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Preventing Neutral Circulating Currents when Paralleling Generators

Prepared by: Anthony (Tony) Hoevenaars, P. Eng
President and CEO
Mirus International Inc.

ABSTRACT

As electrical energy rates continue to rise and the need for secure and reliable electricity grows, many opportunities for distributed generation (DG) have appeared. Equipment used in these applications include diesel or natural gas generators, wind turbines, solar panels, microturbines and fuel cells to name a few. These and other applications, such as standby generation for critical loads, often require the need to parallel multiple generators or other DG sources with themselves or the utility supply.

Controlling circulating currents when paralleling generators in a power system that shares a common neutral can be difficult. In any paralleling operation, it is extremely important that voltages produced by the generating equipment are as closely matched as possible. To properly match voltages, not only do the RMS values need to be similar but the instantaneous values, which are determined by the voltage waveshapes, should be similar as well. When this is not possible, as in paralleling of generators with different winding pitch configurations, circulating currents may appear in the common neutral which bonds the wye connections of the generating sources. These circulating currents can cause overheating in the generator windings and false tripping of overcurrent protection equipment, particularly ground fault detection schemes.

These conditions are most troublesome in permanently connected parallel applications but can also be an issue during closed transition transfers in peak shaving or back-up generation applications. To reduce these circulating currents, which are usually triple frequency in nature, a uniquely wound, multiple coil reactor, such as Mirus' GenLink Dissimilar Pitch Neutral Limiter (DPNL), can be very effective. The unique winding configuration of the GenLink will block the flow of circulating current while introducing minimal effect on the short circuit impedance of the system.

GENERATOR PITCHES, HARMONICS AND VOLTAGE WAVESHAPE

Ideally, all generator sources would produce output voltage waveforms that were 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 their 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.

Table 1 shows the pitch factors for synchronous generators of various pitch types. These pitch factors are multiplied by the respective harmonic fluxes to predict the harmonic voltages [2]. Since differently pitched machines have different pitch factors for each harmonic number, their harmonic voltages and voltage waveshapes will be different as well.

Pitch	Fund.	3rd	5th	7th	9th
2/3	0.866	0.0	0.866	0.866	0.866
4/5	0.951	0.588	0.0	0.588	0.951
5/6	0.966	0.707	0.259	0.259	0.966
6/7	0.975	0.782	0.434	0.0	0.782

Table 1: Pitch factor impact on harmonic voltage magnitudes in synchronous generators [1][2]

Figure 1 provides examples of the 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

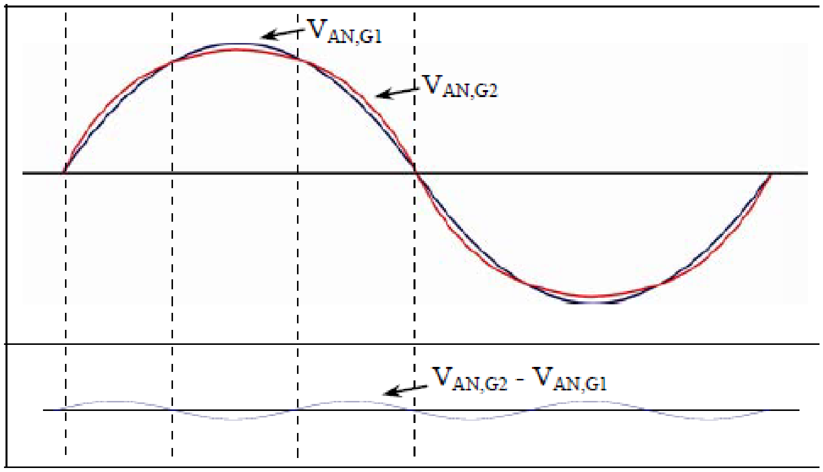

Figure 1: How differences in instantaneous voltages of paralleled equipment can produce line-to-neutral voltages that result in circulating currents

that reflects the instantaneous differences in the two voltages even when the RMS values are identical. 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).

Circulating currents will appear as shown in Figure 2 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.

Since the zero phase sequence impedance of the cables is normally quite small relative to that of the sources, it can typically be ignored. For the system shown in Figure 2 then, the circulating current can be calculated using the following equation:

$$I_N = \frac{3(V_{AN,G_1} - V_{AN,G_2})}{(Z_{0G_1} + Z_{0G_2})} \quad \text{Equation 1}$$

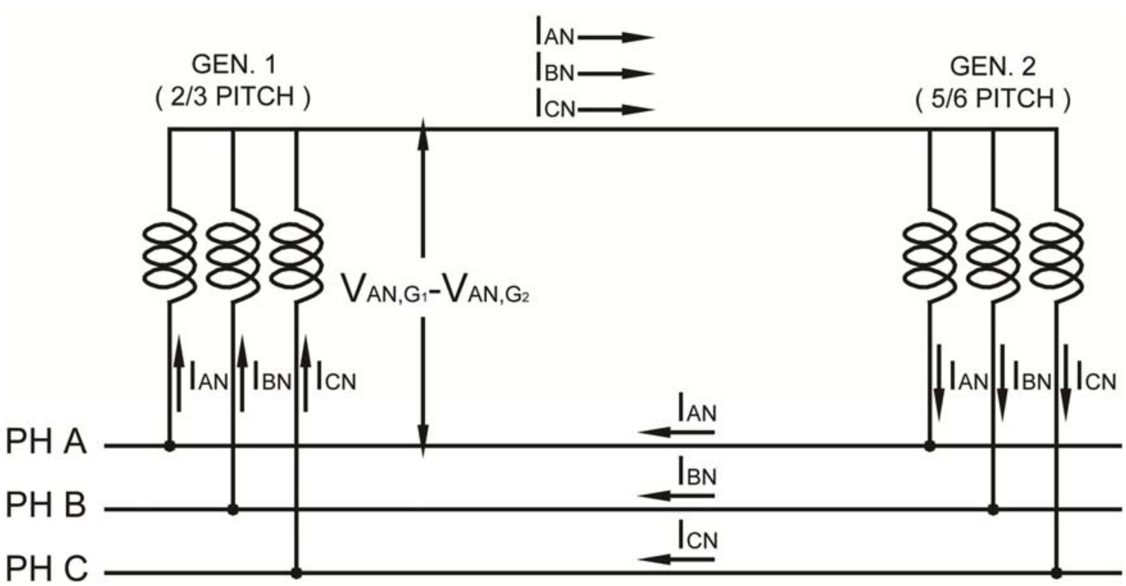

Figure 2: Flow of circulating current in a 3-wire paralleled generator application with neutrals connected and ungrounded

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 [3]. 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, 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 [4]. 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.

TRADITIONAL METHODS OF TREATMENT

The requirement to parallel generators is not new and therefore, circulating currents in the common neutral is also not a totally new phenomenon. What has changed however is the frequency that these incidences are occurring as the use of DG equipment increases.

One method of limiting circulating currents has been to ensure that all generators have the same pitch. This, of course, is not always possible or even preferred especially when expanding a site that has older, existing generators or where generators are being paralleled with the Utility.

Another approach is to add impedance in the common neutral. Standard reactors could be used for this purpose but any impedance added to reduce the circulating neutral current would also significantly reduce the single phase fault level in the system. A slight reduction in fault level may be preferred in large systems where the fault level is initially high but normally the level of impedance required to suitably reduce the circulating current will reduce the fault current to unacceptable levels. A fault level that is too low can be a serious safety concern since it can prevent overcurrent protection from operating and lead to fire hazards, such as arcing faults.

Occasionally, an ungrounded system is employed where the generator neutrals are not connected together. In this scenario, there will be no path for the circulating current to flow. There will also be no path for single phase fault currents so ground fault monitoring and other measures used for ungrounded systems must be employed.

GENLINK DISSIMILAR PITCH NEUTRAL LIMITER (DPNL)

The GenLink DPNL is a multiple winding reactor that is installed in the common neutral of paralleled generators (see Figure 3) in order 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.

The DPNL has three 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 otherhand, is < 1%. This is due both to the unique winding configuration of the DPNL 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 GenLink reactor so fault level under these conditions will be unaffected.

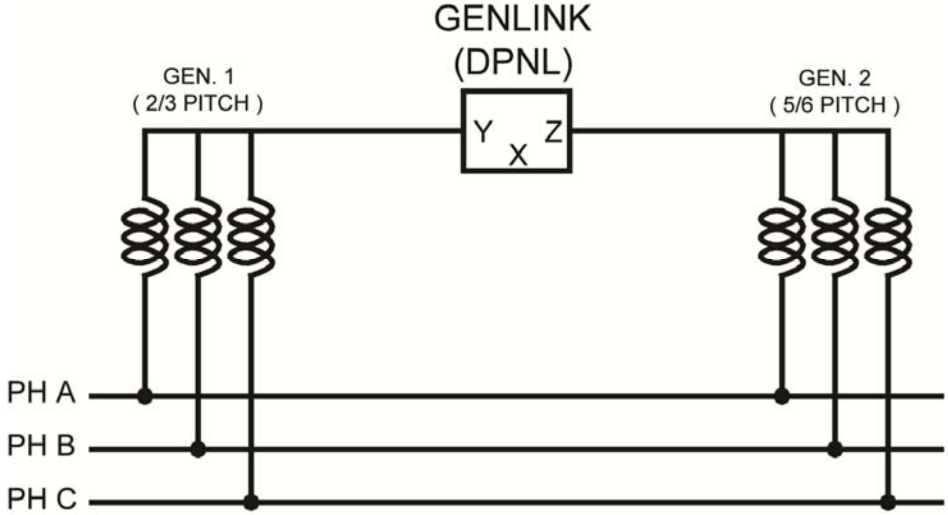

Figure 3: Installation of a DPNL to prevent the flow of circulating current in a 3-wire paralleled generator application with ungrounded neutral

The GenLink is used when two or more generators of dissimilar pitch are paralleled together or a generator is paralleled with an alternate source, such as the Utility. 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 Figure 4.

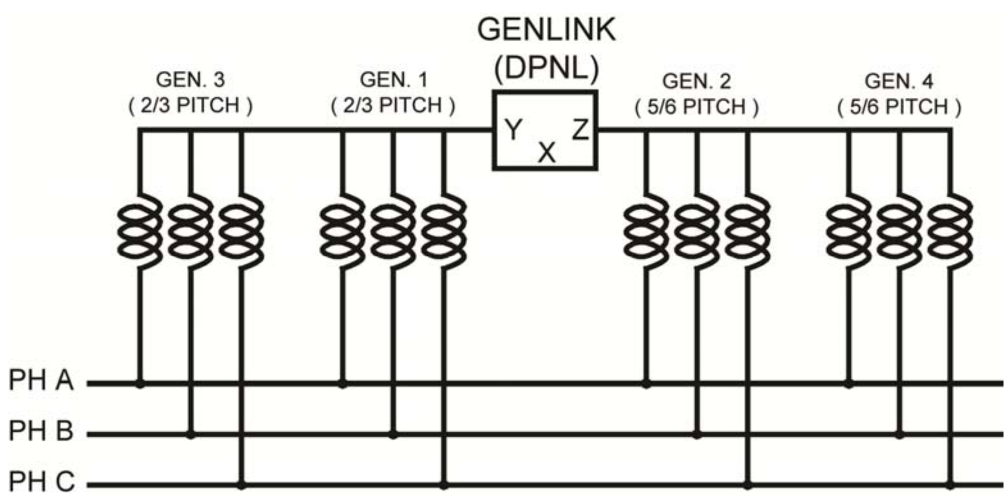

Figure 4: Installation of a DPNL where multiple generators of similar pitch are connected to one or more generators of a different pitch

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.

Figure 5 shows how the DPNL should be connected in a 4-wire application where the neutral is being used as a return path for 1-phase, phase-to-neutral loads. The diagram shows the neutral being grounded at the switchboard which is the recommended location but it 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.

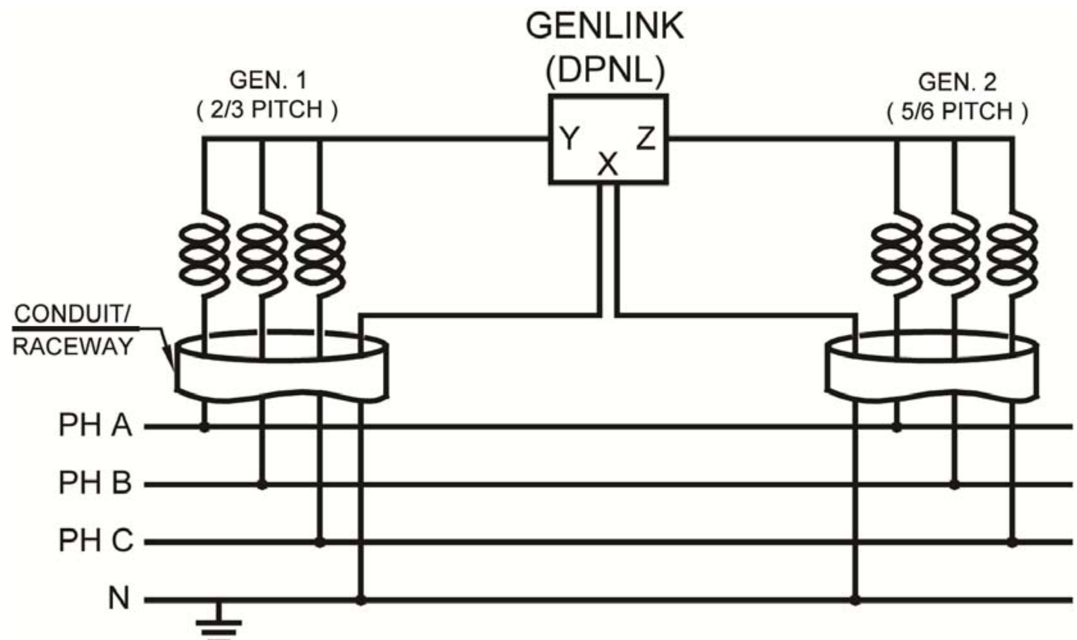

Figure 5: Installation of a DPNL to prevent the flow of circulating current in a 4-wire paralleled generator application

SIZING THE GENLINK DPNL

The amount of current which will circulate between dissimilarly pitched generators or other paralleled sources with slightly differing voltage waveshapes, can be somewhat difficult to determine precisely. As discussed earlier, it will be proportional to the level of instantaneous phase voltage between the sources and the zero phase sequence impedance of these sources. This information is not often readily available however. Fortunately, a conservative approach can be taken in the analysis to ensure that significant reduction is achieved and the mitigation device used can be sized appropriately to handle the load placed upon it.

Using Equation 1, Mirus engineers analyzed various configurations of paralleled sources to determine the level of neutral current that could be expected. These calculations were then repeated but with the impedance of the GenLink DPNL included. From these calculations, a sizing table was established (see Table 2) which allows for easy selection of conservatively sized units 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 GenLink must be sized for the return neutral current as well as the circulating current. For this purpose, it has a dual current rating with the highest rating being for the returned neutral current. Sizing the DPNL, first involves determining the total kW or kVA capacity of all generators or other paralleled sources. Then from the table, the DPNL current rating that corresponds to the total capacity in the appropriate system voltage column is selected.

DPNL Rating (Amps		Total Capacity of all Paralleled Sources kW [kVA]			
Return Neutral	**Circulating**	**208-240V**	**460-480V**	**575-600V**	**660-690V**
200	100	68 [85]	250 [312]	320 [400]	360 [450]
500	250	160 [200]	640 [800]	800 [1000]	900 [1120]
1000	500	335 [420]	1280 [1600]	1600 [2000]	1800 [2250]
1500	750	500 [625]	2000 [2500]	2400 [3000]	2720 [3400]
2000	1000	675 [840]	2500 [3126]	3200 [4000]	3600 [4500]
2500	1250	840 [1050]	3200 [4000]	4000 [5000]	4500 [5625]
3000	1500	1000 [1250]	3800 [4750]	4800 [6000]	5475 [6843]

Table 2: GenLink DPNL selection table for 60 Hz systems [5]

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, the next smaller size unit can be selected.

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 in Figure 6. 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 5/6P winding while the existing 750 kW generator was 6/7P. 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 (see Figures 7 and 9). 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.)

Figure 8 shows the residual current in the neutral after the DPNL was installed and running under peak load condition. The total of 38A was a significant reduction from the initially measured value. It is important to note that most of this current is return neutral current from phase-to-neutral loads. Virtually all of the circulating current was eliminated.

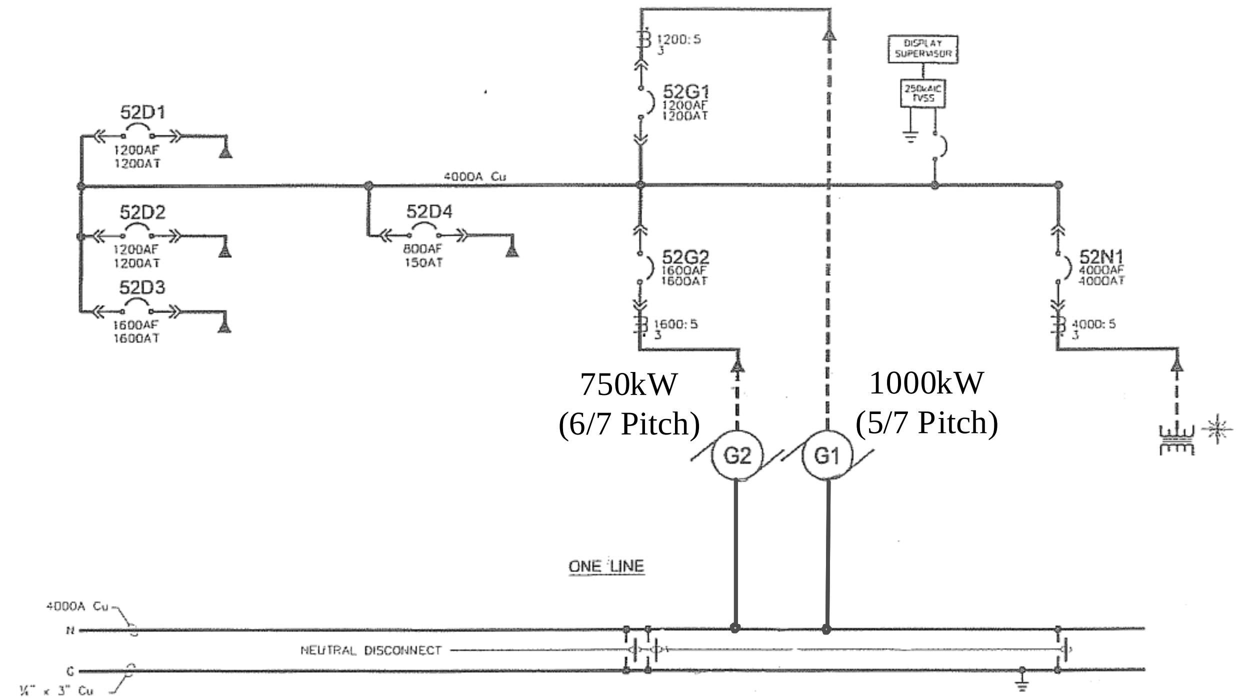

Figure 6: Installation of dissimilarly pitched parallel generators at a distribution facility

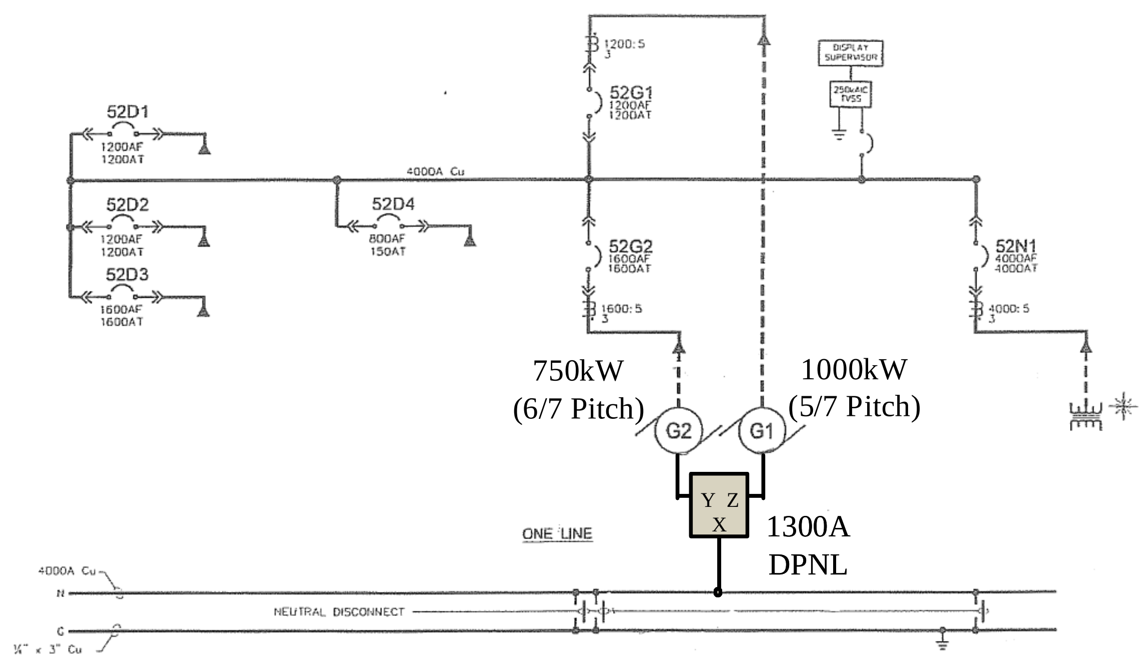

Figure 7: Installation of 1300A GenLink DPNL at distribution facility

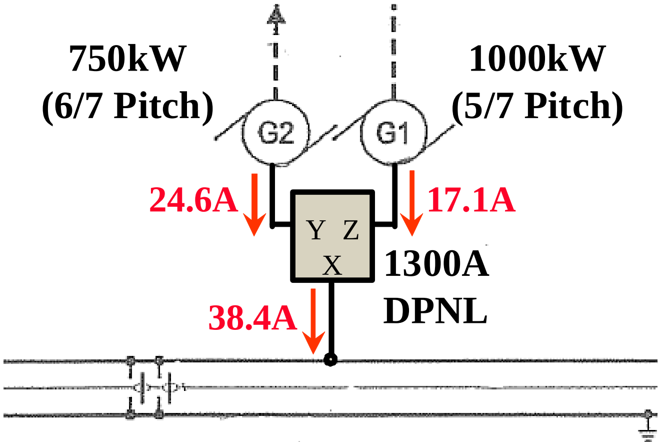

Figure 8: Flow of neutral current after installation of GenLink DPNL

Figure 9: Photo of GenLink DPNL installation

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 [6]. 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, solar panels, 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 (see Figure 10). 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, this would normally require a 2500A multiple winding reactor but based on the amount of 1 ph loads, it was decided that a 2000A unit would be sufficient.

Figure 11 shows the system 3-Line with the GenLink DPNL connected and the measured neutral current values while operating at peak load. 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.

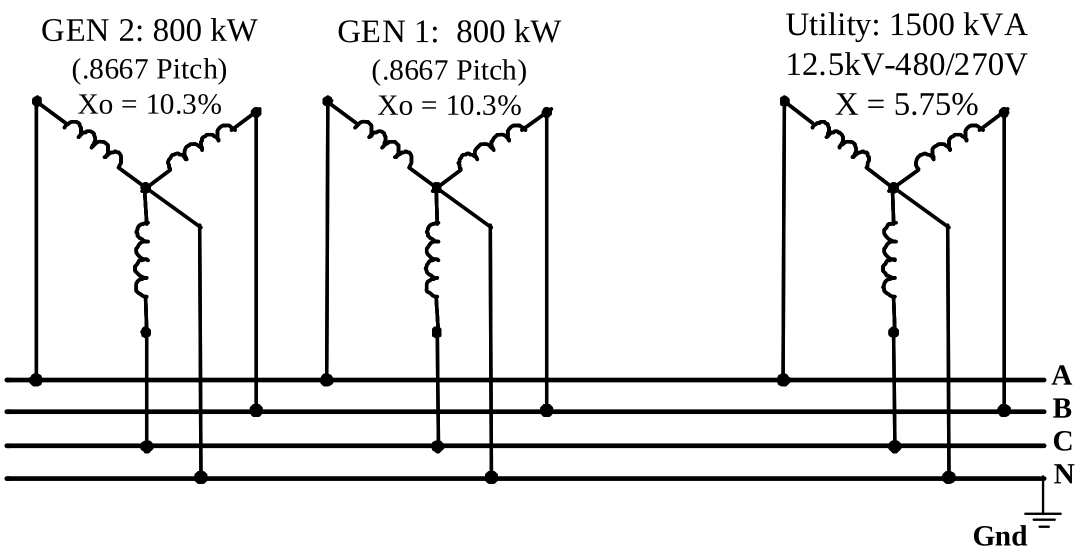

Figure 10: Simplified 3-Line Diagram at an American College Heating Plant

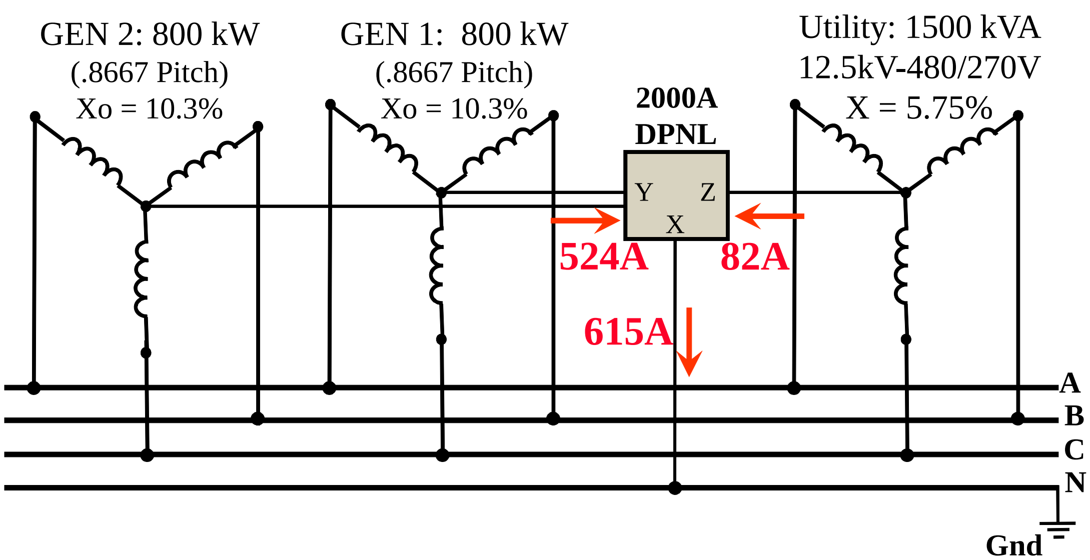

Figure 11: Simplified 3-Line Diagram at an American College Heating Plant with DPNL

CONCLUSION AND SUMMARY

When paralleling multiple generators with dissimilar winding pitches, heavy circulating currents can appear in the common neutral. These circulating currents can be very effectively reduced by the application of the GenLink DPNL. The DPNL is a uniquely wound reactor which 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.

References:

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