GenLink DPNL Technical Guide

How to Prevent Circulating Neutral Current in Parallel Generator Applications

GenLink Dissimilar Pitch Neutral Limiter (DPNL)

Reduces circulating current in the common neutral and/or ground wires of paralleled generators with dissimilar pitches or generators paralleled with the utility. Blocks circulating current without reducing system fault level.

Benefits

- Blocks 3rd harmonic and other circulating neutral current
- Prevents excessive harmonic losses and overheating in generator
- Allows paralleling of generators with dissimilar pitches and generators with Utility transformers
- Substantially increases zero sequence impedance to 3rd harmonic without significantly reducing 1-ph or 3-ph fault level

Key Features

- Inserts >40% impedance in neutral current circulating path
- Reduces neutral circulating current by >75%
- Adds <1% saturated impedance to 1-Ph fault path
- No impedance to 3-Ph fault path
- Use in 3-wire or 4-wire applications or any parallel source application with a common neutral and dissimilar voltage waveforms
- Eliminates generator overheating and false protection trips caused by triple frequency circulating currents
- Built-in ovrcurrent alarm allows for protection against inadvertent overload
- Can be connected as a Neutral Grounding Inductor (NGI) when access to the neutral of the other paralleled sources is not readily available
- Easy to install
- Reliable and proven performance
- Complies with IEEE Std 32, IEEE Standard Requirements, Terminology, and Test Procedure for Neutral Grounding Devices and CSA C22.2 No. 295-15, Neutral Grounding Devices.

Challenges of Parallel Generator Operation

When paralleling equipment such as generators, or other distributed generation sources, to each other or the utility supply, it is imperative that voltages produced by the generating equipment are as closely matched as possible. This means not only the RMS voltage values but the actual voltage waveshapes as well. Voltage waveshape differences result in instantaneous voltages being present between the paralleled sources which can lead to heavy circulating current in the common neutral conductors in 4-wire applications or in the grounds in grounded 3-wire applications. Given the increased usage of this equipment, there are many paralleling applications where the voltage waveshapes can be dissimilar. Common reasons for these differences include:

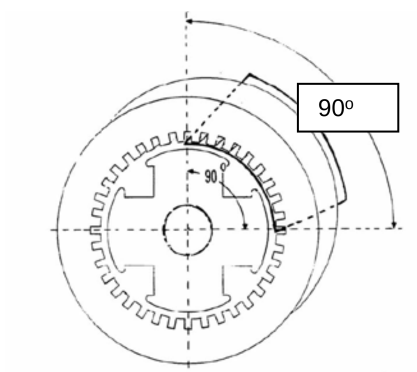
1. Using generators with different pitch configurations made by different manufacturers or by the same manufacturer who has changed its standard pitch designs
2. Synchronous generators with slightly distorted voltage waveforms being paralleled with Utility transformers
3. Wind Turbines, Battery Energy Storage Systems (BESS) or other alternative energy sources which use inverters to convert DC power to AC for connection to the Utility

When neutral circulating current is excessive, it can cause generator overheating and/or false tripping of overcurrent protection. Controlling these circulating currents can be difficult especially if the generators have dissimilar pitch configurations. To limit neutral circulating current, which is often triple frequency in nature, impedance can be added in the circulating path but this is usually best done without restricting the fault current path. By applying a unique multiple winding reactor, neutral circulating currents can be reduced by more than 75% with minimal effect on the short circuit impedance of the system.

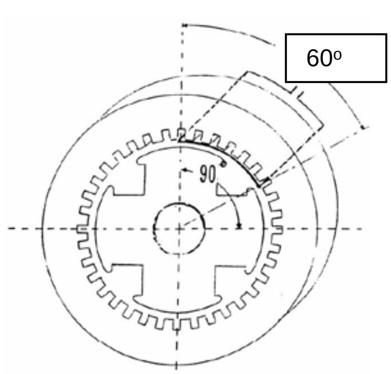
What Causes Neutral Circulating Current in Parallel Generator Applications?

Ideally, all generator sources would produce output voltage waveforms that are purely sinusoidal. Even with their best efforts however, generator manufacturers cannot reach this goal and therefore, generator voltages will always be somewhat distorted and contain harmonics. Which harmonic numbers are present and at whatr level of magnitude is related to how the voltage is being generated. In synchronous generators for example, the harmonic voltages generated are influenced by the particular winding pitch of the generator's alternator.

A generator's winding pitch is defined as the ratio between coil pitch and pole pitch. In a 4 pole machine, the pole pitch is 90 mechanical degrees. In a fractional pitch machine where the coil winding is 60 deg, the pitch ratio is 60/90 or 2/3.



Full Pitch Generator
Coil Pitch = 90°, Pole Pitch = 90°



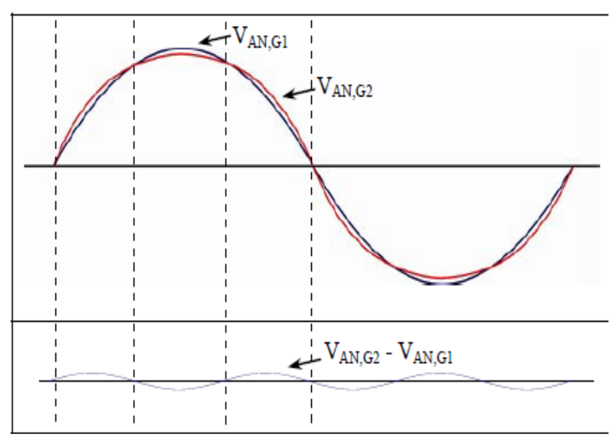
2/3 Pitch Generator
Coil Pitch = 60°, Pole Pitch = 90°

Pitch	Predominant Voltage Harmonics
2/3	5th, 7th and 9th
4/5	3rd, 7th and 9th
5/6	3rd and 9th
6/7	3rd, 5th and 9th

Table 1: Generator Voltage Harmonics

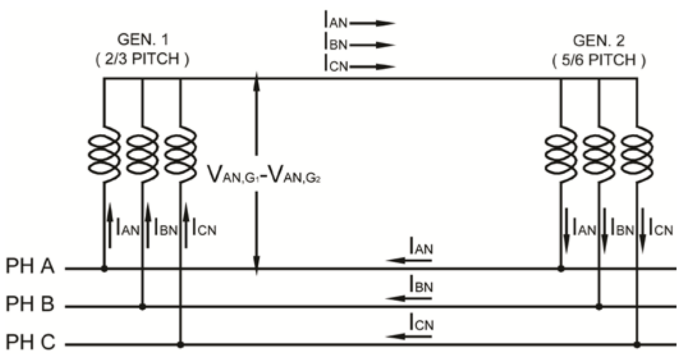
Advantages of fractional pitch machines include a reduction in copper costs and voltage waveforms that are slightly more sinusoidal than full pitch and therefore contain less harmonic distortion. Harmonic voltages will still be present though, with their levels determined by the machines specific winding pitch (Table 1).

The waveforms shown represent line-to-neutral voltages of two dissimilarly pitched generators, G1 and G2. G1 generates a voltage with a slightly higher peak (typical of 5/6 pitch generators) while G2 generates a somewhat flat-topped voltage waveform (typical of a 2/3 pitch generator). When paralleled, these generators will produce a phase-to-neutral voltage that reflects the instantaneous differences in the two voltages even when the RMS values are perfectly synchronized. Since this voltage passes three cycles in the time that the individual generator voltage passes a single cycle (the fundamental frequency), it is primarily triple frequency in nature (180 Hz on a 60 Hz system).



How differences in instantaneous voltages of paralleled generators can produce line-to-neutral voltages that result in 3rd harmonic neutral circulating currents.

Circulating currents will appear as shown and will also be predominantly triple frequency. The amount of circulating current introduced by each phase will be proportional to the magnitude of the differential instantaneous voltage for that phase and the zero phase sequence impedance of the system (generators and connecting cables). The total circulating current in the common neutral will be the sum of the circulating current in each phase.



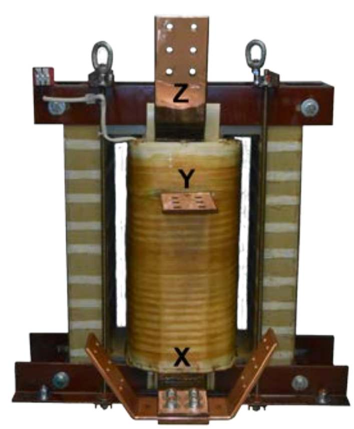
Flow of circulating current in a 3-wire paralleled generator application with neutrals connected and ungrounded.

It is important to note that it is not the generator's specific pitch value that causes the circulating current but rather the difference in voltage waveshape of the two differently pitched generators. Therefore, the fact that a 2/3 pitch generator has a very low pitch factor for the 3rd harmonic does not mean that it will perform any better in paralleling operations. In fact, a 2/3 pitch generator has very low zero sequence reactance and therefore, has less impedance to reduce the flow of circulating neutral current. Circulating currents can result with any generator pitch type when it is not matched with a similarly pitched unit or it is paralleled with the Utility.

Further complicating the issue is that this analysis has assumed that the generator loading is linear. Today's power electronic loads (such as variable speed drives, UPS systems, computer equipment, AC/DC rectifiers, etc.) are nonlinear in nature and as such, are current sources of harmonics. During their operation, the current harmonics they draw will increase the voltage distortion throughout the distribution system. This includes the output terminals of the generator where the generator's source impedance (particularly the subtransient reactance or X_d") will create voltage drops at each harmonic number in relation to the nonlinear load harmonic currents. These voltage drops will introduce additional harmonic distortion at the generator's output terminals. Differently pitched generators will have different impedances to the various harmonics and therefore, the differential voltage may be much greater than would be expected with linear loading.

APPLICATION OF THE GENLINK DPNL TO REDUCE CIRCULATING CURRENT

The GenLink DPNL is a multiple winding reactor which can be installed in the common neutral of paralleled generators to add impedance to block the flow of circulating currents. It does this without significantly decreasing the 1-phase fault level by ensuring that the impedance of the fault path to ground remains low. Also, there is no change to the phase-to-phase fault level.



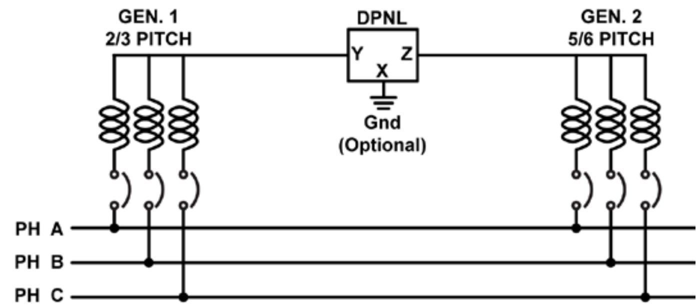
GenLink DPNL Reactor

The reactor has three sets of terminal connections – X, Y and Z. The coils are wound such that the impedance through the Y and Z terminals is several times larger than the impedance between either the Y or the Z terminal to X. The Y to Z impedance is approximately 45% at the triple frequency of the circulating neutral current. The impedance to 1-phase fault current, on the other hand, is < 1%. This is due both to the unique winding configuration of the reactor and to the fact that the core will become saturated during a fault condition, lowering its impedance. The system's 1-phase fault level therefore, will be reduced only minimally. 3-phase and phase-to-phase faults will not pass through the reactor so fault level under these conditions will be unaffected.

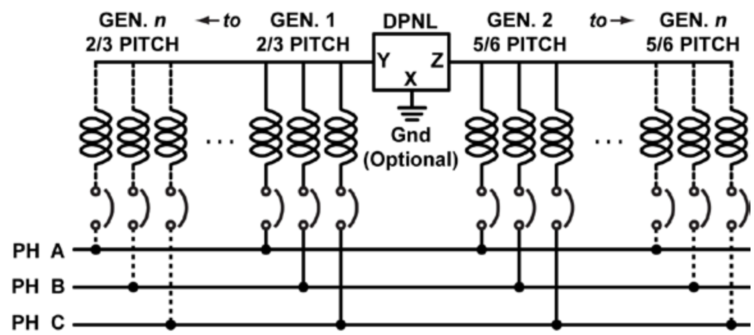
In applications where multiple generators of the same pitch are being paralleled with one or more generators of a different pitch, the DPNL need only be installed in the neutral connection between the two sets of similar pitched generators as shown.

In 3-wire systems, the neutral may or may not be grounded. If grounded, it should be grounded at the X terminal of the DPNL. If left ungrounded, the power system must be equipped with ground fault monitoring as per electrical code requirements.

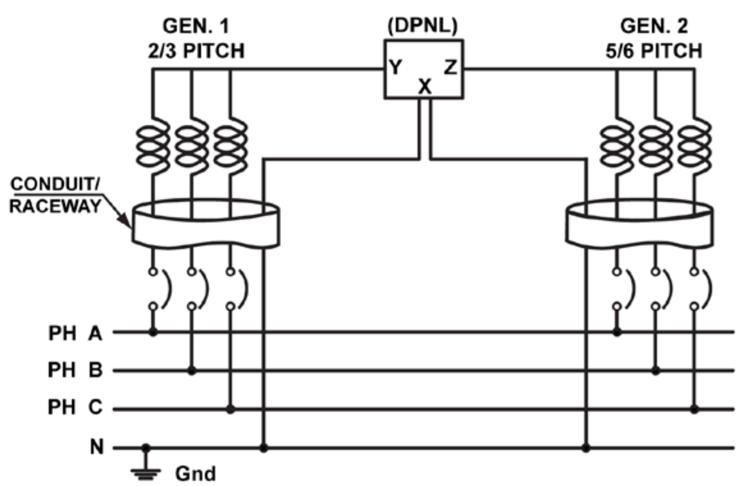
In a 4-wire application where the neutral is being used as a return path for 1-phase, phase-to-neutral loads, the common neutral should be grounded at only one location. This is often at the switchboard neutral but can alternatively be grounded at the X terminal of the DPNL or at the common neutral anywhere else in the distribution system. The requirement is simply that the neutral be properly grounded and grounded at only one location. Also, to reduce stray fluxes, it is recommended that the neutral conductors be run in the same conduit as the phase conductors.



GenLink DPNL installation to prevent flow of circulating current in a 3-wire paralleled generator application with ungrounded neutral



GenLink DPNL installation where multiple generators of similar pitch are connected to one or more generators of a different pitch



GenLink DPNL installation to prevent flow of circulating current in a 4-wire paralleled generator application

SIZING THE GENLINK DPNL

The amount of current which will circulate between dissimilarly pitched generators or other paralleled sources with somewhat different voltage waveshapes can be relatively difficult to determine precisely. It will be proportional to the level of instantaneous phase voltage between the sources and the zero phase sequence impedance of these sources but often, this is not readily available. Fortunately, a conservative analysis can be done to ensure that significant reduction is achieved and that the mitigation device is appropriately sized to handle the load that it could be subjected to.

Mirus has developed a spreadsheet that can be used to estimate the circulating current in an application and select the appropriate size of the neutral blocking reactor needed to ensure safe operation. Basic generator and other source information, including voltage rating and impedance values, can be entered. A conservative default common-mode voltage is then used to calculate the neutral circulating current. From this value, an appropriately rated blocking reactor can be entered into the spreadsheet to determine its effectiveness in reducing the circulating current. (See later section in this Guide for the input data required for this analysis.)

Various configurations of paralleled sources were analyzed using this spreadsheet to determine the level of neutral current that could be expected. These calculations were then repeated but with the impedance of the DPNL included. From this analysis, sizing tables have been established (Table 2) which allow for easy selection of conservatively sized blocking reactors based on the kVA or kW capacity of the paralleled power system.

For 4-wire applications, where the neutral is being used as a return path for 1-phase, phase-to-neutral loads, the reactor must be sized for the return neutral current as well as the circulating current. For this purpose, a dual current rating is applied with the highest rating being for the returned neutral current. Sizing the reactor involves first determining the total kW or kVA capacity of all generators or other paralleled sources. Then from the table, the reactor current rating that corresponds to the total capacity in the appropriate system voltage column is selected.

This will size the unit for a return neutral current rating that is at least 50% of the full phase current rating of the application. For 208-240V systems, where it is much more likely to have phase-to-neutral loads, the return neutral rating will be at least 85% of the full phase current rating of the application. If the actual return neutral current is expected to be higher than these levels, then a larger sized unit can be selected. The larger size will be just slightly less effective in reducing circulating current. For 3-wire applications or for applications where return neutral current is known to be lower, reduced ratings are appropriate and can be selected from a second table (See GenLink DPNL Technical Data Sheet document DPNL-S002-x).

In all applications, sizing should follow the requirements of the applicable electrical code. In the USA, the National Electrical Code section 250.184(A)(2) states: *"The neutral conductor shall be of sufficient ampacity for the load imposed on the conductor but not less than 33 1/3 percent of the ampacity of the phase conductors."* The 'load imposed' is determined by section 220.61(A) as follows: *"The feeder or service neutral load shall be the maximum unbalance of the load determined by this article. The maximum unbalanced load shall be the maximum net calculated load between the neutral conductor and any one ungrounded conductor."*

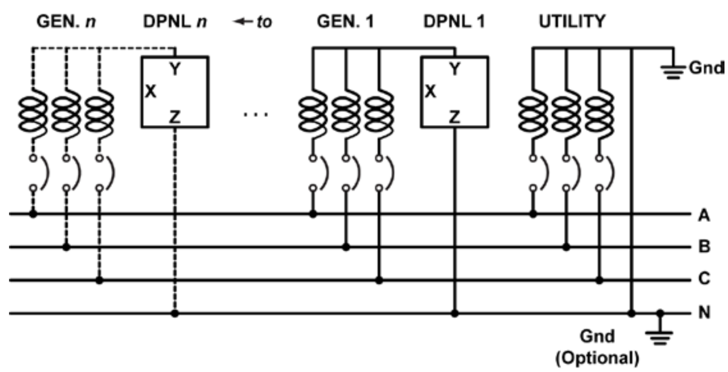
Reactor Rating (Amps)		Total Capacity of all Paralleled Sources - kW [kVA]				
Return Neutral	Circulating	208-240V	380-440V	460-480V	575-600V	660-690V
200	100	68 [85]	120 [150]	250 [312]	320 [400]	360 [450]
500	250	160 [200]	300 [375]	640 [800]	800 [1000]	900 [1120]
1000	500	335 [420]	620 [775]	1280 [1600]	1600 [2000]	1800 [2250]
1500	750	500 [625]	920 [1150]	1920 [2400]	2400 [3000]	2720 [3400]
2000	1000	675 [840]	1200 [1500]	2500 [3126]	3200 [4000]	3600 [4500]
2500	1250	840 [1050]	1540 [1930]	3200 [4000]	4000 [5000]	4500 [5625]
3000	1500	1000 [1250]	1840 [2300]	3800 [4750]	4800 [6000]	5475 [6843]
4000	2000	1350 [1690]	2475 [3095]	5090 [6370]	6370 [7960]	7300 [9130]
5000	2500	1690 [2115]	3095 [3865]	6370 [7960]	7960 [9950]	9135 [11415]

Table 2: DPNL selection table for 60 Hz systems in a 4-Wire application

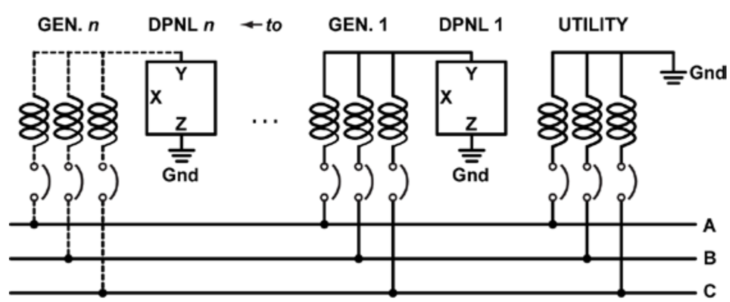
USING THE GENLINK DPNL AS A NEUTRAL GROUNDING INDUCTOR

The GenLink DPNL is most effective when connected to all source neutrals as described previously. This may not always be possible however, especially when there are long distances between the paralleled sources. So in applications where access to the neutral ground point of all sources is not available, a DPNL can be connected as a neutral grounding inductor, or NGI, at the neutral point of one or more of the paralleled sources. In this mode, the DPNL is connected through terminals Y and Z as shown.

When selecting a DPNL for application as an NGI, sizing is determined by the current rating of the source that it is being connected to and following the NEC requirements. Also, to be considered is that the applicable DPNL current rating should be the lower of its two ratings. For example, when connecting a 500A/1000A DPNL as an NGI in a 4-wire application, the expected unbalance phase current must be less than 500A and 500A must be more than 33 1/3% of the phase current rating per NEC 250.184(A)(2). Also, in a 4-wire application, consideration must be given to the amount of harmonics that these loads can contribute to the return neutral current.



GenLink DPNL Application as NGI when Paralleling with Utility Transformer (Grounded 4-Wire)



GenLink DPNL Application as NGI when Paralleling with Utility Transformer (Grounded 3-Wire)

DPNL Rating (Amps)		Phase Current Ampacity of Generator or Transformer [Amps]			
Return Neutral	Circulating	4-Wire		3-Wire	
		208-440V	460-690V	208-440V	460-690V
200	100	100	200	300	300
500	250	250	500	750	750
1000	500	500	1000	1500	1500
1500	750	750	1500	2250	2250
2000	1000	1000	2000	3000	3000
2500	1250	1250	2500	3750	3750
3000	1500	1500	3000	4500	4500
4000	2000	2000	4000	6000	6000
5000	2500	2500	5000	7500	7500

Table 3: DPNL as an NGI selection table for 60 Hz systems

In a grounded 3-wire application, the DPNL should be matched to the NEC requirement for the neutral ground connection.

A final consideration is that connection of the DPNL as an NGI will result in a more significant reduction in the 1-phase fault level than occurs in the standard DPNL connection configuration. The Mirus spreadsheet can be used to calculate this reduction and should be confirmed to be acceptable before proceeding.

SUMMARY

In summary, when paralleling multiple generators with dissimilar winding pitches or power sources with differing voltage waveshapes, heavy circulating currents can appear in the common neutral. These circulating currents can be effectively reduced by the application of a GenLink DPNL neutral blocking reactor. This uniquely wound reactor introduces high impedance in the path of neutral circulating current (triple or any other frequency) but very minimal impedance in the fault current path. This significantly reduces the circulating current by more than 75% with negligible effect on the system fault level. It is very simple to install and, as a purely passive reactor, is extremely reliable.

DATA REQUIRED FOR DETERMINING CIRCULATING CURRENT IN A PARALLEL GENERATOR APPLICATION

To assist with selection of the appropriate GenLink DPNL for an application, the following information is required:

1. Fill in the table with details of the generators or utility transformers or gather data sheets with this information:
2. Identify the installation location:
   a. Indoor enclosed DPNL
   b. Outdoor enclosed DPNL
   c. Open style DPNL to install in generator switchgear or other enclosure
3. Can the neutrals of all generators or utility transformers be accessed and brought to one location for connection to DPNL and grounding at the DPNL?
4. How is the electrical system grounded (solidly, high resistance, low resistance or ungrounded)?
5. Can the sizes and quantities of cables in each generator neutral be identified?
6. Are there any future generator capacity additions planned?

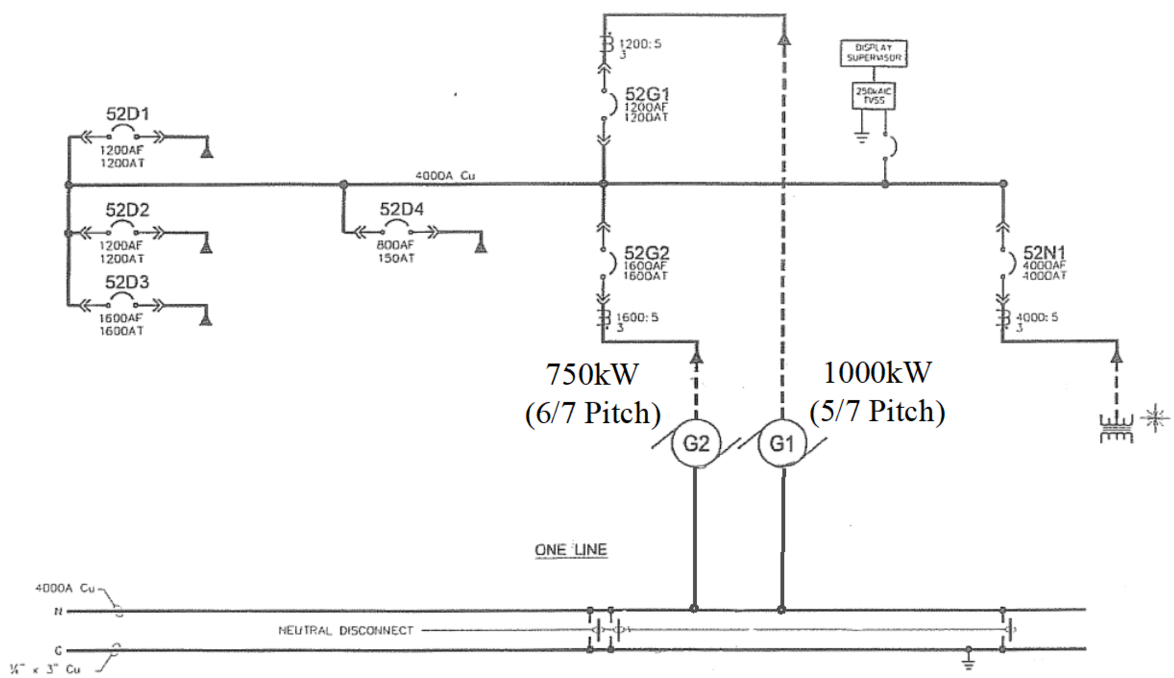
	Gen 1 or Utility Transformer	Gen 2	Gen 3 (if applicable)	Gen 4 (if applicable)
Equipment Tag				
Voltage (V)				
Frequency (Hz)				
Real Power (kW)				
Apparent Power (kVA)				
Power Factor				
Winding Pitch				
Subtransient Reactance (X”d) or +ve Seq Imp (Z)				
Zero Seq Imp. (Xo or Zo)				
-ve Seq Imp. (X- or Z-)				

Appendix A: CASE STUDY OF AN APPLICATION WITH DISSIMILARLY PITCHED GENERATORS

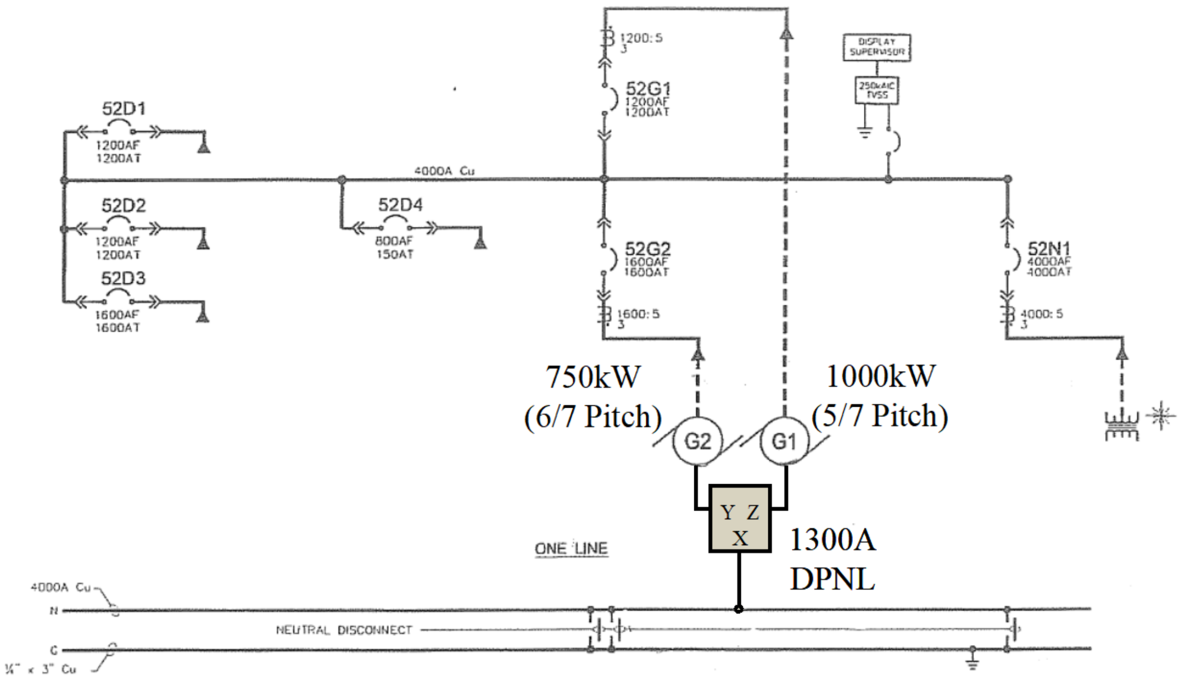
A restaurant industry distribution facility in Conroe, Texas expanded its standby generation capacity by adding a 1000 kW generator to the existing 750 kW unit at the site. A 1-Line of the installation is shown. When energized, the electrical contractor noticed that there was an excessive amount of current in the common neutral of the two generators. The contractor was concerned that this extra current would cause the generators to overheat.

When the new generator was purchased, it was bought from the same manufacturer but being unaware of any issue associated with matching generator pitches, the purchaser never specified a particular pitch configuration. As it turned out, the new 1000 kW generator had a 5/6 pitch winding while the existing 750 kW generator was 6/7 pitch. This difference in pitch was enough to create the circulating current which was measured by the contractor to be in excess of 150A.

In order to reduce the circulating current, a GenLink DPNL was installed in the common neutral between the two generators as shown. A 1300A unit was selected based on the total 1750 kW generator capacity. (This size was available at the time but now a 1500A unit would be used.)

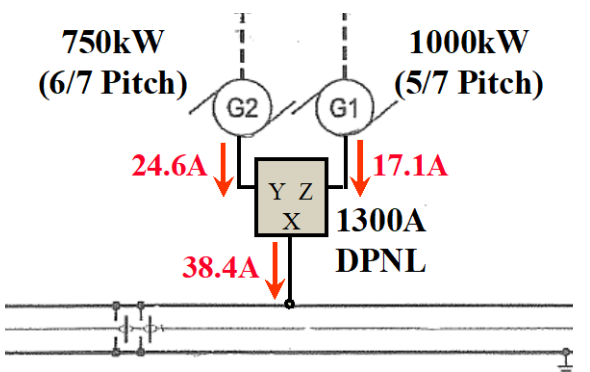


Installation of Dissimilarly Pitched Parallel Generators at a Distribution Facility



Installation of 1300A GenLink DPNL at a Distribution Facility

With the installation of the DPNL, residual neutral current was reduced to 38.4A while running under peak load condition. This was a significant reduction from the initially measured value. It is important to note that most of this residual current is return neutral current from phase-to-neutral loads. Virtually all of the circulating current was eliminated.



Flow of neutral current after installation of GenLink DPNL

Photo of GenLink DPNL installation

APPENDIX B: GENERATOR PARALLELED WITH UTILITY APPLICATION

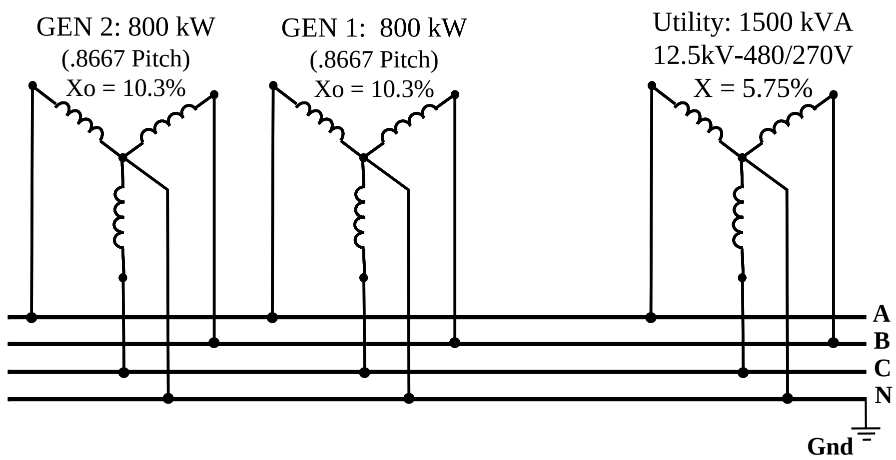
Use of the GenLink DPNL to control neutral circulating current is not only limited to paralleling of dissimilarly pitched generators. It can also be effective in other parallel source applications with common neutrals and dissimilar voltage waveforms. For example, when a generator is operated in parallel with a Utility source, the voltage waveforms are likely to be somewhat dissimilar and therefore result in neutral circulating current. This can occur in either permanently paralleled applications or during closed transition transfers in peak shaving or back-up generation applications. Also, other sources of distributed generation, such as wind turbines, battery energy storage systems, fuel cells, microturbines, etc., can have excessive circulating neutral currents when paralleled with the Utility in 4-wire systems.

After the Heating Plant at an American College was fit up with peak shaving generators, it was found that circulating current in the neutral reached over 900A even with relatively light loading on the system. Two similarly pitched 800 kW generators were paralleled with a 1500 kVA Utility transformer. The excessive neutral current was causing the Utility transformer and generators to run hot even under light loading.

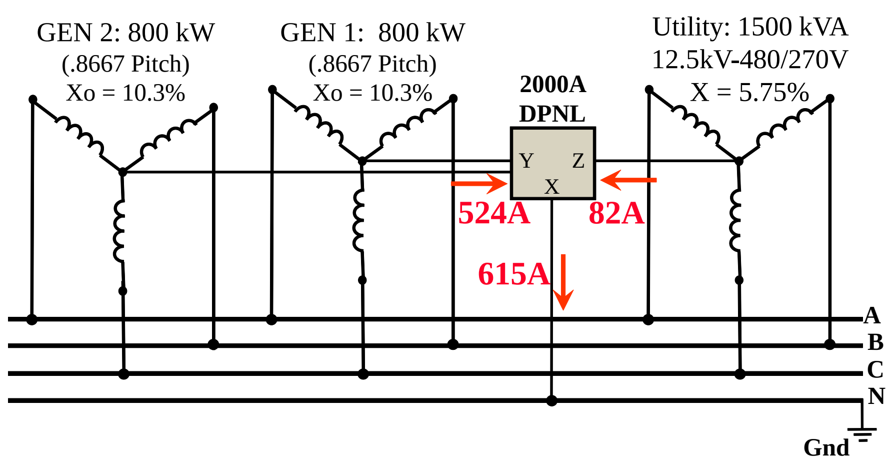
The total supply capacity of this application was 3500 kVA (1500 kVA transformer plus 1000 kVA for each generator). From the selection table in the GenLink DPNL Technical Data sheet, this would normally require a 2500A multiple winding reactor but based on the small amount of 1 ph loads, it was decided that a 2000A unit would be sufficient and still comfortably exceed the 33 1/3% minimum neutral rating as defined in NEC 250.184(A)(2).

With the GenLink DPNL installed, the measured neutral current values while operating at peak load are shown. After installation of the reactor, neutral circulating current was essentially eliminated. The remaining neutral current is the result of 1 Phase, Ph-to-N loads such as the 277V lighting. The reduction was enough to dramatically lower the load on the Utility transformer and generators allowing for their safe operation.

If access to the transformer neutral would have not been available, DPNLs could also be used as NGI's in this application. One for each generator would be required sized to the generator rating as a 4-wire application. From the 4-wire selection chart in the GenLink DPNL Technical Data Sheet DPNL-S002-x, an 800kW generator at 480V would have a phase current rating of 1200A. From the selection table, this would require a 750A/1500A DPNL. Connected as an NGI, this would be rated at the lower current rating of 750A. With a full load current rating of each Generator at 1200A, the DPNL would be over 50% of the Generator phase current rating which is acceptable by NEC code provided the expected current imbalance is not greater than 50%. If it was expected to be higher, a larger DPNL could be selected.



Simplified 3-Line Diagram at an American College Heating Plant



Simplified 3-Line Diagram at an American College Heating Plant with GenLink DPNL