Application Note 102

Stabiliti™ and SunDial™ 30kW Series PCS

Interconnection and Transformer Design Requirements

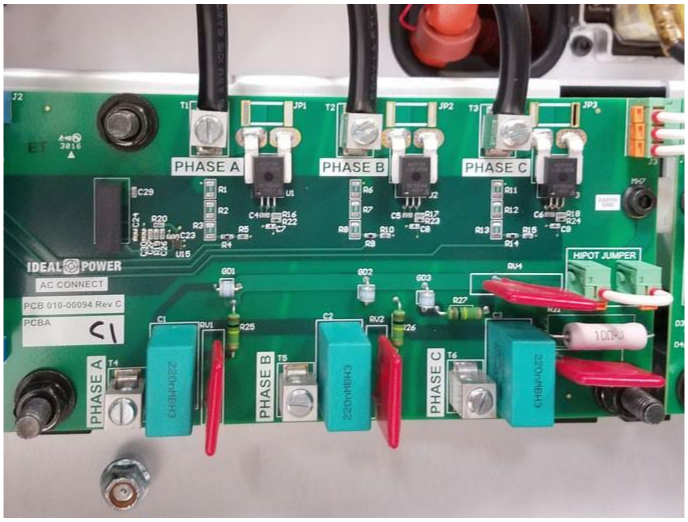
PURPOSE AND SCOPE

Ideal Power Conversion Systems (PCS) are designed to operate in North America at a nominal 480 Vac and 60 Hz on the 3-wire, 3-phase AC power port. Applications that require different AC voltages or applications involving grid-forming capabilities are accommodated by use of a transformer. This application note details considerations and requirements for successful interconnection of the PCS to a facility electrical power system.

PCS ELECTRICAL BACKGROUND

The Stabiliti™ and SunDial™ series PCS both have a 3-wire, 3-phase AC electrical connection interface and power is made phase-to-phase at 480 Vac, 60 Hz in North America. The PCS does not accommodate a neutral wire connection and therefore does not directly produce power at 277 Vac. This configuration is referred to as a delta connected circuit. Refer to the section on zigzag transformers for information on supporting 277 Vac phase-to-neutral loads.

Figure 1: PCS AC electrical connection interface showing 3 phase power connectors.



As with all electrical equipment, an Ideal Power PCS includes components with certain voltage withstand limits and internal overvoltage surge protection. As a result, the AC input voltages must be anchored relative to ground to ensure proper protection of the system. Input circuits which are not constrained and not grounded are referred to as floating and in this case, while the input phases may remain constant phase-to-phase, during power flow they may easily rise in voltage relative to ground by hundreds of volts. The AC input voltages into the PCS must always be constrained phase-to-ground (line-to-ground) to a nominal 277 Vac and anchored by the electrical service external to the PCS. This requirement may be fulfilled by a user-installed facility transformer or by the native utility electrical service into the local facility power system. In case of a fault or unconstrained phases, the PCS includes fault protection for line-to-ground overvoltage events and will shut down at 590 Vpk to help protect standard 600 V rated conductors.

WARNING: UNDER NO CIRCUMSTANCES SHOULD AN UNGROUNDED ELECTRICAL POWER SYSTEM OR UNGROUNDED TRANSFORMER BE CONNECTED TO THE PCS AC PORT.

TRANSFORMERS ELECTRICAL BACKGROUND

AC power transformers are specified by a primary voltage, a secondary voltage and whether the primary and secondary windings are configured as 3-wire delta with 3 phase wires or 4-wire wye with 3 phase wires and a neutral wire. Note that these specifications do not necessarily imply any particular grounding scheme for the circuits connected to either side of the transformer. Either delta or wye may be ungrounded or grounded in a variety of manners.

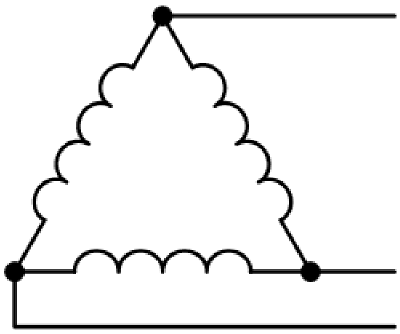


Figure 2: Delta wound transformer

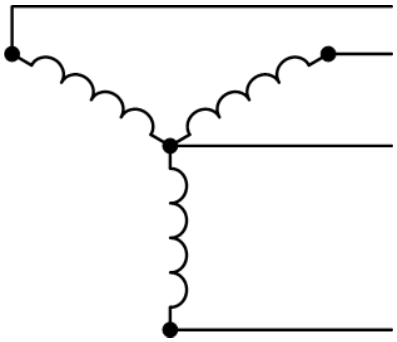


Figure 3: Wye wound transformer

Using typical nomenclature, the primary side is expected to be connected to the utility grid service and the secondary side is expected to be connected to the facility power system downstream of the grid. Using this nomenclature, the Ideal Power PCS will be connected to the secondary side of a transformer at 480 Vac which may be one or more transformer-steps downstream of the main facility grid service.

Generally, the utility grid service into a facility has phase voltages referenced to ground in some way whether at a local point or distant utility-owned transformer. Ungrounded utility grid service is possible but uncommon and not addressed in this Application Note. The typical practice when installing a facility-owned transformer is to have the primary be delta configured and the secondary be wye configured with the mid-point neutral grounded inside the transformer in compliance with the National Electrical Code. The Ideal Power PCS requires this same typical configuration and is discussed in further detail in the following sections of this Application Note.

Typical transformers have electrically isolated primary and secondary windings magnetically coupled for power transfer. However, if the primary and secondary connected electrical systems don't require isolation, an autotransformer may be used whereby the primary and secondary are electrically connected to the same set of windings. Note that autotransformers have fewer total windings than full isolation transformers and therefore are typically smaller, less expensive and have slightly improved efficiency.

Important: isolation transformers or autotransformers with high impedance can affect the power conversion stability of a power converter. Please contact Ideal Power for support with transformer specifications.

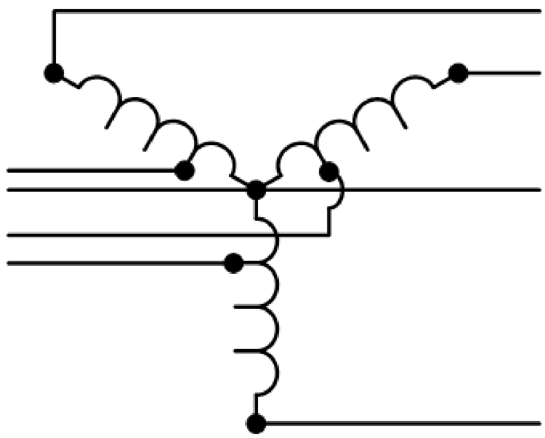


Figure 4: Wye autotransformer windings

Isolation & Energy Storage

By definition, energy storage systems (ESS) contain a high amount of energy which, in the case of an electrical fault, can lead to sustained and dangerous fault currents. Protection from these fault currents for personnel safety and for the wider electrical system is typically accomplished through the galvanic isolation of a stand-alone isolation transformer. The Stabiliti™ and SunDial™ PCS include built-in galvanic isolation by way of a compact, high-frequency transformer in the power conversion core. This is advantageous to be able to eliminate the need for an external isolation transformer in many cases or else simplify the system to use an autotransformer if a voltage step is required. Multiple Ideal Power PCS's may share a common transformer, due to their internal galvanic isolation. There is no requirement to dedicate a transformer to each individual PCS for isolation purposes.

ZIGZAG TRANSFORMERS

The zigzag transformer is a non-isolated specialty transformer which can be comprised of a network of single phase 1:1 isolation transformers (as shown in Figure 6), or constructed as an integrated single unit. A zigzag transformer is used to derive a neutral wire from a 3-wire delta electrical network. The primary winding of each individual transformer, or phase pole of a single transformer is connected 180° out of phase with the secondary winding on the adjacent phase transformer or phase pole. The remaining secondary connections are bonded in common and form the neutral connection of the transformer. The open terminations of the primary windings connect to each phase of the 3-phase delta network.

Figure 5: Zigzag wound transformer symbol

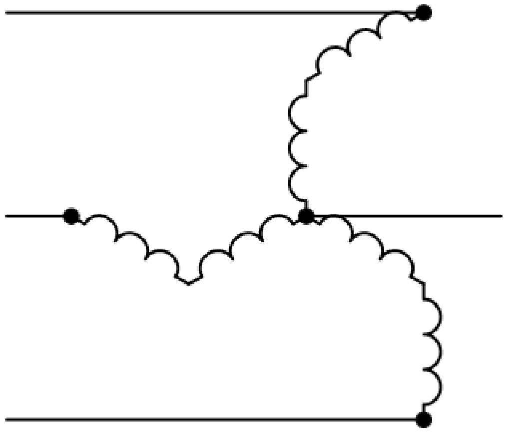


Figure 6: Zigzag Transformer Division of Neutral Current

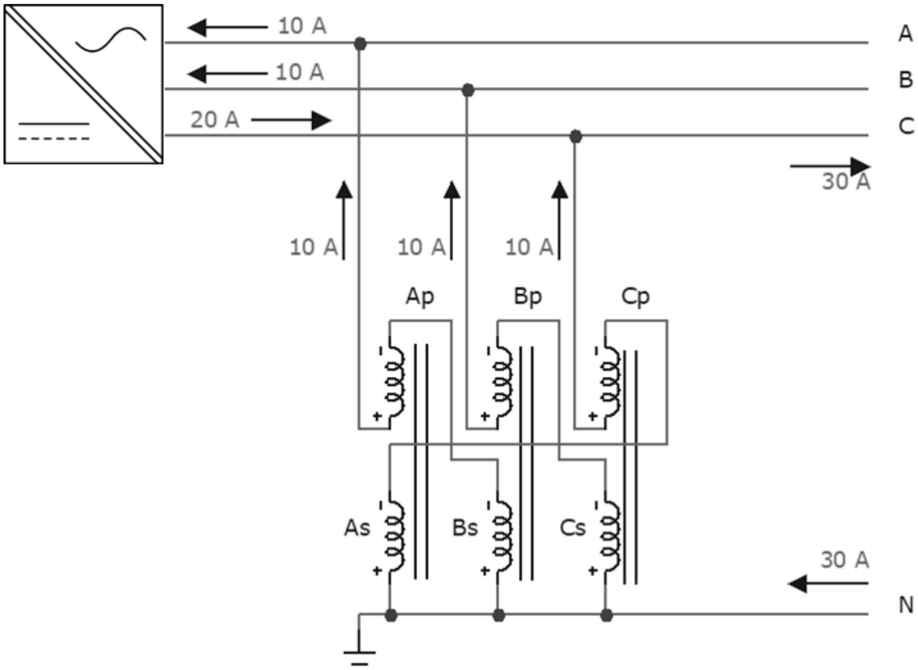


Figure 6 also demonstrates how phase-neutral currents are re-distributed equally among all three phases of the zigzag transformer. The magnitude of the neutral current in secondary coil Cs is equal to the current in primary coils Cp (because of the common magnetic coupling), and Bp (because of the series connection). Applying the same analysis to the remaining coils, it is apparent by inspection that all the winding currents are simultaneously equal, the sum of which is equal to the neutral current. Therefore, each phase current in the zigzag transformer is 1/3rd of the neutral current. In this manner, the zigzag transformer reflects the phase-neutral load as a phase-phase imbalance load at the delta source.

The interconnection of the windings also ensures that the line to neutral RMS voltage remains equal among the three phases. In this manner, the zigzag transformer anchors the otherwise floating delta network symmetrically around ground.

When the zigzag transformer neutral connection is only bonded to ground and only used to anchor the 3-wire delta network, in this document, it will be referred to as an anchoring zigzag or A-Zigzag.

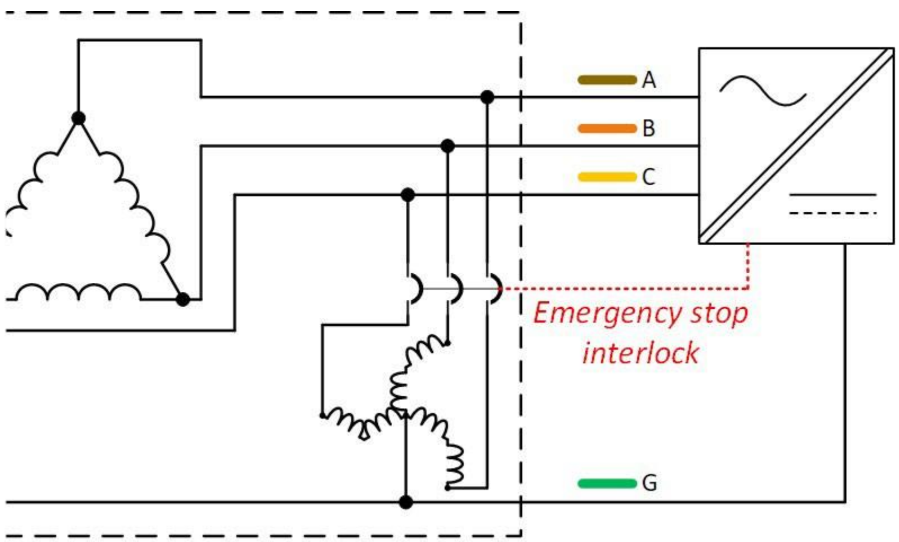
Alternately when the zigzag neutral is connected into an existing facility neutral to interface with a 4-wire wye circuit for phase-to-neutral power transfer, in this document, it will be referred to as an N-Zigzag. The facility neutral wire will be grounded at the service entrance and will remain connected through a deliberate facility islanding event, therefore an N-Zigzag also anchors the facility delta network.

For all the configurations presented in this Application Note involving the A-Zigzag the 3-phase system is comprised of one or more PCS delta outputs and a delta-wound transformer secondary. Neutral current should only flow through the zigzag in the case of unbalanced phase voltages since no loads are present and therefore the zigzag should be sized according to the maximum phase voltage imbalance as constrained by grid codes. The A-Zigzag requires corresponding overcurrent protection (circuit breaker) on the 3 phase input consistent with the noted neutral current. The circuit breaker should be interlocked with the emergency stop input on the PCS to disable operation since a trip would yield a floating delta circuit. Contact Ideal Power for A-Zigzag supplier recommendations.

For applications with an N-Zigzag transformer, it should be sized according to the expected continuous neutral current. Zigzag sizing is typically not specified in terms of a kVA rating as there is no 3-phase power flow. When paired with the Stabiliti™ PCS an N-Zigzag also serves as an anchoring transformer and therefore the discussion above regarding the A-Zigzag applies including the overcurrent protection and PCS interlock. Auto-zigzag transformers are also available that can both derive a neutral and also step voltages up or down.

An example of the zigzag circuit breaker interlock is shown in Figure 7 below and applies to all zigzag configurations discussed in this Application Note. It is omitted in subsequent schematics only for simplicity.

Figure 7: Zigzag transformer circuit breaker interlock with a Stabiliti™ PCS



Note that an N-Zigzag is generally compatible with a pre-existing neutral from the utility service transformer when the system is fully grid connected. Variability in phase impedances between the two transformers should be low resulting in limited neutral current leakage that can be accommodated by the N-Zigzag.

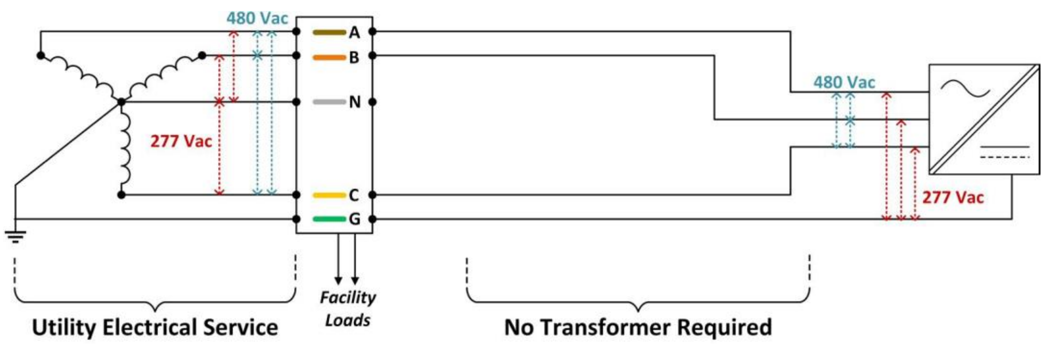
Contact Ideal Power for zigzag transformer support and supplier contacts: support@idealpower.com.

GRID-TIED ONLY APPLICATIONS WITH THE SUNDIAL™ OR STABILITI™

Grid-tied, electrical service case: 480/277 Vac Wye, Grounded

This is a common electrical supply for commercial and industrial facilities and is the primary intended installation case for an Ideal Power PCS. In this situation, the PCS may be directly interconnected to the main distribution panel without a transformer. The electrical connections should resemble Figure 8 below.

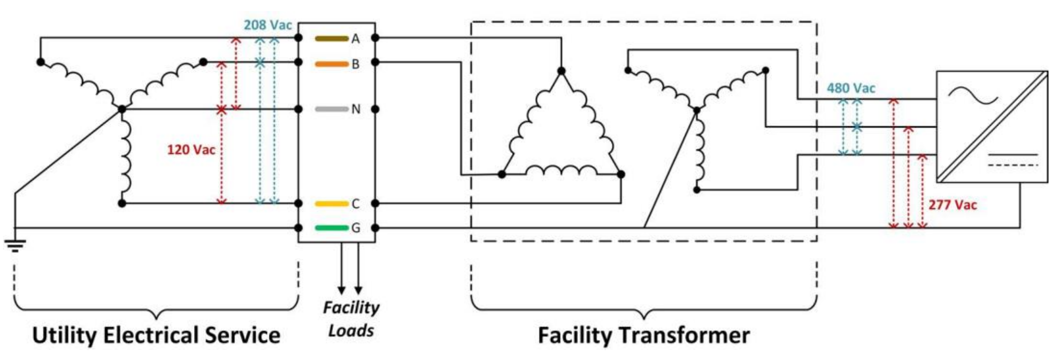
Figure 8: 480/277 Vac electrical service with direct PCS connections



Grid-tied, electrical service case: 208/120 Vac Wye, Grounded

This is another common electrical supply for commercial and industrial facilities. A similar interconnection scheme would apply for other 3 phase electrical supplies that are not 480/277 Vac such as 600/347 Vac found in Canada or 380/220 Vac found in Europe. An Ideal Power PCS may be interconnected with two different transformer options. Option A) 208 Vac delta to 480/277 Vac wye, grounded as shown in Figure 9. Option B) 208 Vac to 480 Vac wye autotransformer as shown in Figure 10. Note that autotransformers have fewer total windings than full isolation transformers and therefore are typically, smaller, less expensive and have slightly improved efficiency.

Figure 9: 208/120 Vac electrical service PCS interconnection with a standard delta-wye transformer (Option A)



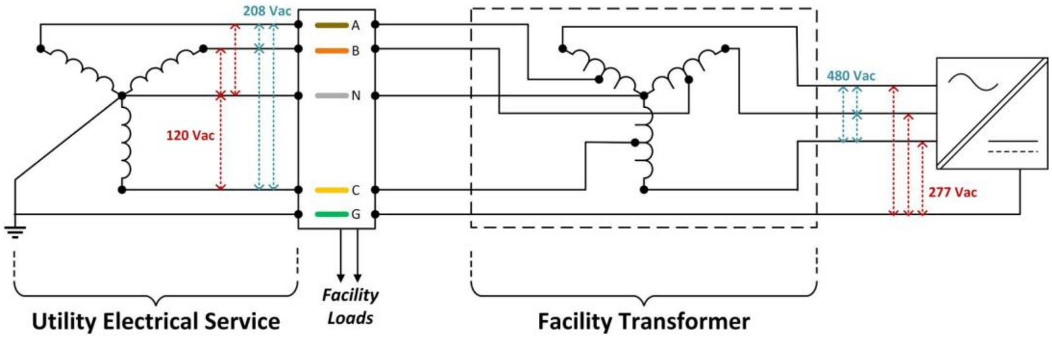


Figure 10: 208/120 Vac electrical service PCS interconnection employing an autotransformer to interface with the PCS (Option B)

Grid-tied, electrical service case: 240 Vac High-Leg Delta

An alternate 3 phase power supply to light commercial/industrial buildings to accommodate standard 240/120 Vac single phase loads and some limited 3 phase loads. In this situation the 240 Vac grounded delta supply is transformed with a delta to 480/277 Vac grounded wye transformer as shown in Figure 11.

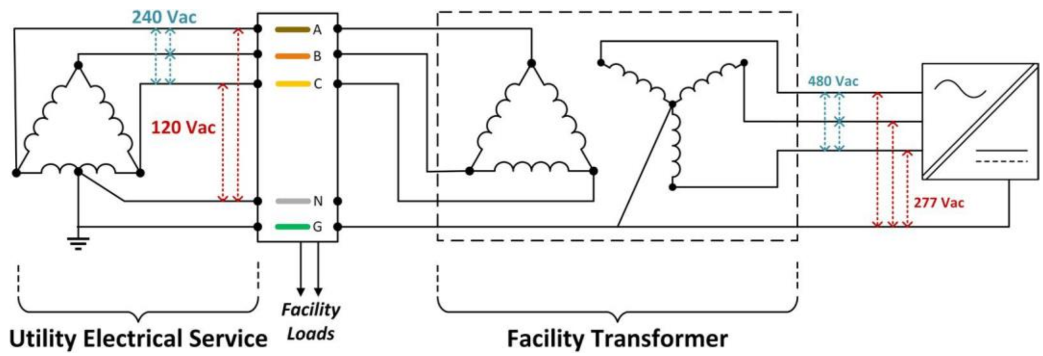


Figure 11: 240 Vac high-leg delta electrical service PCS interconnection with a delta-wye transformer.

A full list of the transformer requirements for grid-tied only PCS interconnection is presented below dependent on the utility electrical service.

Native Utility Electrical Service		Transformer Configuration Required		Figure
Voltage	**Configuration**	**Grid Connection (Primary)**	**PCS Connection (Secondary)**	
480/277 Vac	Wye, grounded	None		Fig. 8
480 Vac	Delta, grounded	Delta	Wye, grounded	
Non-480/277 Vac	Wye, grounded	a) Delta b) Autotransformer	a) Wye, grounded b) Autotransformer	Fig. 9, 10
Non-480 Vac	Delta, grounded	Delta	Wye, grounded	Fig. 11
Any	Open-Delta	*Not Supported*		

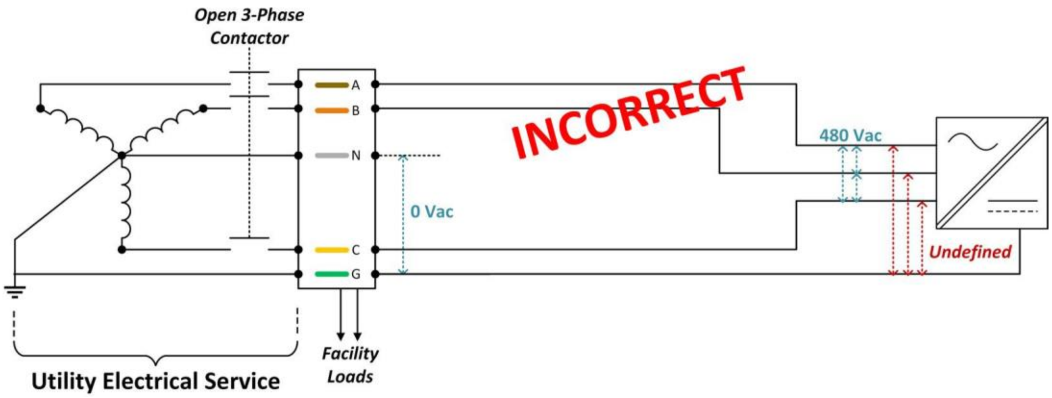
BACKUP POWER OR STAND-ALONE MICROGRID APPLICATIONS WITH THE STABILITI™

When one or more Stabiliti™ PCS is used for backup power or microgrid application, the main utility grid service must be disconnected and isolated, before the PCS may form a local grid for the facility. Once disconnected, any ground anchoring of phase voltages that may have been handled by the utility service will be lost. Recall that the voltages at the PCS inputs must be constrained to a nominal 277 Vac phase to ground by an external transformer. These factors mean extra attention is required when setting up the PCS interconnection for backup power and microgrid applications.

For more information on designing backup power systems with the Stabiliti™ PCS please refer to Application Notes 503 and 504. It is beyond the scope of this Application Note to include all the design elements of a full backup power system. Note that the schematics below show a single PCS but multiple may be paralleled on the same 480 Vac bus.

When the utility service is disconnected, the phase voltages on the facility side become unconstrained relative to ground as the path is broken between the phase lines and the grounded neutral point of the service transformer. The PCS has no means of anchoring its output voltages relative to ground therefore it will float and likely rise to unsafe levels for both service personnel and equipment including the PCS itself. Operating the system in this configuration is likely to damage the PCS, and will void the warranty.

Figure 12: Backup power application without phase voltage anchoring.



In the case of stand-alone microgrids there is no utility electrical interconnection, and therefore the service must be ground referenced by a local, facility-specific transformer. If a microgrid is supported by a diesel generator it is possible that the generator is installed with ground reference to constrain the phase voltages. In this case the generator may be treated like a utility electrical service and the scenario should be considered like a backup power application for the purposes of the interconnection design (even if the PCS is to be the primary source of power for the microgrid). Designers and installers should validate the configuration of any generator.

A few common interconnection scenarios are discussed below. In all cases the transformer configuration presented is compatible with both the backup power state and grid-tied state.

Backup power, electrical service case: 480/277 Vac Wye, Grounded

This is a common electrical supply for commercial and industrial facilities and is the primary intended installation case for an Ideal Power PCS. In this situation, an N-Zigzag transformer may be sized and used to service phase-to-neutral loads as well as to constrain the phase voltages relative to ground. The electrical connections should resemble Figure 13 below. In some cases, switched 277 Vac phase-neutral loads such as lighting ballasts can induce transients and a Y configured capacitor network may be required in parallel to the N-Zigzag for decoupling. These Y capacitors would be installed separately from the transformer at the system level dependent on load characteristics. Contact Ideal Power for support.

An alternate configuration is shown in Figure 14 employing an isolation transformer with an A-Zigzag. This configuration requires less design consideration for neutral currents.

Figure 13: Backup power for 480/277 Vac electrical service employing an N-Zigzag to service neutral currents and constrain the phase voltages relative to ground.

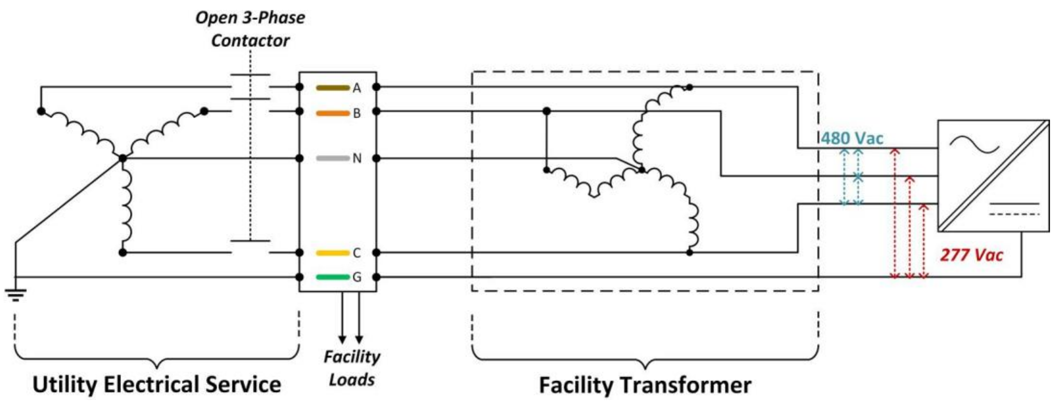
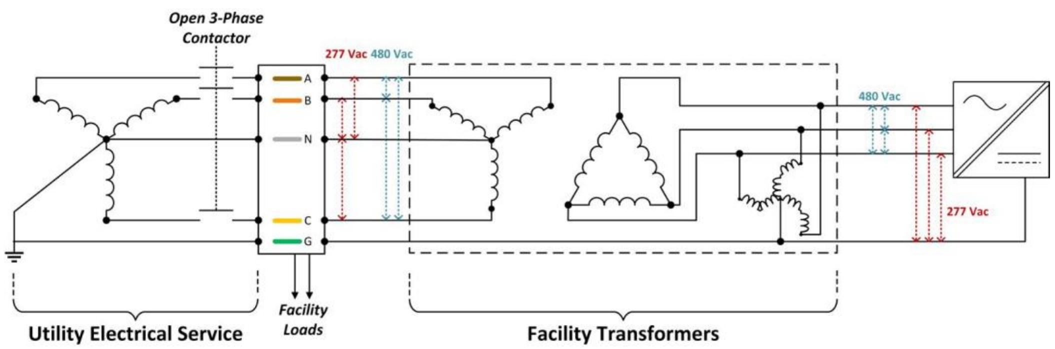


Figure 14: Backup power for 480/277 Vac electrical service employing a 1:1 isolation transformer with a wye primary to service neutral currents and a A-Zigzag to constrain the delta phase voltages relative to ground.



Backup power, electrical service case: 208/120 Vac Wye, Grounded

This is another common electrical supply for commercial and industrial facilities. A similar interconnection scheme would apply for other 3 phase electrical supplies that are not 480/277 Vac such as 600/347 Vac found in Canada or 380/220 Vac found in Europe. An Ideal Power PCS may be interconnected with two different transformer options. Option A) 208/120 Vac wye, to 480 Vac delta in conjunction with a A-Zigzag transformer grounded as shown in Figure 15. Option B) 208 Vac to 480 Vac wye auto-zigzag transformer as shown in Figure 16. A wye-wye transformer will not work since phase-neutral power drawn from the primary is translated to phase-neutral power on the secondary which is not available from the PCS.

Figure 15: Backup power for 208/120 Vac electrical service employing wye-delta and A-Zigzag transformer (Option A).

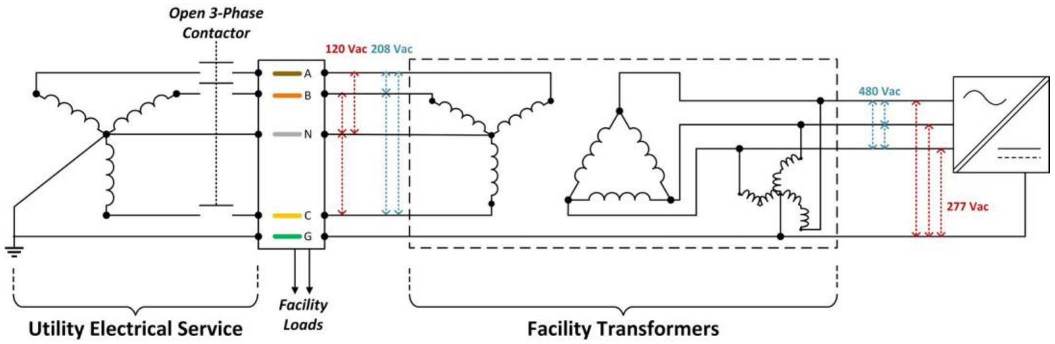


Figure 16: Backup power for 208/120 Vac electrical service employing auto-zigzag transformer (Option B).

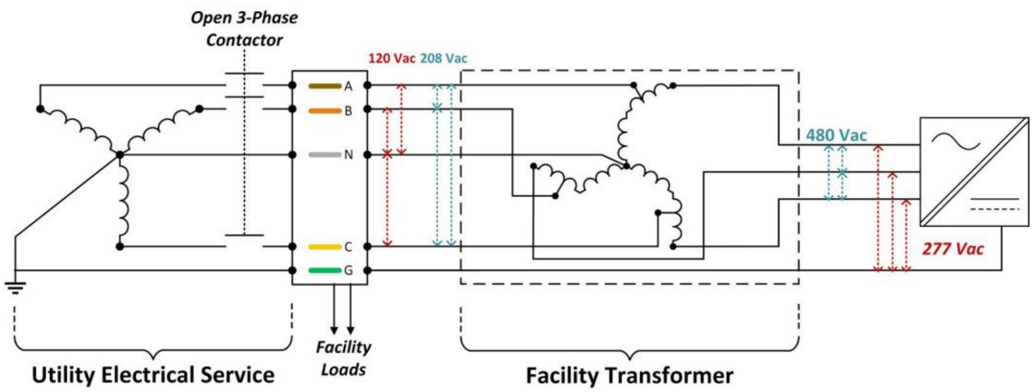
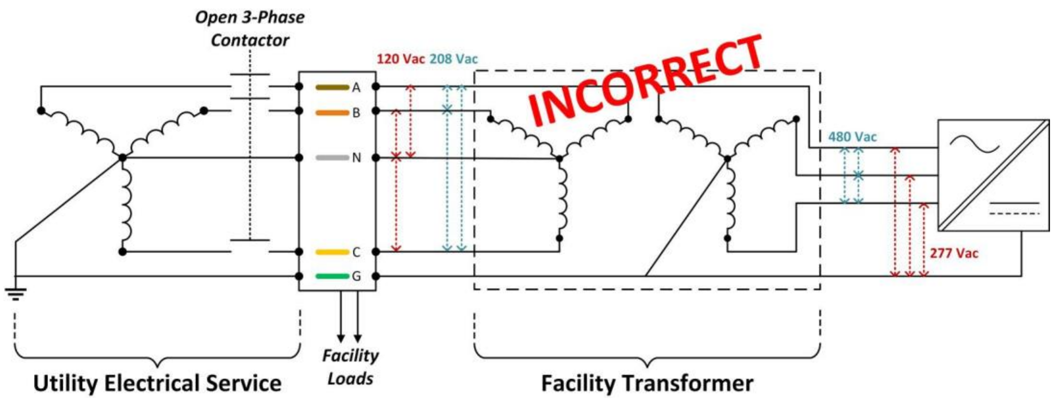


Figure 17: Backup power for 208/120 Vac electrical service cannot be provided with a wye-wye transformer.



Backup power, electrical service case: 240 Vac High-Leg Delta

An alternate 3 phase power supply to light commercial/industrial buildings to accommodate standard 240/120 Vac single phase loads and some limited 3 phase loads. In this situation the supply is serviced in backup with a 240 Vac delta center-tap to 480 Vac delta transformer in conjunction with a A-Zigzag as shown in Figure 18.

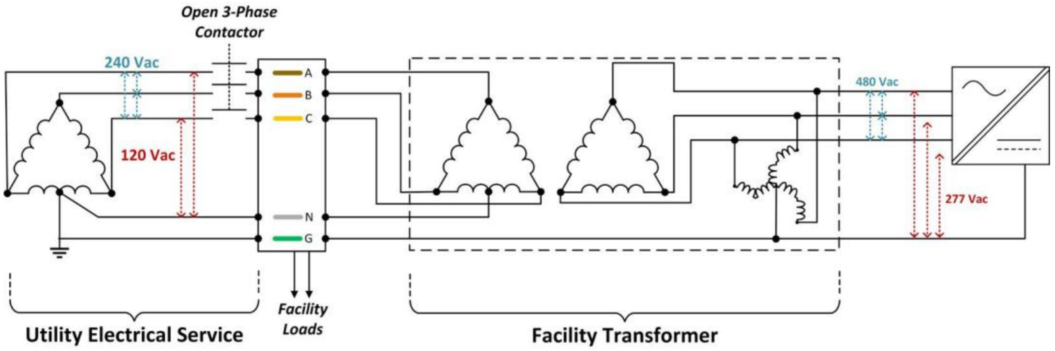


Figure 18: Backup power for 240 Vac high-leg electrical service employing a delta-delta transformer with a A-Zigzag.

A full list of the transformer requirements for backup power interconnection is presented below dependent on the utility electrical service.

Native Utility Electrical Service		Transformer Configuration Required		Figure
Voltage	Configuration	Grid Connection (Primary)	PCS Connection (Secondary)	
480/277 Vac	Wye, Neutral grounded	a) N-Zigzag b) Wye	a) N/A b) Delta + A-Zigzag	Fig. 13, 14
480 Vac	Delta, grounded	Delta	Wye, grounded	
Non-480/277 Vac	Wye, Neutral grounded	a) Wye b) Zigzag Autotransformer	a) Delta + A-Zigzag b) Zigzag Autotransformer	Fig. 15, 16
Non-480 Vac	Delta, corner grounded	Delta	Wye, grounded	
Non-480 Vac	Delta, high-leg neutral grounded	Delta, center-tap	Delta + A-Zigzag	Fig. 18
Any	Open-Delta	*Not Supported*		

Stand-alone Microgrid Service: 480/277 Vac

If the Stabiliti PCS will be used for a stand-alone microgrid at 480/277 Vac with only renewable generation and battery support then an N-Zigzag should be used to service phase-neutral loads and constrain the phase voltages relative to ground.

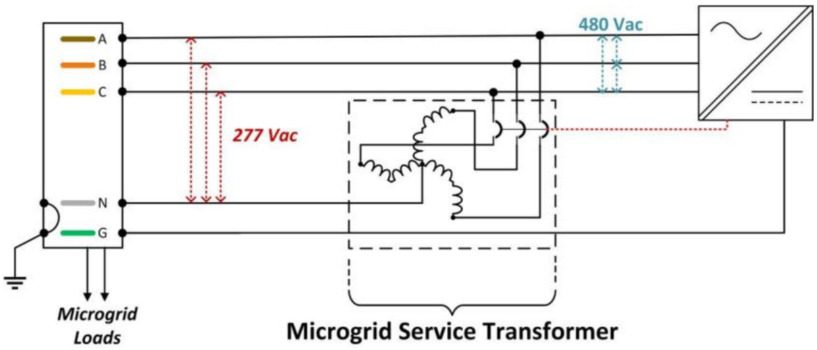


Figure 19: Stand-alone microgrid serviced by the Stabiliti™ PCS and an N-Zigzag transformer.

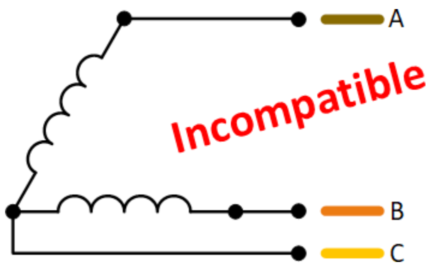
Caution should be used when driving line-to-neutral loads supported by a delta-wye or N-Zigzag transformer, or imbalanced line-to-line loads on the 3-wire converter AC port. The resulting imbalance of current among the three converter phases will result in fundamental frequency current ripple on the DC port(s) used to support microgrid power. Ideal Power is not responsible for damage to DC energy sources resulting from high fundamental current ripple. The user is responsible for understanding the microgrid power requirements and current ripple effects on power DC sources.

OTHER UTILITY GRID SERVICE

Single phase grid-connected service at 240/120 Vac are not supported in any circumstances by an Ideal Power PCS.

Open delta 3 phase grid service, whether grounded or ungrounded, as shown in Figure 20 is not supported in any circumstances by an Ideal Power PCS for grid-connected applications or for microgrid applications.

Figure 20: Open delta grid service is not supported whether grounded or ungrounded.



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