

Back-up generators and harmonic levels

Acceptable level of harmonics

Back-up generators are often found in hospitals, data centers, wastewater facilities, and a variety of other commercial buildings that require power be maintained when utility power is lost. The generator feeds a variety of loads, many of which create harmonic distortion. Too much harmonic distortion can cause problems within the building's various electrical equipment and can result in the generator tripping offline. This technical note discusses how to determine the acceptable level of harmonics for a system that is fed from a back-up (standby) generator.

Why not simply reference IEEE 519?

IEEE 519 is the standard most referenced when it comes to harmonic mitigation. However, as IEEE 519 has evolved from the 1981 to 1992 to 2014 to 2022 versions, the core of standard's tables and numerical requirements have been focused or clarified to make sure that "Customer A" does not negatively impact the overall power grid, and thus not impact the power quality fed to "Customer B." IEEE 519, while it does have suggestions and input that is applicable to an individual utility customer, the standard itself protects the utility and others on the grid.

Some have viewed IEEE 519's Table 2 sub note C as the official standard for acceptable levels of harmonic distortion for systems fed from a generator. IEEE 519-2014 sub note C essentially stated that all power generation *equipment* is limited to 5% TDD (total demand distortion). This reference to "power generation equipment" was often interpreted such that a back-up generator, for instance those at a hospital, should have the TDD limited to 5%. However, sub note C in IEEE 519-2022 was updated to state the 5% TDD target was for power generation *facilities*. This "power generation facilities" clarification shows the intent of IEEE 519 was not to apply this 5% TDD level to back-up generators that do not feed the utility grid. Reference Figure 1 for sub note C.

Also keep in mind that IEEE 519-2022 stresses that its harmonic values are applicable to the PCC (point of common coupling) where the utility meets the user. When a building is running solely from a back-up generator, there is no connection to the utility, thus no applicable IEEE 519 PCC at that moment of operation. From a design standpoint, there is nothing wrong with designing the harmonic mitigation to limit TDD to 5% at the generator. Nevertheless, if this 5% TDD value is chosen, the designer is choosing the 5% value based on their own approach to system design – and not based on any IEEE 519 guidance or standard.

Table 2—Current distortion limits for systems rated 120 V through 69 kV

Maximum harmonic current distortion in percent of I_L						
Individual harmonic order (odd harmonics) ^{a, b}						
I_{SC}/I_L	$3 \leq h < 11$	$11 \leq h < 17$	$17 \leq h < 23$	$23 \leq h < 35$	$35 \leq h \leq 50$	TDD
$< 20^c$	4.0	2.0	1.5	0.6	0.3	5.0
$20 < 50$	7.0	3.5	2.5	1.0	0.5	8.0
$50 < 100$	10.0	4.5	4.0	1.5	0.7	12.0
$100 < 1000$	12.0	5.5	5.0	2.0	1.0	15.0
> 1000	15.0	7.0	6.0	2.5	1.4	20.0

^aEven harmonics are limited to 25% of the odd harmonic limits above.

^bCurrent distortions that result in a dc offset, e.g., half-wave converters, are not allowed.

^cAll power generation equipment is limited to these values of current distortion, regardless of actual I_{SC}/I_L .

Table 2—Current distortion limits for systems rated 120 V through 69 kV

Maximum harmonic current distortion in percent of I_L						
Individual harmonic order ^b						
I_{SC}/I_L	$2 \leq h < 11^a$	$11 \leq h < 17$	$17 \leq h < 23$	$23 \leq h < 35$	$35 \leq h \leq 50$	TDD
$< 20^c$	4.0	2.0	1.5	0.6	0.3	5.0
$20 < 50$	7.0	3.5	2.5	1.0	0.5	8.0
$50 < 100$	10.0	4.5	4.0	1.5	0.7	12.0
$100 < 1000$	12.0	5.5	5.0	2.0	1.0	15.0
> 1000	15.0	7.0	6.0	2.5	1.4	20.0

^aFor $h \leq 6$, even harmonics are limited to 50% of the harmonic limits shown in the table.

^bCurrent distortions that result in a dc offset, e.g., half-wave converters, are not allowed.

^cPower generation facilities are limited to these values of current distortion, regardless of actual I_{SC}/I_L unless covered by other standards with applicable scope.

Figure 1 Comparison of IEEE 519-2014 (left) vs IEEE 519-2022 (right) sub note C

Facility concerns

As previously mentioned, IEEE 519's primary focus is on protecting the utility power quality and not the power quality within a specific user/building. Harmonics are broken down into voltage distortion and current distortion. Current distortion causes the voltage distortion. While current distortion has its negatives (such as increased current draw due to the additional harmonics), the voltage distortion has the biggest impact to sensitive electronic equipment within a building. Running on a back-up generator is typically a temporary event for most buildings. Thus, a key task for a system designer is to identify what harmonic *voltage* levels are acceptable during these temporary events. For example, a typical commercial building may be able to tolerate temporary high voltage harmonic levels while a hospital could not take that risk.

Once the acceptable level of voltage distortion has been determined, based on building type/needs, then a harmonic analysis is needed. A harmonic analysis done solely based on utility power will not accurately depict the voltage distortion levels for generator power scenarios. A lower impedance utility source is much stiffer than a generator feed, so distorting the utility voltage takes more non-linear load compared to a generator voltage supply. For example, a building's load on a utility transformer may result in 2.25% voltage distortion while that same load on a generator may result in 4.10% voltage distortion. A harmonic analysis must be done based on a generator source, in addition to the traditional utility source analysis.

Generator concerns

A generator can trip offline if the building's load causes too much voltage distortion. Modern generators have voltage regulators that support generating a clean sinusoidal waveform at a particular voltage and frequency. A building load that distorts the voltage waveform can cause issues with the voltage regulation of the generator. The generator looks at the zero-crossing of the phase to determine the AC line's frequency. Voltage distortion can cause the voltage waveform to be "fuzzy" at the zero crossing, which leads to inaccurate and inconsistent frequency calculations. The generator interprets the line frequency as jumping around, and attempts to compensate to bring the frequency to the target (i.e. 50 or 60 Hz). Worst case, the generator will surge or oscillate in an attempt to hit the target – ultimately resulting in the generator tripping offline to protect itself. Figure 2 shows the zero-crossing distortion of a single phase. Note how the voltage crosses the zero-crossing multiple times within the blue circle.

Generators are designed and have specifications to tolerate a certain amount of voltage distortion. A system designer must identify the maximum voltage distortion that a generator can handle and then make sure the harmonic analysis shows the voltage distortion will not reach that magnitude. One must also consider that the facility's harmonic loading itself is an added heat creating load on the generator, thus the generator must be sized to handle the harmonic currents too.

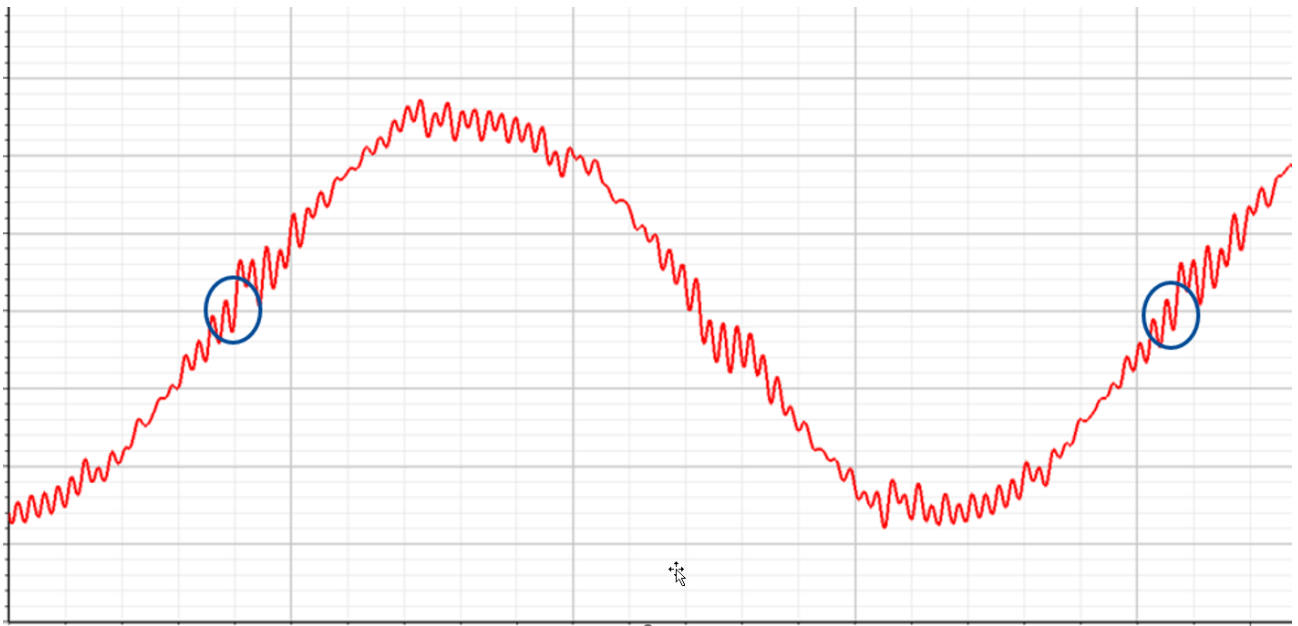


Figure 2 Voltage distortion at the zero-crossing

Strategy

The harmonic mitigation used for a building must be selected such that both the building type and the generator are “happy.” For example, a robust generator may be able to handle up to 10% voltage distortion. However, that level of harmonic distortion is too high for most buildings – thus the building wouldn’t be “happy.”

While voltage distortion is measured in percentage, actual waveform images are helpful to illustrate the quality of the waveform. Figures 3, 4, and 5 provide a visual indication of different levels of voltage distortion. The most obvious distinction of voltage distortion shows “flat-topping” of the top and bottom of the sinusoidal waveform, as shown in the zoomed-in portion of Figure 3. A higher voltage distortion percentage indicates more flat-topping and a generally more distorted waveform. Figure 3 shows 4.5 % distortion. Figure 4 shows 3.2% distortion. Figure 5 shows 1.4% distortion.

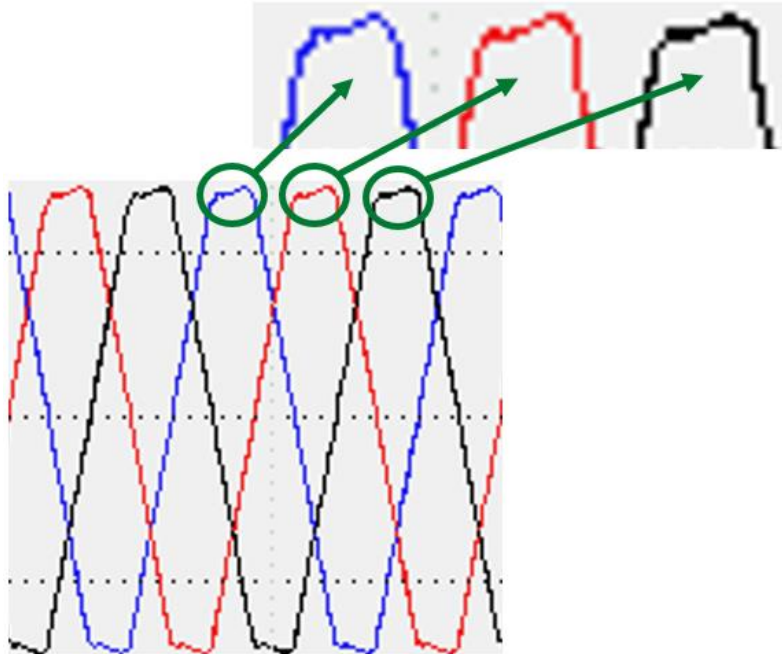


Figure 3 Voltage distortion of 4.5%

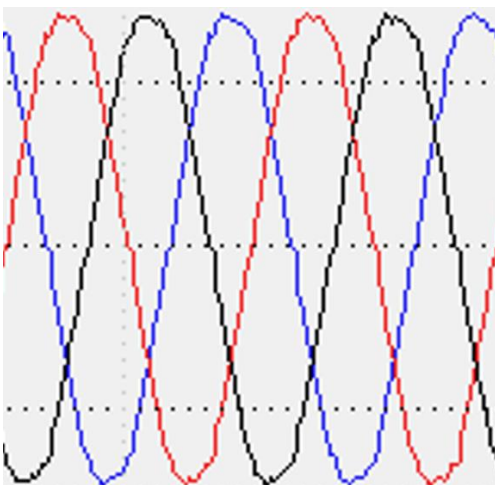


Figure 4 Voltage distortion of 3.2%

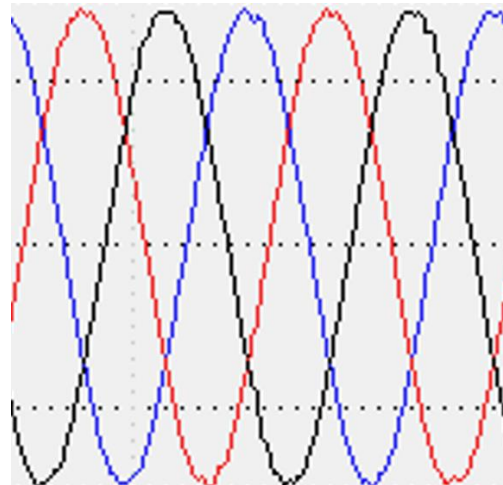


Figure 5 Voltage distortion of 1.4%

From a facility viewpoint, how much voltage distortion is too much? The answer to this question is somewhat subjective and depends on the type of equipment within that building. IEEE519-1992 Table 10.2 attempted to set some guidelines. Reference Figure 6. Special applications, such as those with sensitive electronics like hospitals, airports, data centers, or laboratories should have a maximum of 3% voltage distortion. While the general system, like a typical commercial office building, should not exceed 5% voltage distortion. Even though those values (3% & 5%) help draw the line between acceptable and unacceptable, they should be used as a general reference only, as many power quality experts feel those values are still too high. A system designer must ask themselves; would I really want the voltage distortion level illustrated in Figure 3? Table 10.2 was removed in future IEEE 519 versions, as the standard's numerical targets evolved to focus more on the protecting the utility grid from an individual user.

	Special	General	Dedicated
	Applications ¹	System	System
THD (Voltage)	3%	5%	10%

¹ Special applications include hospitals and airports

Figure 6 Simplified version of Table 10.2 from IEEE 519-1992

On occasion, Table 1 from IEEE519-2022 is referenced as a method to identify an acceptable level of voltage distortion within a building. However, this is a misapplication of that table. For example, Figure 7 shows that table appears to indicate a 480 VAC bus would be OK up to 8% THD. But this table is intended as a point of common coupling (PCC) table and is not intended to be used within a building. Even so, again looking back to Figure 3 as an example of 4.5% voltage distortion as a reference point, a system designer would not want to intentionally allow up to 8% voltage distortion in a hospital, wastewater facility, or commercial building.

Bus voltage V at PCC	Individual harmonic (%) $h \leq 50$	Total harmonic distortion THD (%)
$V \leq 1.0$ kV	5.0	8.0
$1 \text{ kV} < V \leq 69$ kV	3.0	5.0

Figure 7 Simplified version of Table 1 from IEEE 519-2022

A system designer must determine the acceptable amount of voltage distortion the facility should see while on generator power. Then a harmonic analysis should be done for the generator power scenario. There are two solutions if the harmonic analysis shows the voltage distortion levels are higher than the initial target level. The first solution is to oversize the generator, which makes it harder for the generator's output to be distorted. The second solution is to add harmonic mitigation to VFDs. Generally speaking, adding harmonic mitigation is a lower cost option than oversizing a generator. However, sometimes a combination of a little of both solutions together can result in the most cost optimized solution. Note that this approach requires working with a specific generator supplier, as this cost optimization is based on the points where they upsize their alternator, and at what point they upsize the engine for that alternator. However, simply adding harmonic mitigation to the VFDs is typically the preferred solution because this also improves the facility's power quality while on utility power.

Conclusion

IEEE 519-2022 is an excellent tool that sets guidelines on the maximum amount of harmonics a facility is allowed to put back onto the utility. However, IEEE 519 does not set a guideline for limiting the harmonics to a back-up generator, as that generator does not feed back to the utility. A system designer must determine the level of harmonics the facility can tolerate while on generator power, the level of harmonics the generator can tolerate, and then design the system based on keeping the voltage distortion below the smaller of those two numbers. Keeping voltage distortion below 3% is ideal, but most buildings without sensitive electronics can manage periods of up to 5% voltage distortion while on generator power. However, if the building has sensitive electronics (i.e. hospital) that will be operating from generator power, then the system designer must identify the power quality requirements of those sensitive electronics and design in harmonic mitigation that will keep the voltage distortion below those thresholds.