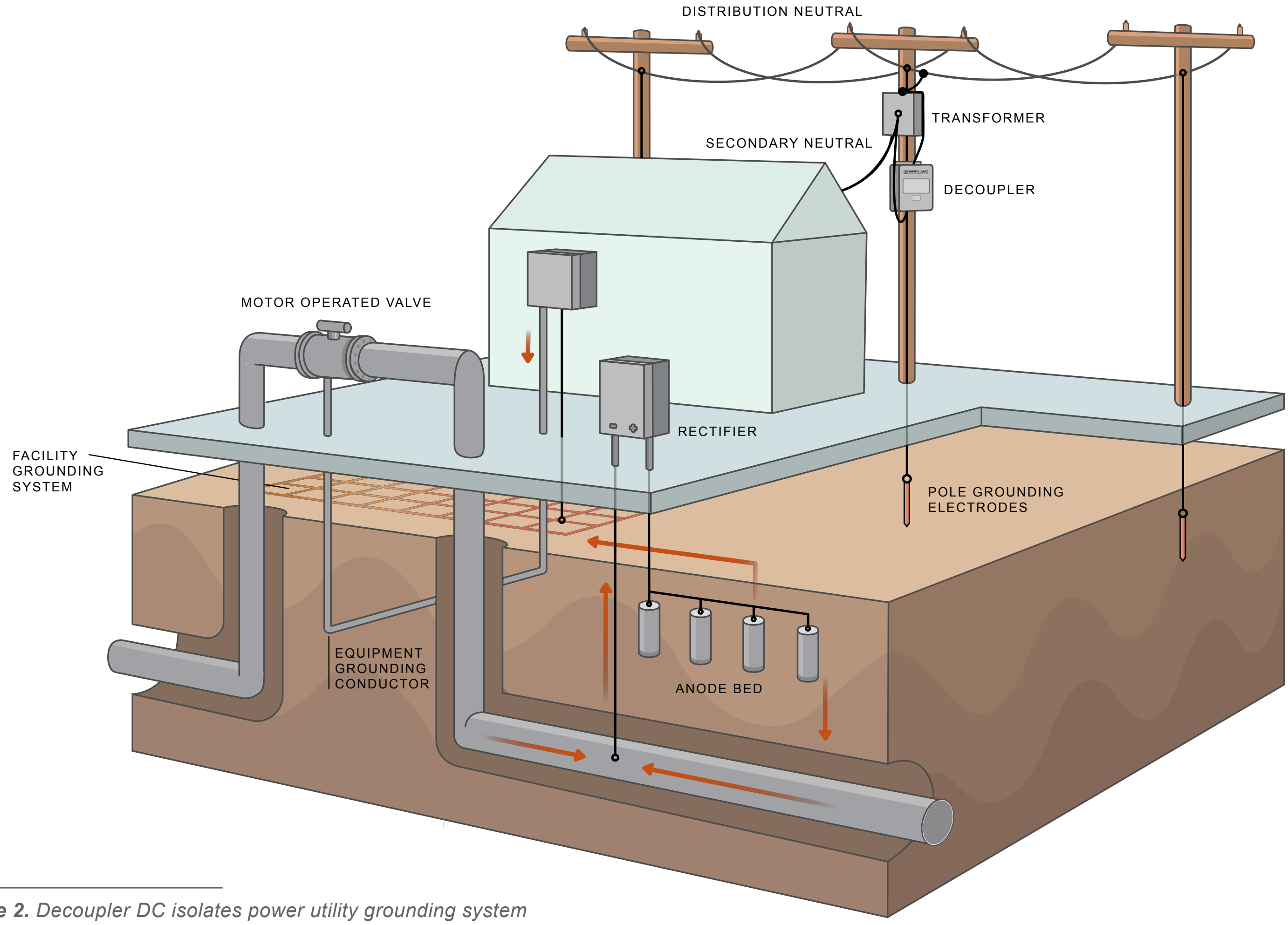


Figure 2. *Decoupler DC isolates power utility grounding system*

The main advantage of decoupling at the transformer instead of at individual electrical grounding conductors within the station is that far fewer decouplers are needed. Depending on the specific power utility connections to a site, a single decoupler is often sufficient to isolate the entire facility from the utility. And because the decoupler AC fault rating is sized to the fault rating of the primary system, a lower fault-rated decoupler may be applied. Overall, the cost for decouplers is far less with this method.

Clearly, the main disadvantage of decoupling at the transformer is that the facility CP system must be designed to protect the entire facility instead of only coating defects on the structure. In addition, since in most cases the utility owns the transformer, the facility operator must gain the cooperation of the utility to install and oversee the decoupler.

Using decouplers in this manner to provide primary-to-secondary bonding and DC isolation has been standardized at many utilities and allows uniform application of devices across the utility system, whether served by single or three-phase, pole or pad mounted transformers. But there is often some confusion regarding the installation methods with different types of transformers and how to ensure all potential paths for CP current bypass have been remedied.

The main goal of this paper is to add clarity regarding decoupler installation at transformers to solve facility CP problems, including connections, possible bypasses, and practices.

Though not discussed in detail in this paper, it is worth noting that another method of installing decouplers to isolate the facility from the power utility is to install a decoupler at the facility's main service panel in series between the ground bus and neutral bus. It should be noted, however, that though this method is safe and effective, it is not explicitly allowed in the US National Electrical Code.

FACILITY-UTILITY BONDING AT TRANSFORMERS

The typical utility single or three-phase distribution circuit has a multiple grounded neutral system, connecting the neutral at various points to grounding electrodes, and referencing the neutral to the secondary neutral and/or grounding system at the transformer. A common single-phase transformer arrangement at a customer service is depicted in Figure 3.

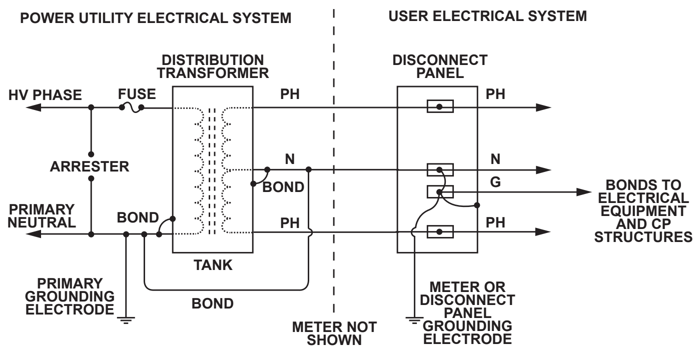


Figure 3. Typical electrical service involving cathodic protection.

Often, the secondary customer's CP system is intentionally, or inadvertently, connected to all facility structures and grounding system. The site grounding conductors and bonds reference the facility to the secondary neutral, which is connected at the transformer secondary neutral bushing to the tank, which in turn ties to the utility's primary neutral, and its grounding system. These connections result in CP current pickup on the utility grounding system and is returned via these bonds at the transformer and service to the cathodically protected facility. Figure 4 shows this current flow, without any isolation.

Note that any bond connecting the primary and secondary neutral provides a path for CP current to flow between the utility ground and the customer's facility ground and in so doing requires the facility CP system to also protect the utility grounding system. There are often multiple bonds that need to be addressed.

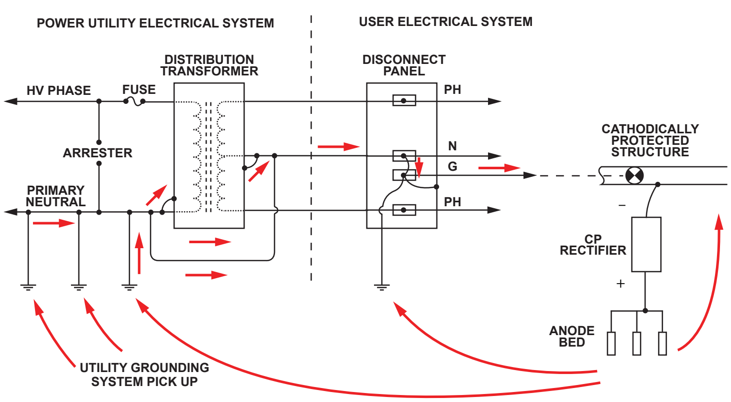


Figure 4. Current flow on typical electrical service involving cathodic protection.

Addition of a decoupler at the transformer, in series with the primary-to-secondary neutral bond, and clearing all bypasses, as shown in Figure 5, results in the facility CP system protecting only that site. Note that one of the bypass points is the tank grounding strap at the secondary neutral bushing. This is removed as the decoupler is installed. The tank remains bonded, as before, to the primary neutral and grounding electrode.

The decoupler, as an AC-continuous device, keeps the secondary neutral solidly referenced to the primary neutral for safety, but blocks DC. The decoupler should be installed with the negative terminal connected to the secondary since that system will be more electronegative than the primary due to being cathodically protected. Figure 6 shows a typical installation of a decoupler at a pole-mounted transformer.

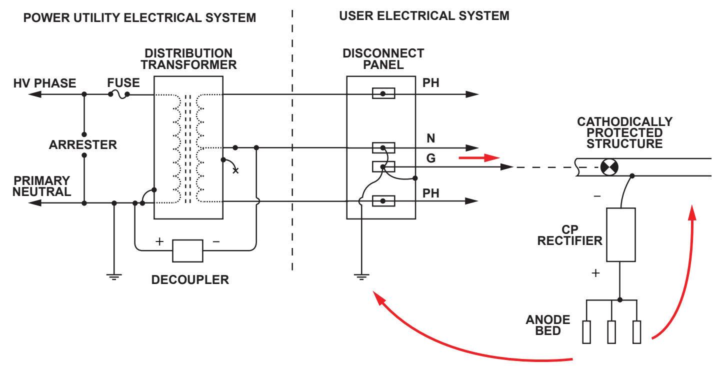


Figure 5. Effect of decoupling on typical electrical service involving cathodic protection.

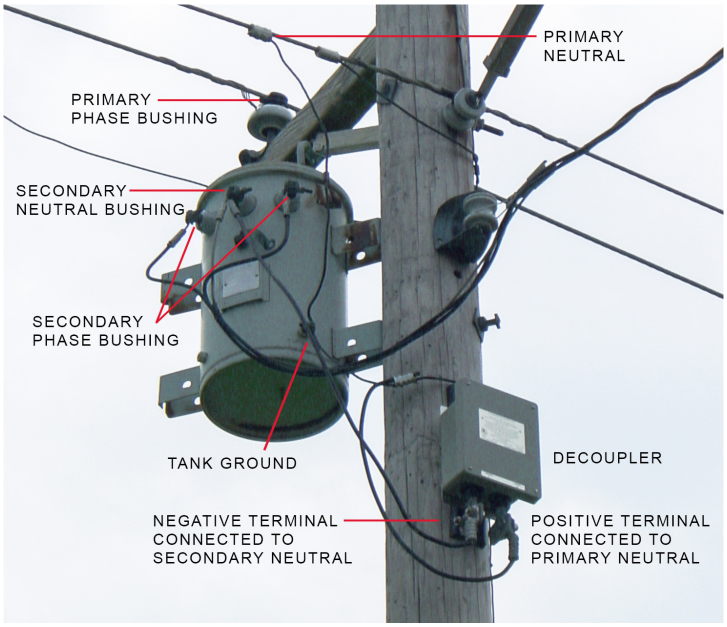


Figure 6. Decoupler installation at a single-phase pole-mounted transformer.

Three-Phase Transformers

Three-phase service encounters the same basic issue as for single-phase transformers due to bonding of primary and secondary neutrals. For pole type transformers arranged for three-phase service, all connections are external to the tank, so decoupling between primary and secondary is the same as for single-phase. However, pad-mounted three-phase transformers have different construction and installation than pole-mounted units that can introduce additional paths, which, if not addressed, can allow for CP to bypass the decoupler. These variations are described below for each configuration of three-phase transformers. For any configuration, the key to DC isolation is to ensure that all direct bonds between the primary and secondary grounding systems are accounted for and either removed or replaced by a decoupler as needed to maintain safety bonding.

Wye-Wye Configurations

In Figure 7, a three-phase wye-wye transformer is shown, with an internal link between the primary and secondary neutrals. Besides the wired bonds and tank grounding straps that exist between primary and secondary neutrals, an internal link bonding the two systems results in a third connection, all of which pass cathodic protection current. Note that some pad-mounted transformers do not have this internal connection, while others that do may not provide access to the link.

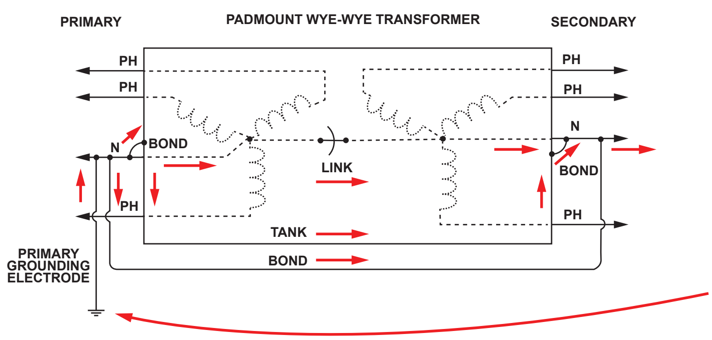


Figure 7. Three-phase pad-mounted transformer connections allowing CP current flow.

DC isolation of the utility connection to the facility CP system at a three-phase wye-wye pad-mounted transformer is illustrated in Figure 8, showing the addition of a decoupler connected between the primary and secondary neutrals, with removal of the secondary neutral bushing ground strap from the tank. The tank remains grounded to the primary neutral and local grounding electrode. If an internal link bonds primary and secondary neutrals inside the tank, this link must be opened, or the transformer changed out for a unit that does not have this internal link.

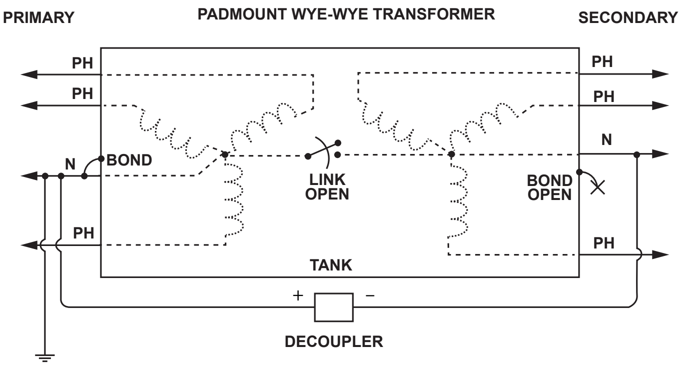


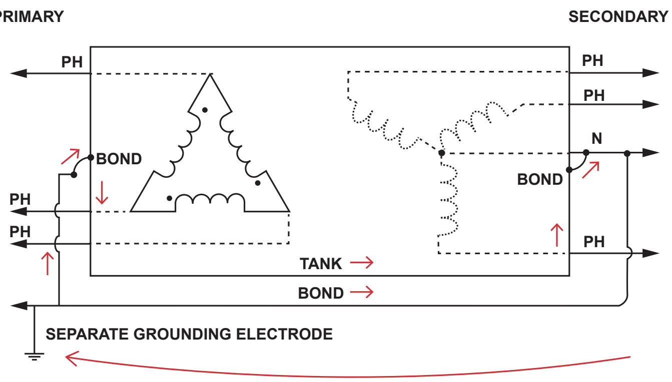
Figure 8. Decoupler installation at a three-phase Wye-Wye pad-mounted transformer.

Delta-Wye Configurations

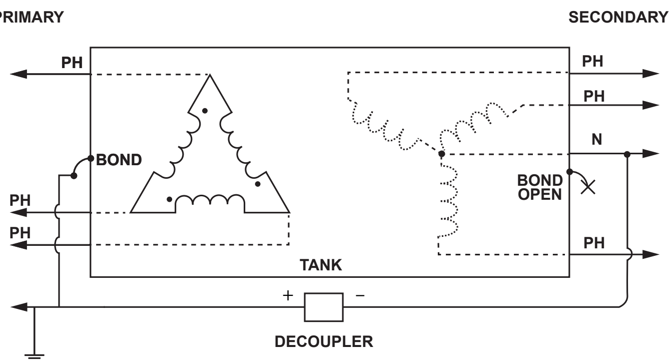
Delta transformer configurations introduce additional variations in how the primary and secondary grounding systems may be bonded. Delta windings, whether on the primary or secondary or both, are typically ungrounded and without a neutral. However, sometimes they are corner-grounded, with one corner of the delta solidly grounded and sometimes a leg of the delta is center-tapped and grounded for four-wire service. In any case, as with wye-wye configurations, it is important to ensure that all direct bonds between the primary and secondary grounding systems are accounted for and either removed or DC isolated using a decoupler. Some configuration variations are described below.

In Delta-Wye configurations where the delta winding is ungrounded, there is often a separate grounding conductor connecting primary and secondary grounding systems and bonded to the neutral on the wye windings as shown in Figure 9a. This grounding conductor may run through or outside of the tank and CP isolation is achieved by inserting a decoupler in the grounding conductor between the primary and secondary and opening the neutral-to-tank bonds on the secondary, leaving in place the primary ground-to-tank bonds as shown in Figure 9b.

Figure 9. Delta-Wye transformer with ungrounded Delta windings and separate grounding wire.



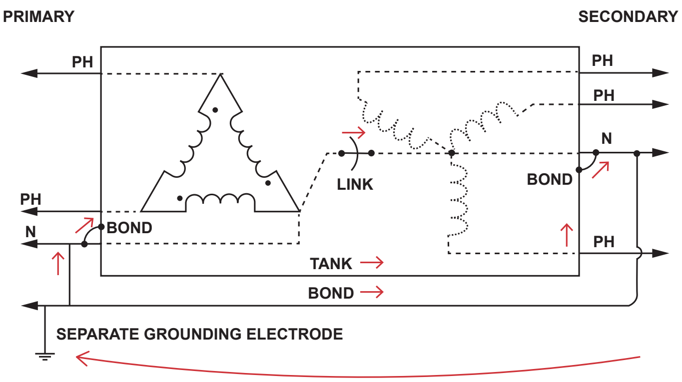
9a. Prior to CP isolation showing CP current paths.



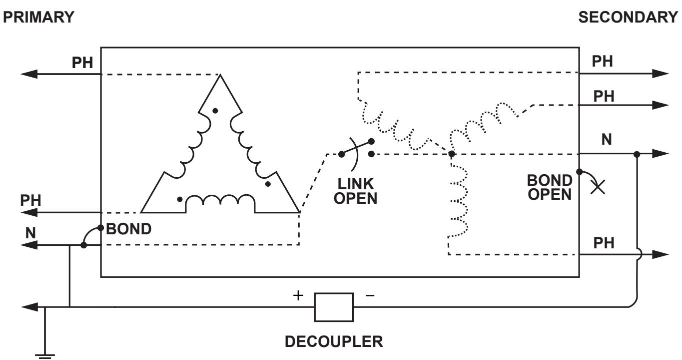
9b. With decoupler installed and CP current paths cleared

For corner-grounded or center-tapped and grounded delta windings, there may be an internal link between the grounded leg on the primary delta and the neutral on the secondary wye that, together with the external grounding wire and the tank housing, will allow CP current to pass between primary and secondary ground as shown in Figure 10a for a corner-grounded arrangement. As with other configurations, CP isolation from the utility is accomplished by installing a decoupler in the grounding wire between the primary and secondary of the transformer together with opening any internal bonds between primary and secondary as well as the bonding strap between the tank and the secondary neutral as shown in Figure 10b.

Figure 10. Delta-Wye transformer with corner-grounded Delta windings and separate grounding wire.



10a. Prior to CP isolation showing CP current paths.



10b. With decoupler installed and CP current paths cleared

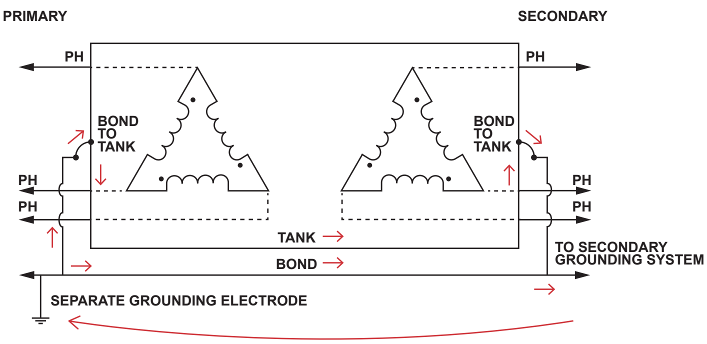
Wye-Delta Configurations

Similar practices should be followed for isolating CP at wye-delta transformers. In any case, ensure that bonding straps to the tank are removed on the secondary side, but remain bonded to the grounding electrode on the primary side.

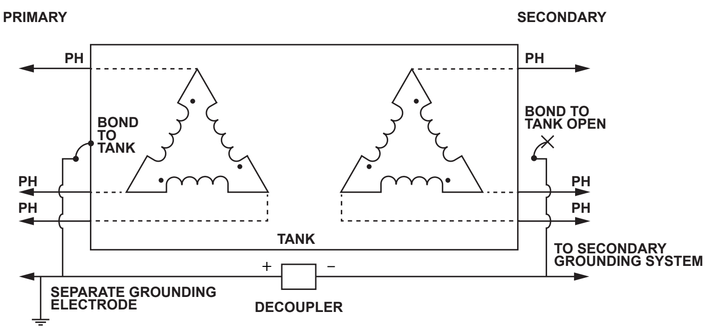
Delta-Delta Configurations

Ungrounded Delta-Delta transformers have no neutrals and so should not have internal bonding links to be concerned with, as shown in Figure 11a. However, any additional grounding wire connecting the primary and secondary grounding systems will need to be remedied by inserting a decoupler in the bond as shown in Figure 11b. In addition, any bond to the tank on the secondary should be opened, leaving the tank grounding bond in place on the primary side.

Figure 11. *Delta-Delta transformer with ungrounded Delta windings and separate grounding wire.*



11a. *Prior to CP isolation showing CP current paths.*



11b. *With decoupler installed and CP current paths cleared*

OTHER POTENTIAL CP BYPASS PATHS TO CONSIDER

In addition to tank grounding straps, internal bonding links and any externally wired bonds, there commonly exist other connections between the primary and secondary grounding systems that provide a path for CP current to bypass the decoupler.

Fencing and/or Grounding Grids

Some facilities, typically with larger pad-mounted or substation class transformers, may have fencing and grounding near the transformer, which may tie to fencing and grounds at cathodically protected facilities that they serve, therefore bonding the primary and secondary systems independent of transformer decoupling. Such an example is illustrated in Figure 12. Bonding between grounding grids must then be separately decoupled at each connection on either the primary or secondary side. As an alternative, if the common fencing is the sole CP bypass path, CP isolation can be achieved by installing a section of electrically insulating fencing in place of metallic material.

In such cases, careful thought should be given to step and touch voltage distribution between discontinuous fencing and/or grounding grids during an AC fault or lightning event.

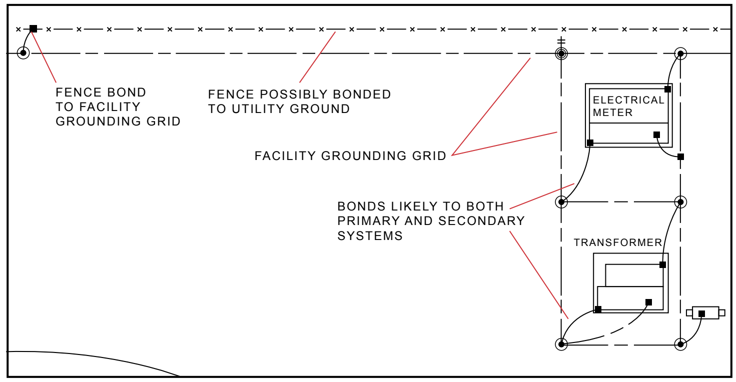


Figure 12. *Site plan showing additional bonding between primary and secondary that allow CP bypass.*

Phone Sheathing

One additional bond between primary and secondary grounding systems that exists in almost all cases is the phone company metallic sheath that ties to both the utility and the facility grounding systems, causing a bypass around the decoupler. If all transformer bonds have been correctly addressed and cathodic protection potentials have not improved, the phone sheath is the most likely bypass. The phone company can provide an open point in their sheath to address this, typically in their pedestal near the facility, which makes this open point safely inaccessible to the public.

Common Transformer X0/H0 Bushing

Another common bypass occurs when the primary and secondary neutrals are connected to a common X0/H0 bushing on the transformer. In this case, there is no place to insert a decoupler to provide isolation. And installing a decoupler in series between the primary neutral and the X0/H0 bushing would permit primary return current to flow continuously through the decoupler, which is never acceptable. In this case, it might not be possible to isolate at the transformer and would be advisable to isolate at other locations between the transformer and the protected structure.

KEY DECOUPLER RATINGS

AC fault current

The most important decoupler rating for use with utility decoupling is AC fault energy capability. Decouplers installed at transformers should be chosen with AC fault ratings greater than the utility primary phase-to-ground current for the clearing time, which can be obtained from the utility. This addresses line-to-ground faults and transformer winding failure. Any fault that occurs on the secondary system would not pass through the decoupler and so the decoupler fault rating does not need to be selected to accommodate secondary fault current. During a fault or lightning event, the decoupler instantaneously re-bonds the two systems and then returns to the normal DC blocking and AC conducting mode following the event. When applied within the device's published energy ratings, robust decoupler products have no lifetime limitation.

Threshold voltage

The device threshold voltage applies to the voltage measured across the device terminals, which is also the voltage difference between the primary and secondary neutral/grounding systems. The voltage on the secondary grounding system should be close to the CP potentials on the protected structure and the voltage on the primary grounding system should be close to the corrosion potential of that grounding system material, likely copper, or $-0.3V_{CSE}$. So typically, the voltage difference between the two grounding systems is approximately -0.8V and standard decoupler threshold voltage ratings of -2/+2V or -3/+1V are typically adequate. If CP potentials are more electronegative than -1.8VCSE then an asymmetric threshold voltage of -3/+1 or greater is recommended in this case.

Steady-state AC current

Since there should be no steady-state AC current flowing between the two grounding systems in this application, the steady-state current rating is less critical.

NEVER INSTALL DECOUPLERS IN SERIES WITH THE NEUTRAL

Decouplers are never to be installed in series in current-carrying neutral conductors. Proper installation involves placement of the decoupler in safety grounds and bonds that connect to a system neutral, without being connected in series in the neutral. Connections to the neutral via equipment grounding conductors, buses, and electrodes are what cause CP problems, which can be remediated via a correctly placed decoupler.

TESTING FOR CP IMPROVEMENT

Often, testing can be performed to confirm that decoupling will be effective in improving CP system performance before a decoupler is purchased. The power utility must be involved with the test when evaluating any potential decoupler installation located on the utility side of the meter. The secondary customer's CP personnel can be present to take readings as the utility temporarily separates the primary and secondary grounding systems for the purpose of testing (The utility service may need to be interrupted momentarily during the test, for safety). If an open circuit can be established during the test, CP personnel can determine if the CP potentials (and current demand) have improved. This temporary isolation test reflects the same DC condition as when a decoupler has been applied, and the client can then know that decoupling would be effective. If an open circuit and associated improvement in CP potentials cannot be achieved, then a metallic bypass still exists elsewhere.

When installing a decoupler at the transformer, the decoupler is typically located on the utility side of the meter and is therefore owned and installed by the utility. After determining the appropriate decoupler AC fault rating from utility-provided data, a decoupler can be purchased by the facility owner and supplied to the utility for installation. When maintenance-free decouplers are used, there is no need for periodic decoupler testing by the utility following installation. Since the utility customer maintains and monitors their CP system in the facility, they will be quickly made aware of unacceptable CP potentials or excessive CP current demand in the event of a decoupler failure. Upon inspection, CP personnel would also be able to confirm a short by measuring an electronegative shift in potentials on the utility's grounding electrodes from the normal (native) values.

SUMMARY

Maintaining DC isolation of pipelines and storage tanks at large, complex cathodically protected facilities can be a major challenge due to the extent of equipment and instrumentation that is electrically bonded to the grounding system as well as the potential for other inadvertent bonds between the protected structure and the grounding system. The challenge is exacerbated by the additional bare surface area presented by the utility through the connections that normally exist between the utility and the customer grounding systems at the electrical service.

Solid-state decouplers can be installed between the primary and secondary grounding systems to provide DC isolation of the facility from the utility, while retaining AC steady-state and fault continuity between the two systems for safety. Standard installation locations on utility services make decoupling straightforward, once the power utility and the owner of the cathodically protected facility understand that this option exists.

REFERENCES

1. Decoupling Electric Equipment Grounding Systems. Dairyland Application Guide. Dairyland Electrical Industries. dairyland.com/applications/decoupling-electric-equipment