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# Managing Non-Linear Loads for Emergency Generators

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## INTRODUCTION

Power systems that have a load profile with a significantly large non-linear load will have harmonics in the system that may adversely affect the operation of power sources, including emergency generators.

These harmonics are distortions that may have unintended consequences and an adverse effect on generator operations. Harmonics may prevent operations, such as automatic paralleling, that require an accurate near sinusoidal waveform. Non-linear loads can also unexpectedly increase neutral currents.

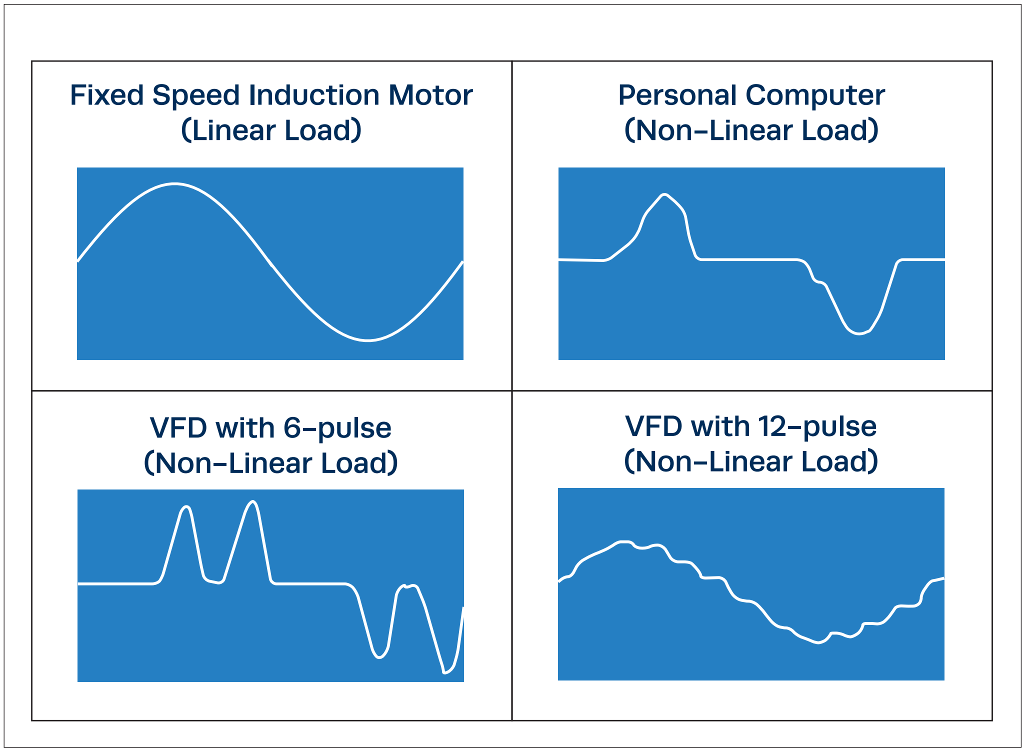
This paper provides key considerations when selecting diesel generator sets for facilities with non-linear loads.

## WHAT ARE NON-LINEAR LOADS?

Non-linear loads are electrical equipment that draw current at certain periods on the system. *Figure 1* shows the difference between a linear load versus 3 types of non-linear load. Linear loads, such as motors, draw current in a purely sinusoidal function that match the sinusoidal output of a power source. Meanwhile, a Variable Frequency Drive (VFD) and personal computer draw current in a non-sinusoidal wave form.

This is an inherent design characteristic for the power electronics systems with non-linear load. This design improves power efficiency, especially when the equipment needs AC to DC conversion. It draws current in short durations, optimized according to the load, to maximize energy conversion. However, the consequence is that the power waveform is distorted by these periodic, short bursts of current demand. The resulting voltage waveform loses the sinusoidal shape and is often described as non-sinusoidal or "harmonic distortion".

*Figure 1*

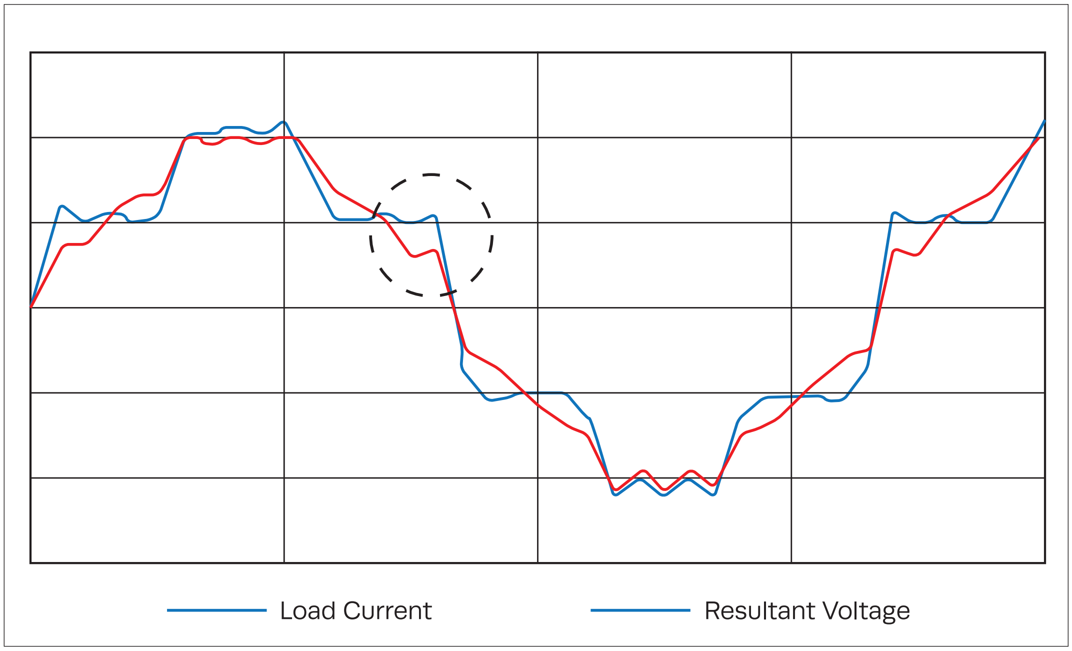



Additional examples of non-linear loads are power converters, battery chargers, Uninterruptible Power Systems (UPS), Soft Starts and Variable Frequency Drives. These loads have electronics that include diodes, inductors, capacitors and fast switching devices. These devices are used in combination to achieve a higher efficiency, AC to DC conversion.

## HARMONIC DISTORTION EFFECT ON GENERATORS

Emergency generators provide power as a sinusoidal voltage waveform. When non-linear loads are applied, the voltage waveform is distorted because of the non-linear equipment, see *Figure 2*. Depending on the magnitude of the distortion, this may introduce adverse effects on the generators.

*Figure 2*




The effects of this distortion include voltage notches in the power source, internal losses, false zero crossings, overheated neutrals, and torque pulsations in line voltage. For example, when a genset is intended for paralleling operation, distorted voltage waveforms might prevent a smooth paralleling operation.

Additionally, harmonic distortion can also manifest in additional current in the neutral conductors. This increases the current seen by the neutral of an otherwise balanced three-phase systems.

Power systems with large non-linear loads and high harmonic content also have adverse effect on other loads, not just the power source. It is important that system designers find ways to mitigate and adapt to non-linear loads and resultant harmonic distortion.

# MITIGATION STRATEGIES

## OVERSIZING THE GENERATOR

A common method of reducing the effect of harmonic distortion is to oversize the alternator on a generator so that a non-linear load power draw is much lower than the alternator's KVA rating, in effect masking the harmonic distortion. For example, an unfiltered ballast used for LED lighting might have VTHD of 3.1% even if the ITHD is 167% because its power draw is much lower relative to the alternator KVA rating. On the other hand, a six-pulse UPS with ITHD 28.9% can have VTHD of 15.4% even if the linear load is only 50% of the total alternator's capacity.

A larger alternator will typically have more tolerance for harmonic distortion.

## SELECT GENSET WITH LOWER GENERATOR REACTANCE

Harmonic currents are typically high frequency, short duration events, therefore, the sub-transient reactance – the lowest reactance – determines the generator's response. An alternator with low sub-transient reactance will better absorb the harmonic currents which despite increasing the internal losses within the stator and rotor will result in lower voltage drops and thus reduce distortion.

## FILTERING TECHNIQUES

Harmonic distortion can also be mitigated by filtering equipment which target certain frequency ranges that contain harmonic distortion. There are a wide range of products designed to filter harmonic distortion at the Point of Common Coupling (PCC). A Passive filter is a type of filter that utilizes inductors and capacitors to filter harmonic distortion in the desired frequency ranges. Active filters are more expensive but also more robust in dealing with harmonics. These filters actively produce a waveform opposite of the harmonics and effectively counteract harmonics, restoring the power waveform closer to a sinusoidal shape.

## USING LOWER ITHD LOADS

By using devices that produce low levels of current distortion, the effect on the voltage supply is greatly reduced. Examples of these devices include a 12 or 18 pulse VFD which are more complex and reduce harmonics through faster switching.

## RECOMMENDATIONS

Rehlko recommends analyzing the load profile of a system.  By knowing which loads are non-linear, the harmonic content of a system can be determined. This can be done by system studies or by using metering equipment capable of measuring the harmonic distortion. The designer should consider this along with other generator sizing considerations.

The first effort should be using harmonic filters on non-linear loads to reduce the harmonic distortion caused by the load. Only when considerable effort is made to reduce the harmonic content of the system, should the generator type and size be selected. This will ensure that the generator is not burdened by harmonics and it can operate within its limits.

Rehlko's online generator sizing application allows the user to simulate a power system with non-linear loads. It recommends a generator size and model that is most capable of handling this load profile and offers harmonic filters as a solution for harmonic distortion that exceeds specifications. The Rehlko Power Solutions Center Sizing and Specification application is found at www.pscweb.rehlko.com.

## SUMMARY

Non-linear loads are common types of loads in a power system. Although this type of equipment can be more efficient, it introduces harmonic distortion in the power system.

Harmonic distortion can increase neutral currents and impact the functionality of voltage sensing devices in the power system.

Making sure that harmonic distortion is reviewed as part of the overall criteria for selecting a generator and alternator combination, can ensure the generator is operating smoothly throughout its intended life cycle.

## ABOUT THE AUTHORS

Fuad Ahmed is Project Design Engineer at Rehlko. He holds a master's degree in electrical engineering from the University of Wisconsin-Madison. Fuad joined Rehlko in 2024 and is a part of the Electrical Industrial Solution engineering team, responsible for providing design and technical direction in the development of custom generator sets.

Al deLeon is a Senior Project Engineer at Rehlko Energy. He holds a Bachelor of Science degree in electrical engineering from Marquette University. Al joined Rehlko in 2022 with extensive experience in facility design as a consulting engineer for more than a decade. He has been part of engineering teams designing large industrial, commercial, and educational buildings with generator systems. He has also designed wind, hydroelectric, and solar power plants.

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Power Systems, Rehlko's largest division, delivers worldwide energy solutions designed to ensure resilience for mission-critical applications of all sizes. Building on more than a century of expertise and dedication, the company offers complete power systems, including industrial backup generators (HVO, diesel, gaseous), enclosures, hydrogen fuel cells systems, automatic transfer switches, switchgear, monitoring controls, genuine parts and end-to-end services. As a global company with service partners in every country, Power Systems provides reliable, cutting-edge technology to keep industries and businesses running.
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