VARIABLE FREQUENCY DRIVES AND HARMONIC ABATEMENT TECHNIQUES

This paper will focus on the impact of harmonics when applying Variable Frequency Drives. Its purpose is not to provide an extensive study on this subject but rather to offer guidance to engineers and users on the use of harmonic mitigation solutions with GE AF-600 FP™ and AF-650 GP™ drives.

IEEE 519 provides guidelines for recommended harmonic levels in electrical distribution systems including maximum voltage and current distortions. In general, when harmonic mitigation is used to reduce THID to IEEE 519 limits, IEEE voltage limits are also met. Therefore this paper focuses on the issue of current distortions (THID).

Harmonic currents are multiples of the fundamental frequency (60Hz) that are greater than the fundamental frequency. Continuous conduction or linear loads (e.g., across the line starters) contribute very little harmonic current while discontinuous conduction situations (e.g., non-linear loads like VFDs) contribute an infinite number of odd and even harmonic currents. Figure A provides an illustration of the VFD input current waveform when no filters or harmonic mitigation techniques are used.

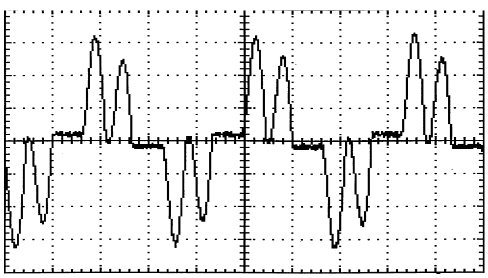

Figure A

Even harmonics (e.g., 2nd, 4th, …) are not a concern to most installations as they cancel each other out and add a minor amount to total line current. In contrast, odd harmonics (e.g., 3rd, 5th, …) add a significant amount to the non-sinusoidal and fundamental currents and are a major concern to most installations. The level of harmonics that a VFD adds to the electrical line is heavily dependent on the distribution line's impedance – the higher the impedance, the lower the harmonic content. Table 1 provides typical VFD harmonics depending on the input line impedance.

Harmonic Number	INPUT IMPEDANCE						
	0.50%	1%	1.5%	2%	2.5%	3%	5%
5th	0.8	0.6	0.5	0.46	0.42	0.4	0.32
7th	0.6	0.37	0.3	0.22	0.2	0.16	0.12
11th	0.18	0.12	0.1	0.09	0.08	0.073	0.058
13th	0.1	0.075	0.06	0.058	0.05	0.049	0.039
17th	0.073	0.052	0.04	0.036	0.032	0.03	0.022
19th	0.06	0.042	0.03	0.028	0.025	0.022	0.008
% THD - I	102.5	72.2	59.6	52.3	47.6	44.13	34.96
Amps Increase	43%	23%	17%	13%	11%	9%	6%

Table 1 [(1)]

Several techniques can be used to mitigate harmonics. The most commons are:

- Line Reactors
- DC Chokes
- Multi Pulse drives
  - 12 Pulse Drives
  - 18 Pulse Drives
- Passive Filters
- Active Filters

Line Reactors

Three phase line reactors added in series with a VFD will reduce harmonics. This is a relatively inexpensive solution and can lower harmonics by 50% depending on the amount of impedance added to the line. The most common values of AC line reactors are 3% and 5%.

DC Chokes

Instead of placing line reactors in series with the VFD, a DC choke can be added to the drive's DC bus reducing approximately the same amount of harmonics as the AC reactor. The advantage of DC chokes is they are smaller in size and are often mounted inside the VFD. All GE AF-600 FP™ and AF-650 GP™ VFDs incorporate DC chokes in the drive, providing harmonic reduction without incurring additional material or installation cost to the user.

Multi Pulse Drives

12 and 18 pulse drives are alternative solutions to reduce harmonics. In 12 pulse drives, the 5th and 7th harmonics are theoretically non-existent. Similarly, an 18 pulse drive only injects the 17th harmonic and higher to the line. To achieve the multiple pulse effect, additional converter bridges and phase shifting transformers are used making the solution expensive and increasing panel size.

Passive Filters

Passive filters consist of static components like inductors, capacitors, and resistors arranged in predetermined fashion to either attenuate the flow of harmonic currents through them or to shunt the harmonic component into them. There are several types of passive filters but the most effective is the low pass broadband filter, which offers great performance and versatility with low risk of resonance with the line.

Active Filters and Front Ends

Most passive techniques aim to cure the harmonic problems once they have been created. Active filters, or active front ends, use dynamic switches like IGBTs and other power components to stop harmonics from occurring in the first place. Current flow through a switch is manipulated to recreate a waveform that linearly follows the applied voltage waveform. Apart from the active front ends, there also exist active shunt filters that introduce a current waveform into the distribution network that when combined with the harmonic current cancels the later and results in an almost perfect sinusoidal waveform. The disadvantage of these solutions is still their cost.

GE's Approach to Harmonic Mitigation

GE offers several solutions to control harmonic content with drives.

DC Link Reactor incorporated into the drive

GE includes DC link reactors in all of our drives. The AF-600 FP™ Fan and Pump drive has a DC link reactor incorporated with a value equivalent to a 5% AC line reactor. This reduces the harmonics from over 100% in system without any mitigation techniques to approximately 35% THID. The AF-650 GP™ General Purpose drive has a DC link reactor incorporated with a value equivalent to 3% AC line reactor that reduces the harmonics to approximately 44% THID.

Multi Pulse Drive

Both the GE AF-600 FP™ and AF-650 GP™ drives can be integrated with a phase shift transformer for an 18 Pulse solution. This reduces THID to less than 5% provided all current and voltages are well balanced and the system is running at full load current. An 18 pulse solution was chosen over a 12 pulse one since 12 pulse drives are limited in the level of correction they provide and at best limit THID to 15%.

Passive Filters – Matrix Series D Harmonic Filters

GE Matrix filters are multi stage low pass filters specially configured to reduce the harmonics created by VFDs without causing power system resonance. Unlike single stage passive devices, Matrix filter's design typically achieves 5% THID at full load with worse case current distortion at 8% THID or less in any load between 0% and 100%. As shown in Figure B, Matrix filters have superior performance to 18 pulse drives under light load and unbalanced line conditions.

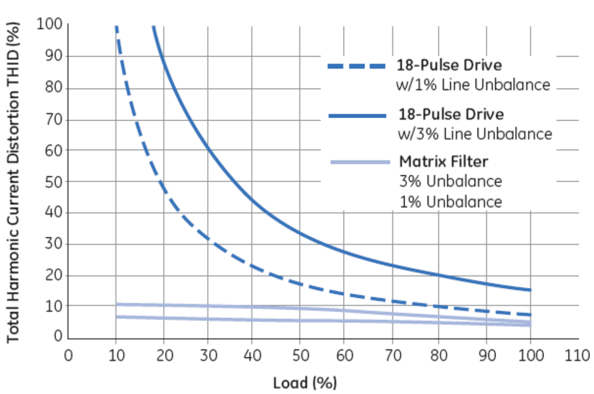

Figure B (2)

In addition to performance benefits, the Matrix filter has size and pricing advantages to an 18 pulse drive. Table 2 shows price and size differences of one solution over the other. This example is for typical non by pass solutions and should be used only as reference for reduction in cost and size when using Matrix filters. Size information provided here should not be used for design purposes.

HP @ 460V	Price Matrix vs. 18 P	Matrix panel dim (in) typical	18 Pulse panel dim (in) typical
40	51%	78.1x38.6x22.8	90.0x36.0x24.0
50	53%	78.1x38.6x22.8	90.0x36.0x24.0
60	56%	78.1x38.6x22.8	90.0x36.0x24.0
75	63%	94.6x49.0x26.0	90.0x36.0x24.0
100	73%	94.6x49.0x26.0	90.0x72.0x24.4

Table 2

Summary of discussion and conclusions

GE offers the following harmonic solutions and performance with our drive product lines. THID with no harmonic solution is included in Table 3 as a base line reference of solution performance. Actual results may vary based on distribution system's impedance.

Mitigation Solution	THID
No mitigation	>100%
AF-650 GP (with standard DC link reactor)	44%
AF-650 GFP (with optional line reactor)	35%
AF-600 FP (with standard DC link reactor)	35%
AF-600 FP (with optional line reactor)	28%
AF-600 FP or AF-650 18 Pulse	<5% (balanced line)
AF-600 FP or AF-650 GP with Matrix D	<5%

Table 3

GE's flexibility in offering allows us to provide the correct variable frequency drives and harmonic mitigation solution based on customers' specific needs and requirements. Please contact your GE Sales Representative, System Engineer, or Drives and Controls Business Development Leaders for support in selecting the appropriate solution for your application.

References
(1) - Table 1, Harmonic Reduction using Broad Band Harmonic Filters, FETP-103,
(2) - Figure B, Matrix Harmonic Filter Series D, GEH-7256