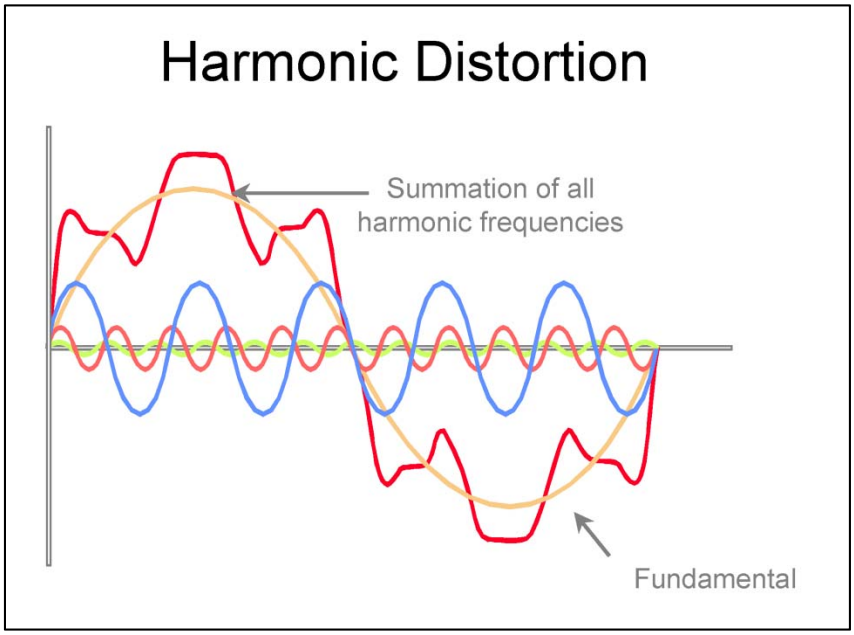
Generation Selection and Non-Linear Loads

The purpose of this white paper is to review some of the basic functionaility of non-linear loads such as - **Variable Frequency Drives (VFDs), Light Emitting Diode (LED) Lighting Systems, Battery Chargers, Welders and UPS Systems** and how they can impact a limited power source such as a standby generator set. These impacts can be mitigated by proper generator selection and sizing.

Harmonic Distortion and Non-Linear Loads - VFDs, LED Lighting

Harmonics are created anytime diodes and/or thyristers (SCRs) are used to convert AC to DC as they switch on and off, creating a non-linear load. These haromincs will create distortion of the generator output waveform creating additional heat in the generator windings which can adversely affect the service life of the generator. In addition, the Total Harmonic Distortion (THD) may impact sensitive loads on the generator – including the VFD – the source of the distortion.



6 Pulse VFD Harmonics

In the example above, the orange fundamental sine wave, represents the idealized output waveform from the generator. In a 6-pulse drive, one that has 6 diodes or SCRs rectifying the AC power to DC, the 5th harmonic (300Hz) is quite large, as seen in the blue sine wave. The 7th harmonic (420Hz) is seen in the pink sine wave. The summation of all of these sine waves is shown in red, and shows the distortion of the generator output.

The harmonic distortion is inversely propotional to the number of diodes used to rectify AC to DC. The 6, 12, or 24 pulse references the number of diodes or SCRs that make up the rectifier assembly. As the number of harmonics increases, the lower their amplitude, which reduces the impact on the generator. The reduction of the 5th, 7th and 11th harmonics have the greatest practical affect.

marathon™ Generators

Comparison of VFD Load Characteristics

The data in the following table has been developed based on Marathon Generator application experience from our GenSys selection program. The load is the same: a 50Hp motor load, with different VFD assumptions: No VFD, and 6, 12 or 24 pulse VFDs.

As expected, starting the motor Across-the-Line results in the largest required Start kVA . Note that the SCR loading is 0, which is what we would expect as there are no diodes or SCRs present in the motor load. The harmonic content of the 6 Pulse VFD load results in a signifcantly higher Peak SCR kVA as compared to the simple running kW load

	Across-the-Line No VFD	6 Pulse VFD	12 Pulse VFD	24 Pulse VFD
Run kW	42.00	46.67	46.67	46.67
Run kVA	48.00	58.33	51.85	49.12
Start kVA	288.48	72.92	64.81	61.40
SCR kW	-	53.67	51.33	-
SCR kVA	-	67.08	57.04	-
Peak SCR kVA	-	83.85	71.30	-

These values should give your customer an approximation of the affects of 6 and 12 pulse VFDs on generator selection. In addition, the “The Law of Diminishing Returns” applies. A 6 pulse VFD will be the lowest cost VFD, with the highest level of harmonics. Mitigation steps such as adding DC Inductors, Line Reactors and/or moving to a 12 pulse VFD will greatly reduce the THD, while increasing the cost of the VFD system. As you may imagine, these are generic VFD assumptions. Actual operating characteristics may vary widely.

These impacts can be mitigated by proper generator selection and sizing. When selecting a generator with one or more **Non-Linear devices as the predominent load(s),** the generator should be selected and sized based on evaulation of several factors including:

- **% of Load that is Non-linear.**
- **Characteristics of the VFD e.g. 6 pulse, 12 pulse, 18 pulse.**
- **Peak SCR kVA required.**
- **Total load required and Temperature Rise of Potential Generator Selection.**
- **Subtransient Reactance (X''_d) of Potential Generator Selection.**

The harmonics imposed on the generator due to Non-linear loading may also produce notches in the voltage waveform severe enough to cause misfiring of the power rectifiers in a shunt excited generator’s AVR due to false zero-crossings. When this occurs, the generator’s terminal voltage will become unstable. A PMG Excitation Support System will eliminate this cause of generator unstability.

Generators with VFD and/or other Non-Linear Loading Conditions should be equipped with a PMG Excitation Support System (PMG & DVR2000E+/EC+ or PMG & PM500).

marathon™ Generators

Generator Sizing for VFD and Other Non-Linear Loading Conditions

The following chart provides guidence on generator sizing based on the expereince of Marathon Generators Application Engineers and best practices in the field.

% of Load that is Non-Linear	6 Pulse VFD Severely Non-Linear	12 Pulse VFD Moderately Non-Linear	18 Pulse VFD Mildly Non-Linear
100%	Select a generator based on **Total Load** with a **80°C R/R.** Verify Subtransient Reactance: **X''d ≤ 7%** , Good **X''d > 7%,** select a larger unit.	Select a generator based on **Total Load** with a **105°C R/R.** Verify Subtransient Reactance: **X''d ≤ 10%** , Good **X''d > 10%,** select a larger unit.	Select a generator based on **Total Load** with a **105°C R/R.** Verify Subtransient Reactance: **X''d ≤ 12%** , Good **X''d > 12%,** select a larger unit.
25% < **LOAD** < 100%	Select a generator based on **Total Load** with a **105°C R/R.** Verify Subtransient Reactance: **X''d ≤ 9%** , Good **X''d > 9%,** select a larger unit.	Select a generator based on **Total Load** with a **105°C R/R.** Verify Subtransient Reactance: **X''d ≤ 12%** , Good **X''d > 12%,** select a larger unit.	Select a generator based on **Total Load** with a **105°C R/R.** Verify Subtransient Reactance: **X''d ≤ 14%** , Good **X''d > 14%,** select a larger unit.
LOAD ≤ 25%	Select a generator based on **Total Load** at customer required temperature rise. Verify Subtransient Reactance based on the non-linear portion of the load: **X''d ≤ 12%** , Good **X''d > 12%,** select a larger unit.	Select a generator based on **Total Load** at customer required temperature rise. Verify Subtransient Reactance based on the non-linear portion of the load: **X''d ≤ 14%** , Good **X''d > 14%,** select a larger unit.	Select a generator based on **Total Load** at customer required temperature rise. Verify Subtransient Reactance based on the non-linear portion of the load: **X''d ≤ 14%** , Good **X''d > 14%,** select a larger unit.