Stabiliti 30C/30C3

Application Note 102

Stabiliti Grid Interconnection and Transformer Design Requirements.

Purpose and scope

CE+T America Power Conversion Systems (PCS) are typically interconnected to the North America grid at 480 Vac / 60 Hz; outside of North America, such grid interconnections are typically made at 400 Vac / 50 Hz. Installations that require different AC line interconnection voltages or installations that support grid-forming/microgrid capabilities will require an external transformer. This document details requirements for interconnection of the Stabiliti's AC1 power port to a facility electrical power system for all the interconnection use cases noted above.

Disclaimer

This application note should be used in conjunction with other product and safety documentation provided by CE+T America. The intended audience is engineering and lab personnel familiar with high-voltage/high-power systems and the general safety issues related to the wiring and use of 3-phase AC electricity, battery systems, and PV energy sources. This document does not purport to make recommendations regarding conformance with applicable electrical codes. A qualified electrical engineer should be engaged to do detailed system design and ensure conformance with applicable codes. Refer to the product datasheet for detailed specifications upon which to base any detailed designs.

PCS Electrical Background

The Stabiliti™ series PCS have a 3-wire, 3-phase AC electrical connection interface and all power is made phase-leg to phase-leg at 480 Vac / 60 Hz or 400 Vac / 50 Hz. The PCS does not have a neutral wire connection and therefore cannot source or sink power into a neutral. This configuration is referred to as a delta connected circuit. Refer to the section on zigzag transformers for information on supporting phase-to-neutral loads. For 400 Vac / 50 Hz applications, the nominal 30 kVA AC nameplate power rating is derated to 25 kVA; full 30 kVA power is available at 480 Vac / 60 Hz.

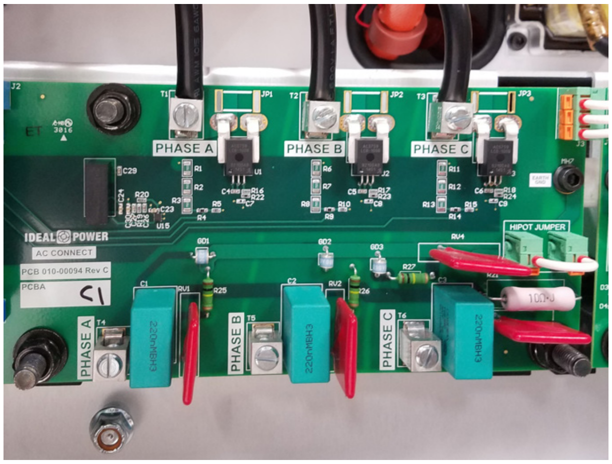

Figure 1. AC Connect Board

As with all electrical equipment, the Stabiliti PCS includes components with certain voltage withstand limits and internal overvoltage surge protection. As a result, all AC input voltages must be anchored and balanced relative to earth ground to ensure proper system protection. Floating AC interconnections which are not properly anchored and balanced are NOT allowed. Although the input voltages of floating interconnections may remain constant phase-to-phase, they may easily rise in voltage relative to earth ground by hundreds of volts when power transfers are underway. The AC input voltages into the PCS must always be constrained phase-to-ground (line-to-ground) to a nominal 277 Vac or 230 Vac phase-to-neutral, and anchored by the electrical service external to the PCS.

The anchoring requirement may be fulfilled by a user-installed transformer or by the native utility electrical service. In case of a fault or unconstrained phases, the PCS includes fault protection for line-to-ground overvoltage events and will shut down and fault at 590 Vpk to help protect standard 600 V rated conductors.

Warning: Under no circumstances should a floating electrical power system or ungrounded transformer be connected to the Stabiliti's 3-wire AC Port.

Transformer Basics

AC 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 legs or 4-wire wye with 3 phase legs and a neutral. 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 depending on application.

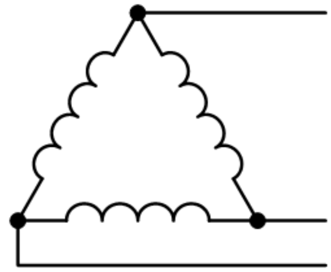

Figure 2. Delta wound transformer

Using typical nomenclature, the primary side is expected to be connected to the utility grid service at an intermediate voltage and the secondary side is expected to be connected to the facility power system downstream of the grid. Using this nomenclature, the Stabiliti PCS will be connected to the secondary side of a transformer at 480 Vac / 400 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 services do exist but are quite uncommon and are not addressed in this Application Note.

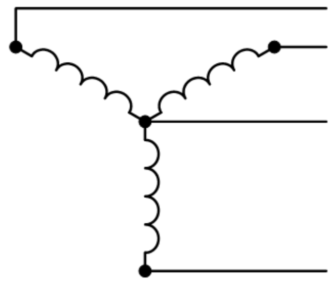

Figure 3. Wye wound transformer

The typical practice for a facility-sited transformer is to have the primary be delta configured and the secondary be wye configured with the mid-point neutral grounded wihtin the transformer in compliance with Local Electrical Code Requirements. The Stabiliti PCS requires this same configuration and is covered in greater detail in the following sections of this Application Note.

Typical transformers have galvanically isolated primary and secondary windings. However, if the primary and secondary connected electrical systems don't require galvanic 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 dual-winding isolation transformers and therefore are smaller, generally less expensive and deliver slightly improved efficiency.

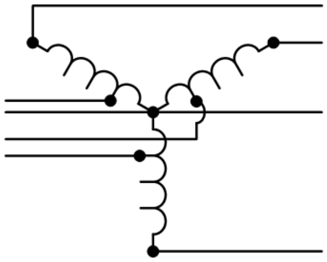

Figure 4. Wye autotransformer

Important: isolation transformers or auto-transformers with high impedance can affect the power conversion stability of a power converter. Please contact CE+T America for support with transformer specifications.

Isolation & Energy Storage

Energy storage systems (ESS) contain a high amount of energy which, in the case of an electrical fault, can lead to 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 dedicated dual-winding transformer. The Stabiliti™ PCS includes built-in galvanic isolation by way of a compact, high-frequency transformer in the power conversion core. This is advantageous because it eliminates the need for an external isolation transformer in most cases or enables the use an autotransformer when a voltage step-up or step-down is required.

Multiple CE+T America 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 or safety purposes.

Zigzag Transformers

The zigzag 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 unit. A zigzag transformer is used to derive a neutral 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.

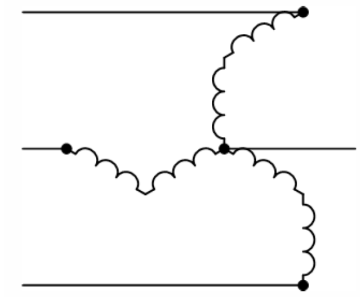

Figure 5. Zigzag wound transformer

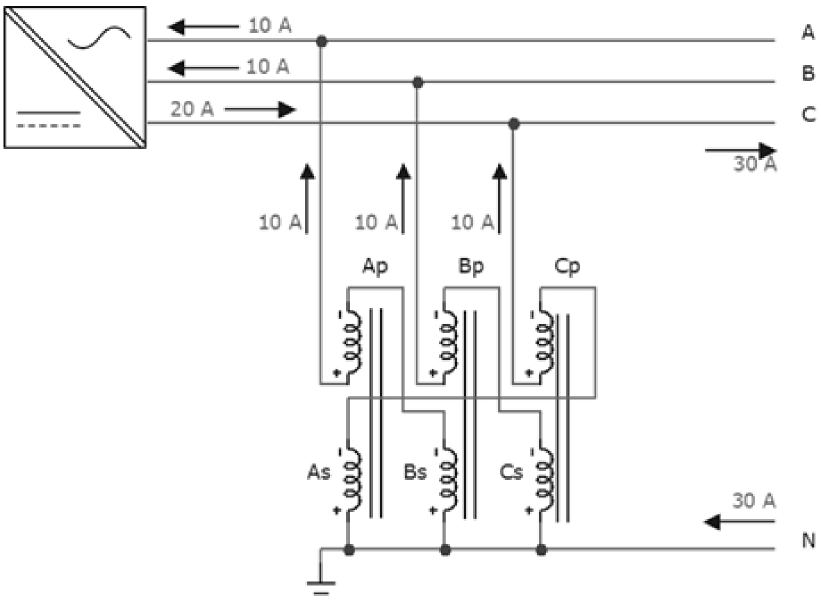

Figure 6. Zigzag Transformer Division of Neutral Current

Figure 6 also demonstrates how all phase-neutral currents are redistributed 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 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. As a result, the zigzag transformer reflects all phase-to-neutral loads as phase-to-phase loads at the delta source.

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

When the zigzag transformer neutral connection is bonded to ground and only used to anchor (supports no neutral currents or loads, 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 to balance phase-to-neutral currents, 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 Stabiliti PCS to disable operation since a breaker trip would yield a floating delta circuit.

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.

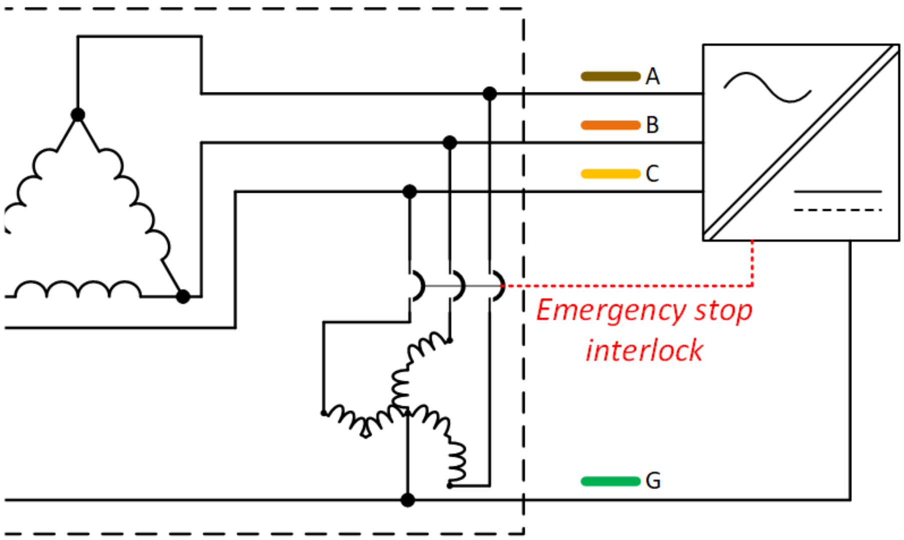

Figure 7. Zigzag transformer circuit breaker interlock with a Stabiliti™ PCS

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 CE+T America for zigzag transformer support and supplier contacts: tech.support@cetamerica.com

Grid-tied only applications with the Stabiliti™

Grid-tied, electrical service case: 480 / 277 Vac or 400 / 230 Vac Wye, Grounded

This is a common electrical supply for commercial and industrial facilities and is the primary intended installation case for an CE+T America 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.

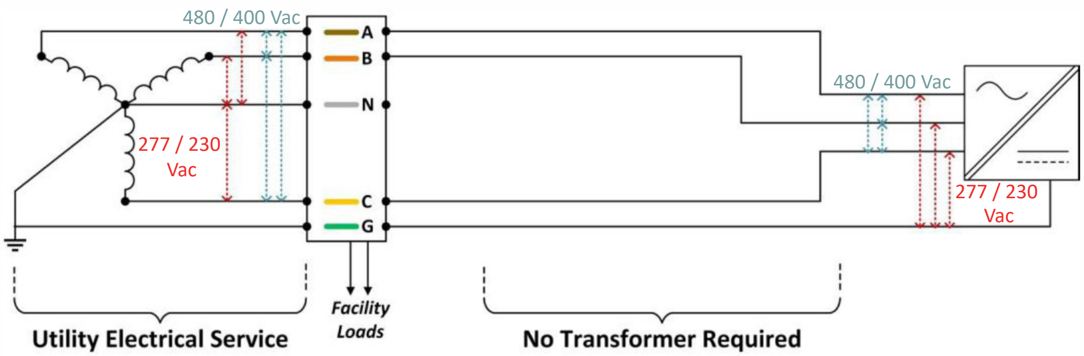

Figure 8. 480/277 Vac or 400/230 Vac electrical service with direct PCS connections

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

This is another common electrical supply for older commercial and industrial facilities in North America. A similar interconnection scheme would apply for other 3 phase electrical supplies that are not 480/277 Vac such as 600/347 Vac often found in Canada. A Stabiliti 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.

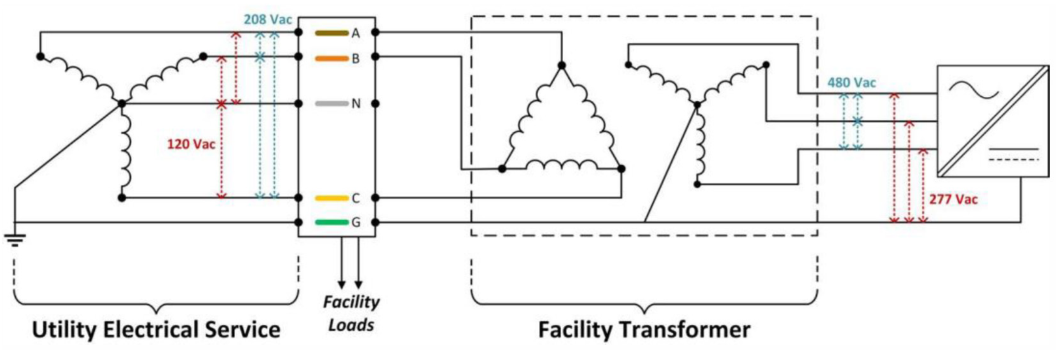

Figure 9. 208/120 Vac electrical service interconnection with a standard delta-wye transformer (Option A)

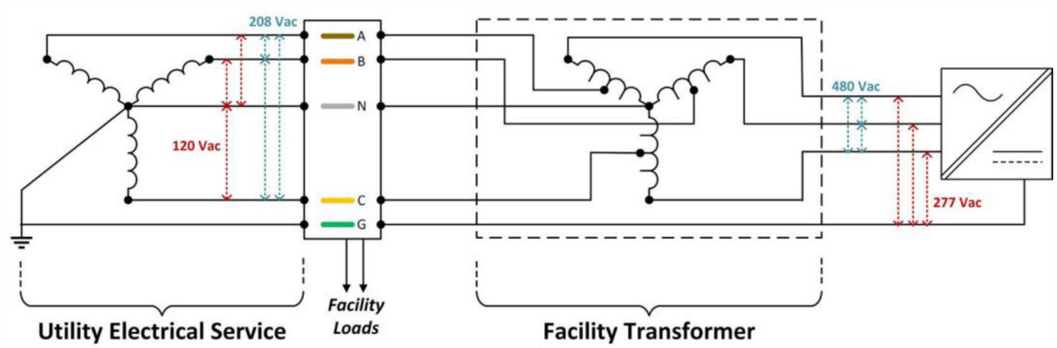

Figure 10. 208/120 Vac electrical service interconnection utilizing an autotransformer (Option B)

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

An alternate 3 phase power supply to light commercial/industrial buildings in North America 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.

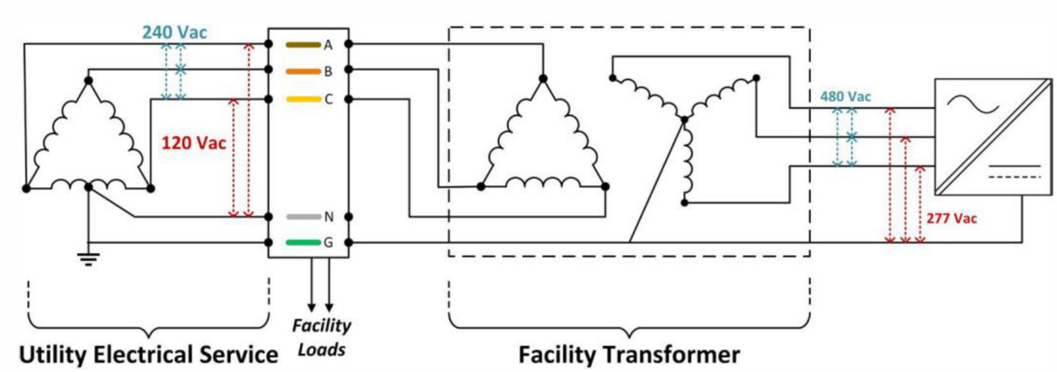

Figure 11. 240 Vac high-leg delta electrical service interconnection with a delta-wye transformer

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 or 400/230 Vac	Wye, grounded	None		Fig. 8
480 Vac or 400 Vac	Delta, grounded	Delta	Wye, grounded	
Non-480/277 Vac or Non-400/230 Vac	Wye, grounded	a) Delta b) Autotransformer	a) Wye, grounded b) Autotransformer	Fig. 9, 10
Non-480 Vac or Non-400Vac	Delta, grounded	Delta	Wye, grounded	Fig. 11
Any	Open-Delta	Not Supported		-

Backup Power or Stand-alone Microgrid Applications with the Stabiliti™

When the Stabiliti PCS is used for backup power or microgrid applications, the main utility grid service must be disconnected and isolated, before the PCS is allowed to form a local grid to support a backup load panel. 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 / 230 Vac phase to ground by an external transformer. These factors mean extra attention is required when setting up the PCS interconnection for for both 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. For simplicity purposes the schematics below show a single PCS but systems may be paralleled on the same 480 / 400 Vac bus, sharing a common transformer.

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.

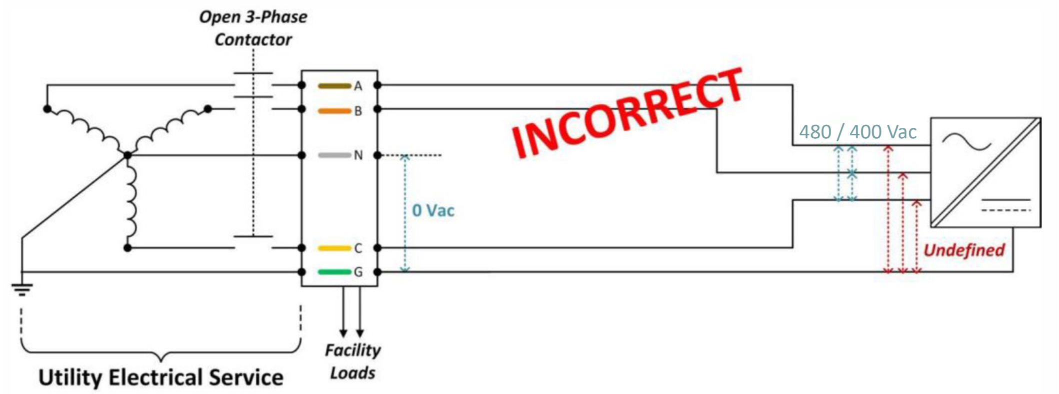

Figure 12. Backup power application without phase voltage anchoring

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 prior to install and commissioning.

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

Backup power, electrical service case: 480/277 Vac or 400/230 Vac Wye, Grounded

This is a common electrical supply for commercial and industrial facilities. In this use case, an N-Zigzag transformer must be sized and used to service phase-to-neutral loads as well as to constrain the phase voltages relative to ground. In some applications, switched 277/230 Vac phase-neutral loads such as lighting ballasts can induce current transients and a Y configured capacitor network may be required in parallel to the N-Zigzag to ensure decoupling and proper voltage anchoring. These Y capacitors would be installed separately from the transformer at the system level dependent on load characteristics. Contact CE+T America for support. Typical electrical connections are shown Figure 13 below.

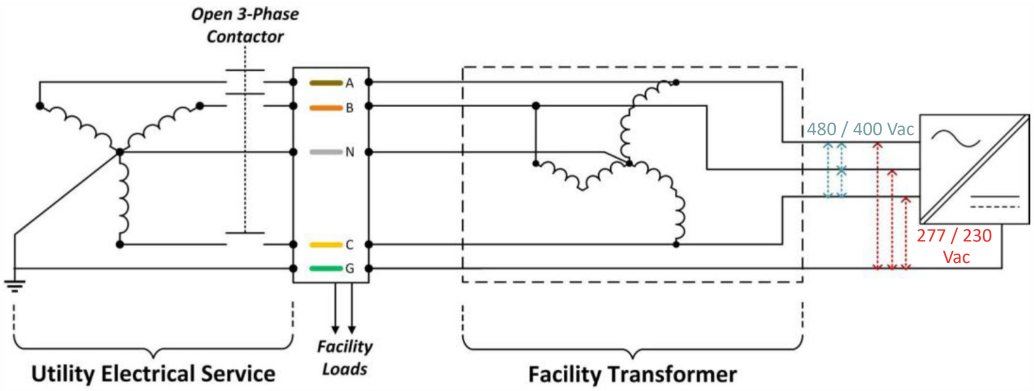

Figure 13. Backup power for 480 / 277 Vac or 400 / 230 Vac electrical service employing an N-Zigzag

An alternate configuration is shown in Figure 14 employing an isolation transformer paired with an A-Zigzag. All neutral currents in this configuration are supported by the isolation transformer. The A-Zigzag provides anchoring only, which simplifies overall design.

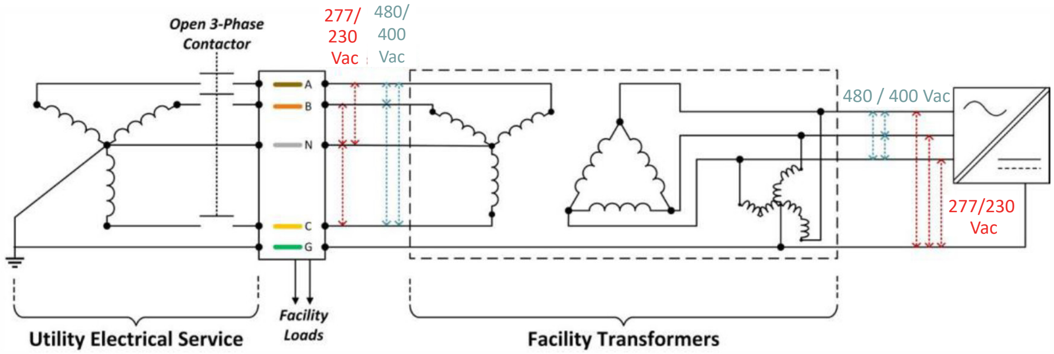

Figure 14. Backup power for 480 / 277 Vac or 400 / 230 Vac electrical service employing a 1:1 wye primary isolation transformer and a A-Zigzag

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

This is another common electrical interconnection for commercial and industrial facilities in North America. A similar interconnection scheme would apply for other 3 phase interconnections that are not 480/277 Vac such as 600/347 Vac utilized in Canada or 380/220 Vac found in Europe. A Stabiliti PCS may be interconnected with two different transformer options; for simplicity, only North American voltage options are indicated in the figures. Option A) 208/120 Vac wye, to 480 Vac delta in conjunction with an 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.

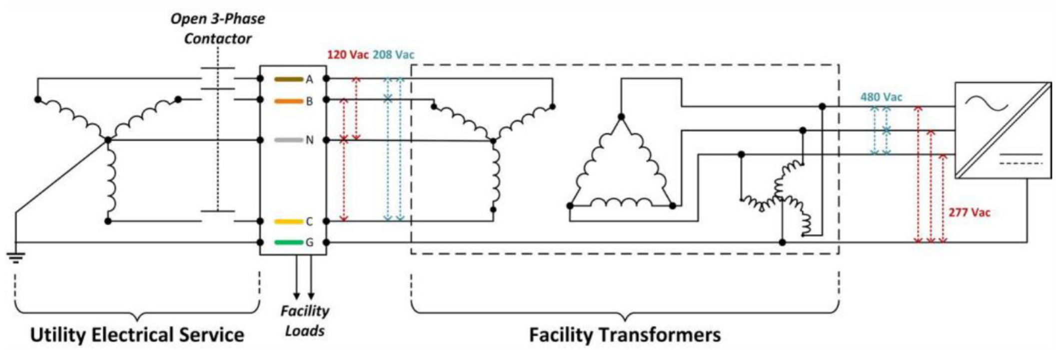

Figure 15. Backup power for 208/120 Vac electrical service employing wye-delta and A-Zigzag transformer (Option A)

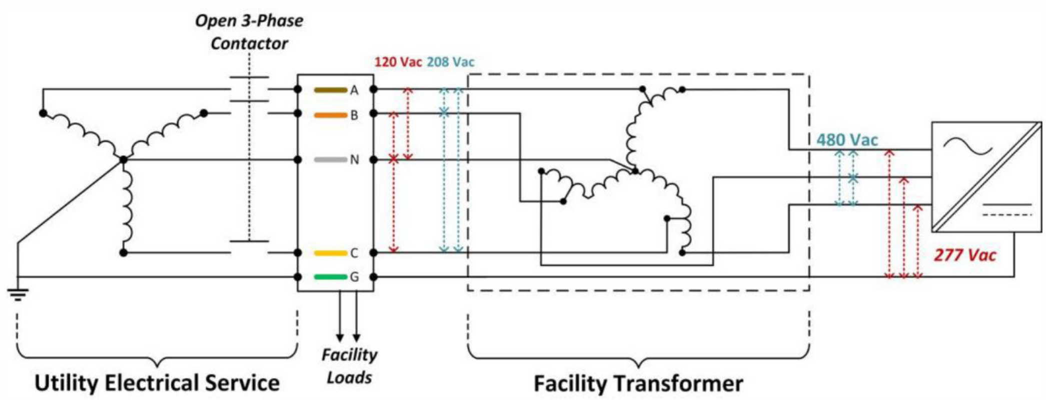

Figure 16. Backup power for 208/120 Vac electrical service employing auto-zigzag transformer (Option B)

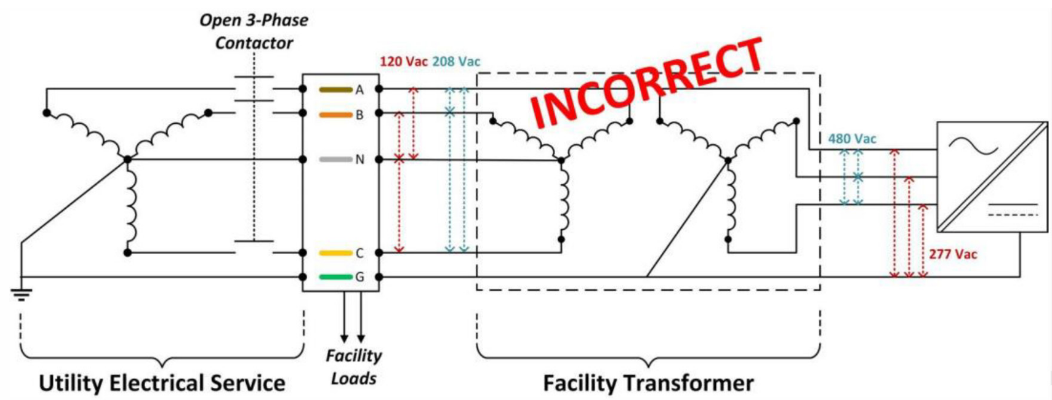

Figure 17. Backup power for 208/120 Vac electrical service: wye-wye transformer is NOT supported

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

An alternate 3 phase power supply to light commercial/industrial buildings in North America accommodates 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 an A-Zigzag as shown in Figure 18.

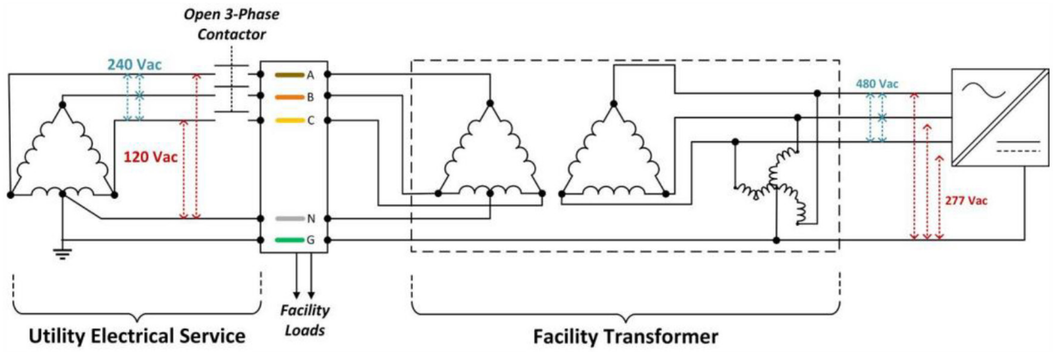

Figure 18. Backup power for 240 Vac high-leg electrical service employing a delta-delta transformer with a A-Zigzag

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 or 400/230 Vac	Wye, Neutral grounded	a) N-Zigzag b)Wye	a) N/A b) Delta + A-Zigzag	Fig. 13, 14
480 or 400 Vac	Delta, grounded	Delta	Wye, grounded	-
Non-480/277 Vac or 400/230 Vac	Wye, Neutral grounded	a) Wye b) Zigzag Autotransformer	a) Delta + A-Zigzag b) Zigzag Autotransformer	Fig. 15, 16
Non-480 or 400 Vac	Delta, corner grounded	Delta	Wye, grounded	-
Non-480 or 400 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 or 400/230 Vac

If the Stabiliti™ PCS will be used for a stand-alone microgrid at 480 / 277 Vac or 400 / 230 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.

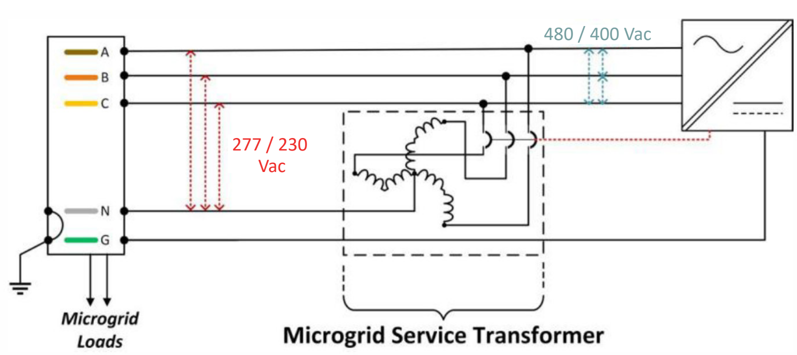

Figure 19. Stand-alone microgrid serviced by the Stabiliti™ PCS and an N-Zigzag transformer

Caution should be used when supporting single-phase or otherwise imbalanced line-to-line loads on the 3-wire converter AC port. As part of the design and commissioning process, it is highly recommended that a load survey be made, with the goal of balancing all facility single-phase loads across all 3-phase legs as evenly as possible. This will often require rewiring of both 3-phase load panels as well as single-phase load panels within the facility.

Without the balancing as described above, the resulting imbalance of current among the three converter phases will often result in higher fundamental frequency current ripple on the DC port(s) used to support microgrid and backup power loads. Such high ripple currents may compromise battery operating life, for example.

CE+T America 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 Interconnections

Single phase grid-connected service at 240 / 120 Vac or 400 / 230 Vac are not supported in any circumstances by a Stabiliti PCS. Additionally, open delta 3-phase grid service, whether grounded or ungrounded, as shown in Figure 20 is not supported in any circumstances by an CE+T America PCS for grid-connected applications or for microgrid applications.

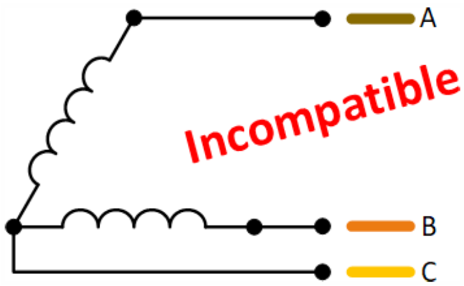

Figure 20. Open delta grid service is not supported whether grounded or ungrounded

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