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Eliminating 3rd harmonic currents in paralleled generators.

Michael Z. Lowenstein, Ph.D., President MZL Enterprises
Consultant to Harmonics Limited by Jefferson Electric.

Distributed generation is becoming a more common design requirement for engineers and contractors, as facility managers seek to ensure continuing operations and gain more control over energy costs. Though backup systems have been around for years, maintaining optimal operations when multiple generators are involved remains a challenge.

Paralleling multiple generators on a common bus can lead to 3^{rd}-harmonic currents circulating in the ground system. Triggered by differences in generator pitch, these currents cause increased heating of the generator windings and often result in ground-fault tripping of generator breakers. As a result, generators may need to be operated at less than full capacity to avoid breaker tripping.

Various approaches have been used to address this problem – but most of these raise issues of their own. However, applying a passive 3rd harmonic suppression system in the generator ground circuit can eliminate circulating ground currents without raising other side effects.

Drivers – and challenges

Power continuity is becoming a major concern for critical-load facilities such as computer centers, hospitals, electronic manufacturers, financial institutions, and university systems. While short-term backup can be provided by UPS systems, long outages are supported by emergency generators. In many large facilities, multiple generators are paralleled to handle the emergency load.

In addition, some facilities are looking beyond backup scenarios, and incorporating distributed generation plans to both protect their own operations and generate excess power to sell back to their utility. To allow this, designers must successfully parallel multiple generator sets to a common bus and export the power to the utility. As windmill farms proliferate – to name one potential source of excess electricity generation – the need to parallel many smaller generators with the utility becomes more prevalent.

In any of these scenarios, the equipment involved can have differing generator characteristics, resulting in circulating 3rd-harmonic currents in the neutral. These circulating harmonic currents can create nuisance ground fault tripping decreasing system reliability, can damage generators Extra current means extra fuel and reducing the circulating currents can result in significant cost savings.

Circulating 3rd harmonic currents in the neutral will exist when multiple generator sets share the same terminal or bus voltage, but produce slightly different internal voltage due to variances in their winding pitch. In the most elementary form of a paralleling arrangement, this current flows out of the line leads of one generator, through the paralleling bus and into the second generator. It does not flow into the loads. This current, called "circulating current", is in addition to the normal line current supplied to the connected loads. as illustrated in Figure 1.

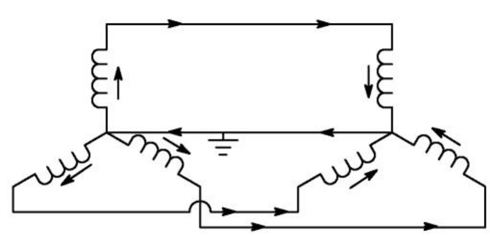

Fig 1. 3rd harmonic currents circulate between the two generators.

Circulating 3rd-harmonic currents are more common than one might anticipate. For example, cost concerns could lead some end users to turn to used generators for standby applications that are needed infrequently. Used equipment, while operationally reliable, might incorporate different pitch windings, raising the potential for 3rd-harmonic problems.

Mismatching also may occur as a facility grows and develops, and generator-plant needs expand. The added equipment may be sourced from a different manufacturer and may have a different winding pitch.
Failure of existing equipment can force facility managers to purchase or rent generators on short notice, with little room for choice. Available options may have a different winding pitch from those systems that are still operating. And natural disasters may require immediate generator acquisition with limited choice available. Any of these all-too-common scenarios can put the end user and parallel power-generation system at risk of generating circulating 3rd-harmonic currents - an unreliable and potentially damaging situation.

This problem is thoroughly outlined in a data sheet from Caterpillar.[1]

Traditional approaches
Circulating 3rd harmonic currents are not a new problem. Engineers and contractors have developed several strategies to help minimize potential damage when paralleling generators from different makers.

One approach is to match generator pitches. If multiple, paralleled generators are all of the same pitch, then they should all produce similar 3rd harmonic voltages, minimizing circulating currents. However, there is evidence that, even with the same pitch, generators from different manufacturers may have different enough 3rd-harmonic voltages to cause significant circulating harmonic currents.

Another method involves installing resistors, reactors, or switches to limit circulating currents.[2] Resistors and reactors reduce fundamental and harmonic current flow. However, if this equipment is large enough to be effective, it also may affect protective-relay operation. In addition, resistors and reactors produce heat, which is wasted energy.

A newer solution
A more recent solution is the harmonic suppression system (HSS), which impedes only the flow of 3rd harmonic current. The HSS circuit consists of an LCR (reactor, capacitor, resistor) parallel-resonant tank circuit, which is tuned to the 3rd harmonic (180Hz for 60Hz distribution systems.). (Fig. 2a.) This type of circuit has a nearly infinite impedance at the tuning frequency and relatively low impedance at all other frequencies. (Fig.2b.) The HSS is totally passive in operation, with an impedance at the fundamental frequency usually below 0.05 ohms. As a result, little fundamental energy is dissipated as heat, yet high impedance at the 3rd harmonic limits flow of 3rd-harmonic currents to a very low value.

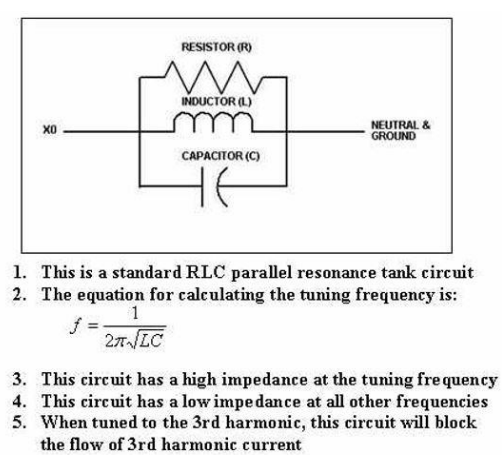

Fig. 2a. HSS circuit

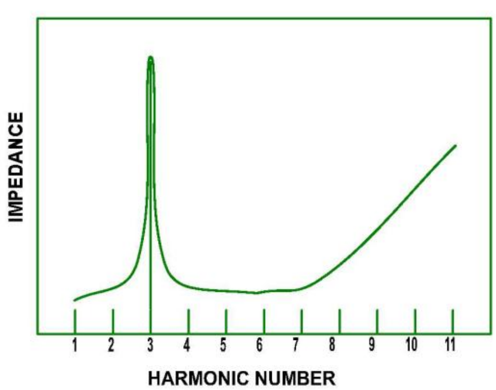

Fig. 2b. HSS impedance curve

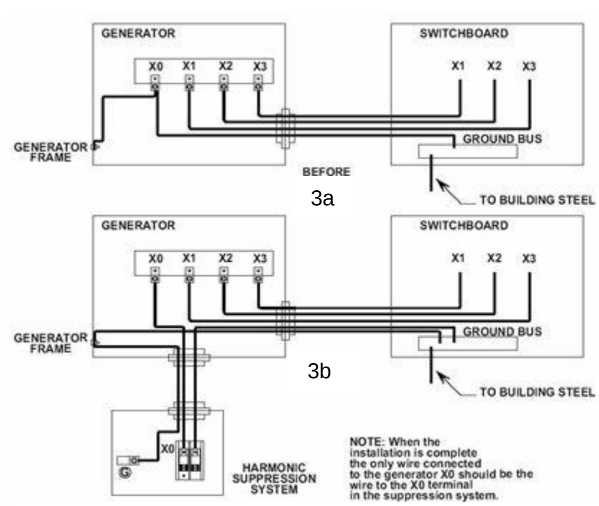

Fig. 3a, b. Delta connected generator without and with HSS.

Figure 3a shows the usual wiring for a 4-wire generator feeding a delta-connected panel. The generator's common connection is landed at the ground bus within the switchboard, and this bus is connected to building steel or an earth ground. The common is also connected to the generator housing, providing safety and code compliance and ensuring that a common ground potential exists for the installation.

Figure 3b illustrates how an HSS could be installed connected between the common connection of a 4-wire generator and the grounding system. Instead of being directly connected to the switchboard ground bus, this generator common is connected through the harmonic suppression system. Since the harmonic suppression system prevents flow of 3rd harmonic currents, these currents are blocked from both the common and phase wires. The generator frame is connected to the ground bus with a separate safety-grounding wire, ensuring that the desired common ground potential exists.

Figure 4. shows the effect on 3rd harmonic current flow of inserting the HSS in the ground circuit of one of the paralleled generators.

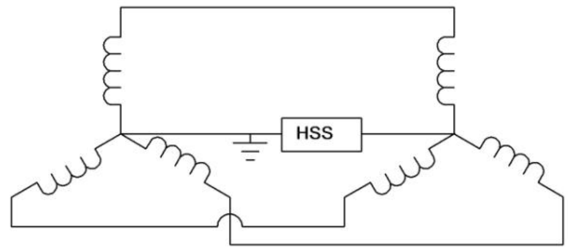

Figure 4. 3rd harmonic currents no longer circulate

Opportunities
Many opportunities exist for beneficial installation of the HSS.

1. New Construction: In multiple generator installations, even when all generators are manufactured by a single supplier, 3rd harmonic circulating currents have been observed. If generators are purchased from several suppliers, the likelihood that these currents will arise is increased. If problems are encountered, installation of an HSS on the offending generator or generators will solve it easily in the most cost-effective manner.
2. Increasing Capacity: As a facility grows in size the need to increase backup capacity will grow. It is possible that new generators available will not match the pitch of those already installed, particularly if the facility is older. If a problem is encountered, the HSS will solve the problem.
3. Disaster Recovery: A business renting emergency and backup generators must be certain that the rented units will be compatible with other equipment on the site. Installing an HSS on each rental unit as a matter of course will ensure that no pitch-matching problems will occur and that the generator can operate at full load immediately upon being connected.
4. Refurbished Equipment: A business refurbishing old or failed generators is not likely to be able to match the pitch of generators already owned by a facility. An HSS on each refurbished generator eliminates this requirement.

Conclusion

It is should be evident that the HSS is a simple and effective product for eliminating circulating 3rd-harmonic currents in paralleled generators. It is more cost-effective than traditional grounding resistors or reactors and dissipates

Reference 1, *Engine Data Sheet, EDS70.4*, Caterpillar, March, 1993.
Reference Google grounding resistors. One good general article follows:
http://apps.geindustrial.com/publibrary/checkout/System%20NGR?TNR=White%20Papers|System%20NGR|generic

Appendix A: Case Studies

Stanford University
Stanford University located in Palo Alto, California, operates a backup power system to ensure that vital campus functions can keep operating, even if utility power is lost. A new 1.2 MW generator was installed recently to increase this backup power capacity. During load testing, managers discovered that operating the new generator at levels above 600 amps resulted in tripping of the ground fault breaker. With the generator at 35% loading, the ground current was measured at 235 amps rms, with 232 amps of this current determined to be 3rd harmonic.

An HSS was sized for this generator based on ground-wire size requirements – in this case, a 400 amp rated unit was specified. After installation, following the wiring diagram shown in Figure 3b, 3rd-harmonic ground current was measured at less than 5 amps. With the ground current under control, the generator was easily brought to 100 percent load, with no breaker tripping problems. Figure 4. shows the generator ground current before and after the HSS was installed.

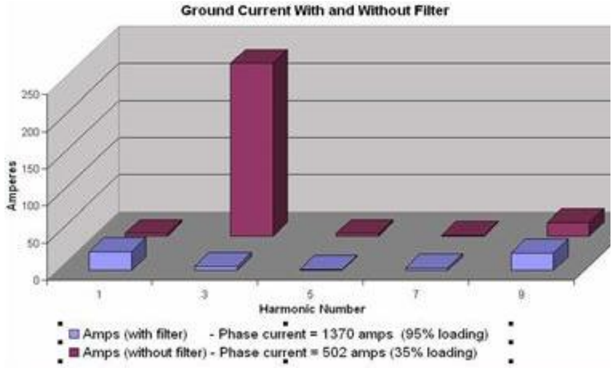

Figure 4. Stanford University HSS installation

Dane County Landfill

At the Dane County Sanitary Landfill Site No. 2, located just outside Madison, Wis., methane gas is captured through a series of wells and piped to a central onsite generation facility. After drying and cleaning, the gas is used to generate electricity. The energy produced is sold under contract to the local utility, and revenues offset landfill operating costs.

The facility initially began operation with two paralleled Caterpillar G3516,820kW methane gas fueled generators, but because the landfill continued to expand and produce more methane gas, Dane County facility operators decided to add a third generator. This generator was of different pitch than the other two, but no problem was anticipated. When the third generator was powered up, high ground currents were encountered, and the ground-fault relay tripped when the load reached 80 percent of the generator's capacity. Measurements indicated a ground current of 450 amps, all of which appeared to be 3rd harmonic. To permit operation the relay was disabled, but neither the engineer nor the operators were comfortable with this mode of operation, and a permanent solution to the ground current problem was sought.

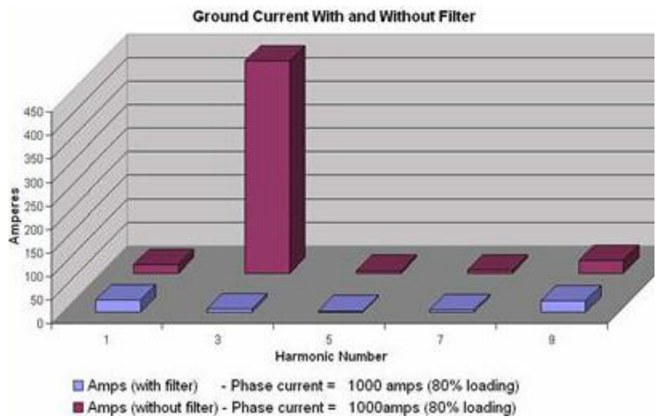

Figure 5. Dane County landfill HSS installation

Fig 6. Dane County HSS Location

To address the situation, operators installed a 400 amp HSS, and the generator was again tested at 80 percent load. Results before and after the HSS installation are shown in Figure 5. The ground current was reduced from 450 amps to under 10 amps. The ground-fault relay was re-connected and full operation with three generators on line was continued.

As the photo illustrates, the HSS was attached to the top of the switchgear and wired directly to the ground bus inside. Installation took only a few hours and results were immediate.

Magee Hospital, Pittsburgh

At Magee the existing installation consisted of (2) CAT 3512 gensets rated at 1250kW each both with a 4/5 pitch. Being added was a CAT C32 1000kW with 2/3 pitch. When the 3 units were tested with a 1000kW on the on- site load bank over 900 amps of current was being carried by the C32's neutral.

The use of a grounding reactor was considered but the cost to rewire the existing installation along with the reactor's limitation of not really solving the 3rd harmonic problem made it an

Fig 7a. Magee Rooftop Installation.

unviable choice. Another option was the use of a custom built sensing and switching system to change the load connection from wye to delta when the 2/3 pitch generator came on line. Not only was this approach expensive but, due to the requirement for a regular maintenance program, it created a possible failure mode. The solution selected by the design engineer was a harmonic suppression system which was installed on the roof of the hospital in the generator room The HSS was the perfect solution to the hospital's 3rd harmonic current problem. It was the least expensive, and being completely passive, maintenance was not an issue, The HSS completely eliminated the 3rd harmonic current and was installed in less than 10 hours. The installation time included lifting the unit by crane to the roof of the hospital.

Fig 7b. Magee New Generator.

Fig 7c. Magee HSS.

Fig 7d. Magee HSS Wiring.

G3 = New Generator						
Applied Load	KW per gen	Load Distribution	% Load	Neutral Amps	%3rd Harmonic	3rd harmonic
500kw	234	G3 & G1	23	33	6%	2 Amps
500kw	232	G3 & G2	23	35	6%	2 Amps
500kw	243	33kw 1ph A G3, G2	24	35	6.40%	2 Amps
500kw	234	33kw 1ph B G3, G2	23	35	6.2	2 Amps
500kw	239	33kw 1ph C G3, G2	24	36	6%	2 Amps
1000kw	234	33kw 1ph A G1, G2, G3	47	35	9.90%	3 Amps
1000kw	230	33kw 1ph B G1, G2, G3	46	36	9.90%	3 Amps
1000kw	232	33kw 1ph C G1, G2, G3	46	37	9.70%	3 Amps
1000kw	450	G3 & G1	45	34	9.70%	3 Amps
1000kw	450	G3 & G2	45	35	9.70%	3 Amps
1000kw	291	G1, G2, G3	29	47	7.10%	3 Amps
		Circulating 3rd harmonic current before installation of HSS				900 Amps

The above table shows the results of testing on the three-generator system after installation of the GenMax. The GenMax has reduced 3rd harmonic neutral currents of 900 Amps to a tiny current, less than 3 Amps. These results are typical of a HSS installation on generator systems where the generators have different pitches.