Preventing Circulating Current in the Common Neutral of Paralleled Generators

With the continual rise in electrical energy rates and increasing need for secure and reliable electricity power supply, 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.

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.

To reduce these circulating currents, which are usually triple frequency in nature, a uniquely wound, multiple coil reactor, such as Mirus' Dissimilar Pitch Neutral Limiter (DPNL), can be very effective. The unique winding configuration of the DPNL 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.

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

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

Figure 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.

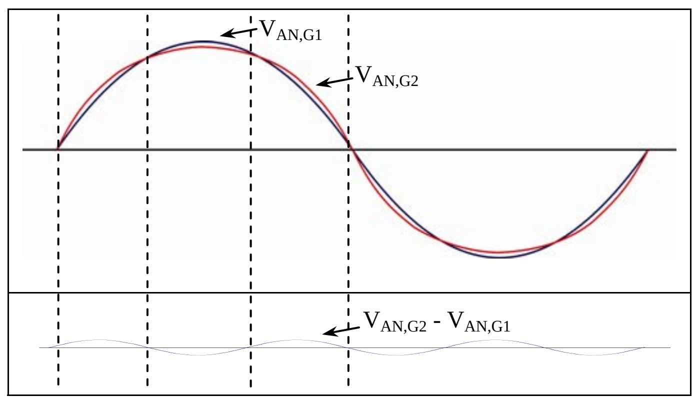

Figure 2: How differences in instantaneous voltages of paralleled equipment can produce line-to-neutral voltages that produce circulating currents in the common neutral

Figure 2 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 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. Circulating currents will appear as shown in Figure 3 and will also be predominantly triple frequency.

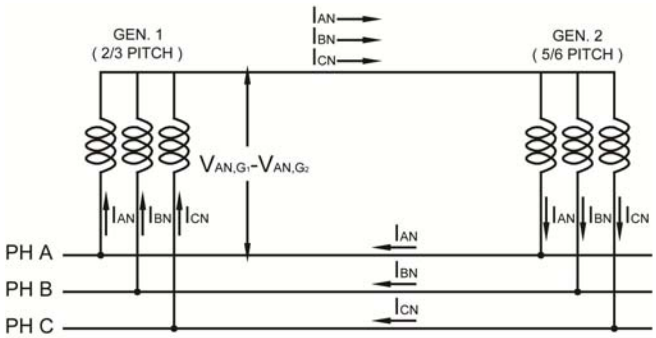

Figure 3: Flow of circulating current in a 3-wire paralleled generator application with neutrals connected and ungrounded

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 generators. The total circulating current in the common neutral will be the sum of the circulating current in each phase.

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, just because the 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.

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 with older, existing generators.

Another approach is to add impedance in the common neutral. Standard reactors could be used in this application 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.

Occassionally, 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.

DISSIMILAR PITCH NEUTRAL LIMITER

The Dissimilar Pitch Neutral Limiter (DPNL) is a multiple winding reactor that is installed in the common neutral of paralleled generators in order to add impedance to block the flow of circulating currents (see Figure 4). 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.

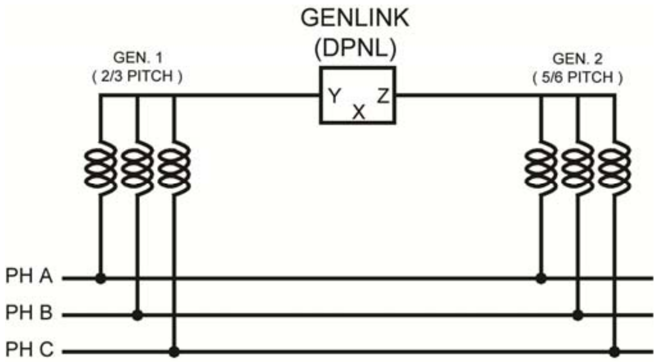

Figure 4: Installation of a DPNL to prevent the flow of circulating current in a 3-wire paralleled generator application with ungrounded neutral

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. By connecting the common neutral through the Y and Z terminals and grounding the X terminal, circulating currents will be dramatically reduced while any 1-phase fault currents would be decreased only marginally. Since the DPNL is connected only in the common neutral, it will not impede the path of phase-to-phase 1-phase or 3-phase faults.

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 show in Figure 5.

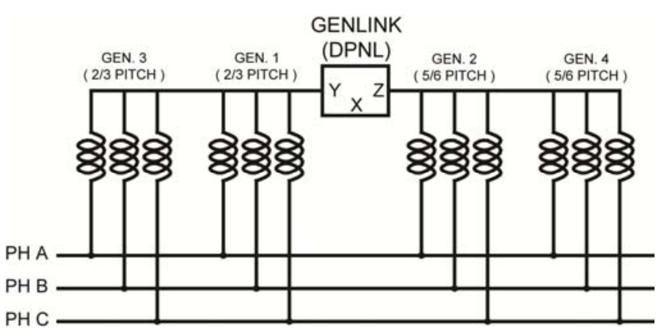

Figure 5: Installation of a DPNL where multiple generators of similar pitch are connected to one or more generators of a different pitch

DPNL AND 4-WIRE SYSTEMS

For 4-wire applications, where the neutral is being used as a return path for 1-phase, phase-to-neutral loads, the DPNL must be sized for the return neutral current as well as the circulating current. For this purpose, the DPNL has a dual current rating. To size the DPNL in 4-wire applications, ensure that the neutral return current from all phase-to-neutral loads does not exceed the DPNL return neutral current rating. If neutral current is expected to exceed the recommended DPNL rating, then a larger size DPNL should be selected or a Mirus NCE-FAI should be used to reduce neutral current (consult factory for sizing). For 3-wire applications with no return neutral current, smaller DPNL's can be used.

Figure 6 shows how the DPNL should be connected in a 4-wire application. 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 is properly grounded and grounded at only one location. Also, the neutral conductors should be run in the same conduit as the phase conductors, as shown, to prevent excessive stray fields.

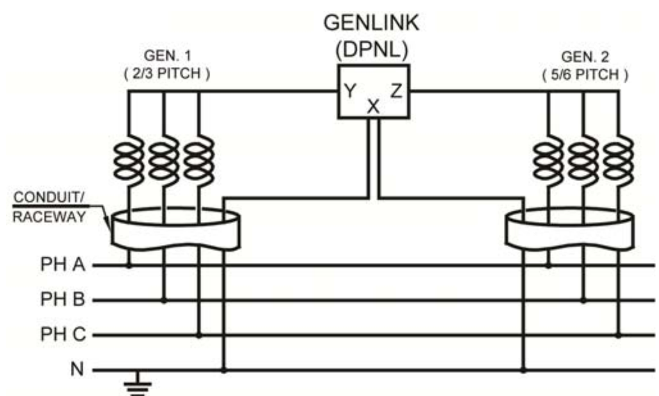

Figure 6: Installation of a DPNL to prevent the flow of circulating current in a 4-wire paralleled generator application with grounded neutral

OTHER APPLICATIONS FOR DPNL

Although the DPNL has been designed for paralleling applications of dissimilar pitched generators, it can be applied in any parallel source application with a common neutral and dissimilar voltage waveforms. For example, when any generator is operated in parallel with a Utility source, the voltage waveforms are likely to be dissimilar and therefore result in neutral circulating current. 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.

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 Mirus' Dissimilar Pitched Neutral Limiter. 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 with negligible affect on the system fault level. It is very simple to install and, as a purely passive reactor, is extremely reliable.

REFERENCES

[1] John P. Nelson, *A Better Understanding of Harmonic Distortion in the Petrochemical Industry*, IEEE Transactions on Industry Applications, Vol. 40, Issue 1, Jan.-Feb. 2004, pp 220-231

[2] *Generator Winding Pitch and Harmonics*, Engine Data Sheet EDS 70.4, Caterpillar, March 1993

[3] Graham R. Phillips, *Design of Stand-by Generators for Non-linear Loads*, IEEE Industry Applications Society 1992 Conference Proceedings, pp 185-189 Vol. 1, Oct. 1992

[4] *Lineator Advance Universal Harmonic Filter Questions and Answers*, MIRUS-FAQ002-A1, pp7-8, Feb. 28, 2005. http//www.mirusinternational.com/pages/faq.html#auhf

[5] Stephen Drouillhet, *Preparing an Existing Diesel Power Plant for a Wind Hybrid Retrofit: Lessons Learned in the Wales, Alaska, Wind-Diesel Hybrid Power Project*, National Renewable Energy Laboratory, NREL/CP-500-30586, August 2001