Excessive numbers of VFDs may catch Utilities attention

Introduction

Variable Frequency Drives (VFDs) continue to evolve since their noted success in the early 1990s. With little effort, one can find hundreds of articles written about their advantages when used with a fan or pump as compared to that of a damper or control valve. In these applications, the primary benefit occurs when slowing the motor reduces the kilowatt uses by the cube of the speed change. In other words, reduce the speed to 50% and reduce the energy consumption to $(½)^3$ or about 12.5% rated kW. Sometimes the usage of VFDs in a facility grows to the point they become the predominant load. At first glance this seems like a success story with reduced energy consumption and a lower electrical bill. However, the Power Company may recognize another phenomenon occuring as the VFDs may add harmonics to the grid causing harmful results.

VFDs Benefits

VFD costs have remained flat, their physical frame sizes continue to get smaller, yet their intelligence grows larger. VFDs are a no-brainer for Variable Torque applications such as pumps and fans and tend to dominate the industrial space.

VFDs get a lot of attention for the precision motor control, however, rarely is the input of the VFD discussed. The topology of the input primarily defines how “clean” the waveform into the VFD will be. Before VFDs, Power Companies were more concerned with starting large motors across the line. Inrush currents of 6 to 7 times the full load could mean a dip in supply voltage and stressing of the grid. Motors operating lightly loaded create a low power factor. The utility enforces a penalty for both occurrences known as “demand factor charge” and “power factor penalty”. VFDs ultimately diminish these penalties to near negligible amounts which reduces overall costs as these penalties can be upwards of 30% on a utility bill. However, now with VFDs, non-sinusoidal currents are being drawn from the utility and the providers are taking note of this potential harmonic problem.

We will explore the different types of VFD inputs from a high level point of view attempting to add some clarity to this confusing phenomenon.

Basic VFD Topology

AC motors by default operate across the line at a given speed. To vary the speed, a VFD is inserted in front of the motor. The VFD will vary the voltage and frequency proportionally. The easiest method to manipulate the voltage is to first convert it from AC (provided by the utility) to DC and then invert the DC to a simulated variable voltage, variable frequency AC waveform.

For simplistic purposes, split the VFD into 3 parts: A Converting Section, DC section, and Inverting Section.

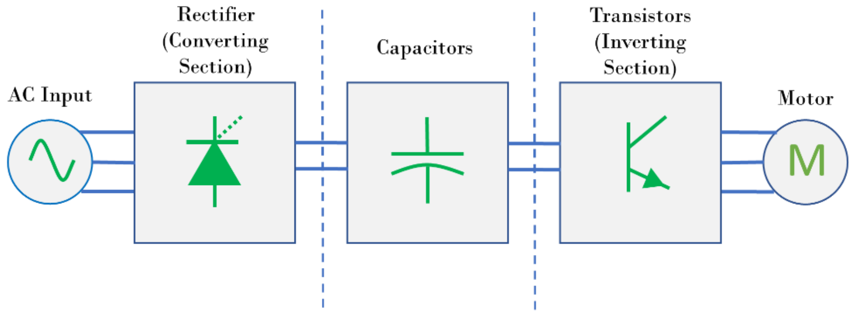

Figure 1. Topology of VFDs to convert fixed line voltage/frequency to variable voltage/frequency.

VFDs use a type of one-way electronic device known as a Diode or SCR to convert the AC line voltage into DC voltage. The DC voltage will have some ripple due to not being a quite perfect rectification, so large capacitors are used to smooth out the DC voltage. The heart of the VFD is the bank of transistors that are used to chop up the DC voltage and re-create a simulated AC waveform. This method of chopping is referred to as Pulse Width Modulation (PWM). The microprocessor in the VFD is primarily dedicated to this section of the VFD and this is the one technology most manufacturers “brag” about having the best motor control algorithm. The output of the VFD is shielded from the input with the capacitors, so since this article is only for input harmonics, the motor control will be excluded, so the input section can be explored in more detail.

From the prior discussion, the line voltage must be converted to DC in some method. The majority of VFDs use 6 diodes or SCRS or a combination of both. These are commonly referred to as 6-pulse drives. These drives take standard 3-phase voltage and convert it to DC without the need for special hardware outside the VFD. The waveform of the 6-pulse VFD does not behave as a linear load and when enough of these are used in a facility, it will ultimately raise the harmonic content enough to grab the utilities attention.

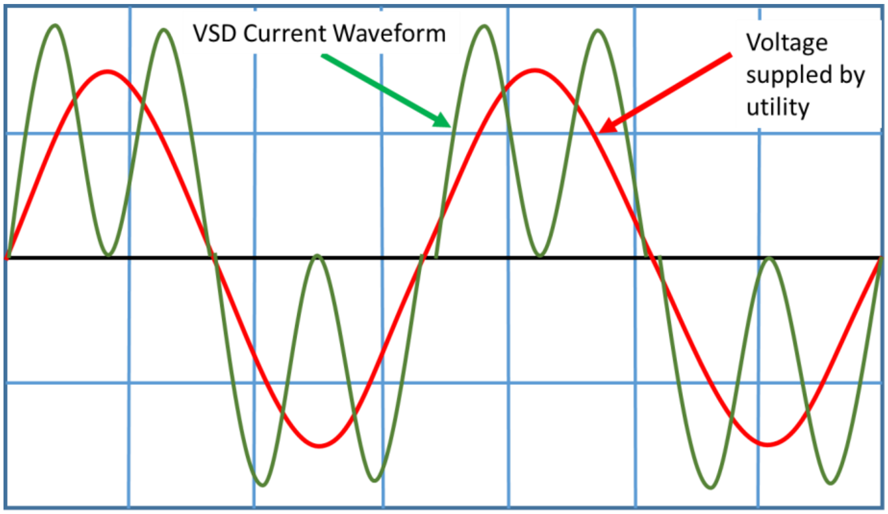

Figure 2. Line Voltage in its purest form, shown with VFD non-linear current.

So, what is non-linear loading? To keep it simple, the current is not in the same format as the voltage being supplied by the utility provider. This is referred to as "harmonic current" because embedded in the current waveform are multiples of the primary waveform. For a 6-pulse VFD, this is the 5th, 7th, 11th, 13th, 17th, 19th harmonic. This document will not dive into how this occurs, but will simply state that the Total Harmonic Distortion (THDi) will be in the range of 50-70% harmonic content. If this was the only loading on the utility, it would be considered "harmonic rich" and it would be highly recommended to add a harmonic mitigation device to correct the problem. At this point, the user is confused because the reason for the VFD was to lower consumption and it did exactly that.

Harmonic currents if large enough will distort the voltage creating a voltage harmonic on the grid which can affect the nearby users of the utility. The internal harmonics within the user's own facility will cause heating in transformersj, cabling and may interfere with sensitive electronics such as PLCs, computers and DCS communications. For more details on limitations, The Institute of Electrical and Electronic Engineers (IEEE) has created a recommendation document referred to as IEEE519-2014.

Harmonic Mitigation Options

Since 6-pulse VFDs are the dominant choice, least expensive VFD to choose from, let's review the methods to mitigate the harmonic content produced by these VFDs.

The lowest cost method is to add an inductor on the input of the VFD or as it is more commonly known as an AC reactor. These simple devices will reduce the harmonic current typically by almost half, so instead of 60%, we can expect a reduction in the 35-45% range.

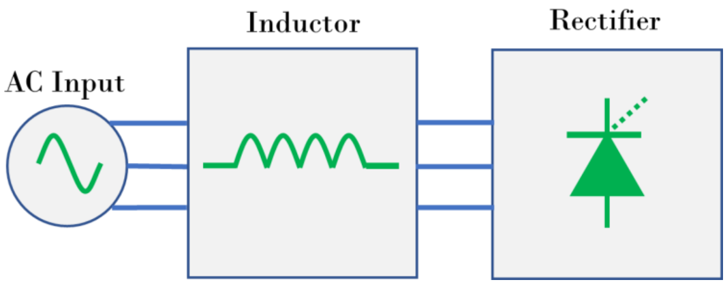

Figure 3. A reactor placed in front of the VSD. AC Reactors slow the current fluctuations thus reduce harmonics.

Filtering is another method to correct for harmonic distortion. There are many different versions on the market, but we will discuss the passive and active ones. Passive, meaning they are simple pieces of hardware, where active will be dynamically adjusted using a microprocessor and some feedback devices.

Passive filters use capacitors and inductors precisely configured to "notch" or "trap" the offensive frequency (or multiple frequencies). These devices must be sized for the rated load, so "oversizing" them defeats the purpose and the filtering amount is reduced. With a typical notch type filter, harmonics can be reduced below 8% THDi.

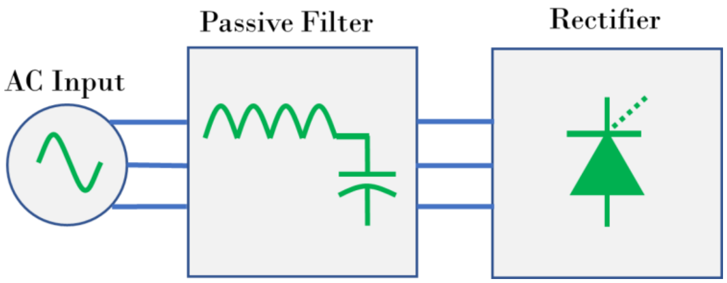

Figure 5. A passive filter installed in series with the VFD.

Active filters use both capacitors and inductors, but add a microprocessor to control transistors to inject equal and opposite harmonics back into the grid. By applying opposing harmonics to the VFD-created harmonics, the resultant harmonic content is well below 5% THDi. Another benefit is that active-filters operate just as well at light load or rated loads. Since these are Parallel type devices, a user can utilize one active filter for multiple VFDs. The negative side is that active filters cost considerably more than passive devices. So, it is best to decide early whether to go with passive devices on each VFD or use an active device on an installation of multiple VFDs.

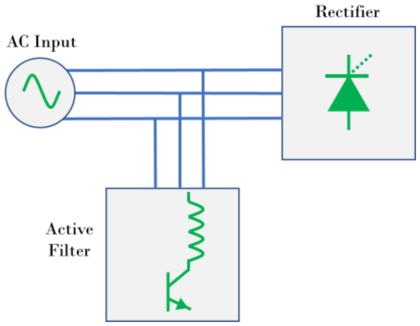

Figure 6. An active filter is a parallel device that goes in parallel with one or more VFDs.

The above solution spoke about 6-pulse mitigation techniques, but how about changing the VFD input instead of adding external devices?

Other input types are 12-pulse, 18-pulse, etc in multiples of 6. Looking first at the 12-pulse VFD, it uses 2 rectification modules along with a custom wound transformer that provides (2) 3-phase outputs shifted electrically by 30°. By shifting the waveform, the harmonic content is reduced to 12-15%. The

12-pulse configuration adds some complexity, costs and space, but is a viable solution.

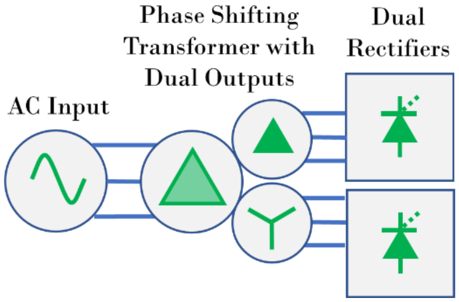

Figure 4. A 12-pulse VFD with a special Delta-Delta/Wye transformer.

By continuing to add special phase-shifting transformers and adding additional rectifier modules, the harmonic content will continue to be reduced. This is more commonly prevalent on larger VFDs above 1000HP where their contribution is a considerable amount. Once 18-pulse is reached, the harmonic content will be 5% or less THDi.

Putting all the possibilities for harmonic mitigation gives us this chart to tie in some relative numbers.

Technology	**Total Harmonic Distortion (THDi)**	**Cost**
6-pulse VFD	50-70%	$
6-pulse VFD with reactor	35-45%	$$
6-pulse VFD with passive filter	6-10%	$$
6-pulse VFD with active filter	3.5-5%	$$$
12-pulse	10-14%	$$$
18-pulse	4-6%	$$$$

Table 1. Many technologies exist to keep harmonics mitigated, but need to be weighed accordingly.

Summary

This article merely touches each mitigation solution from a single VFD standpoint and tries to highlight the most common methods used to solve these issues. The best solution may be a hybrid version of everything discussed. The system as a whole needs to be viewed by a Power Quality expert to analyze and make recommendations. Otherwise, the Utility may recognize the harmonic values are well above the recommended tolerances set forth by IEEE519-2014 and enforce users to make corrections. By using commercially available simulation tools, an engineer can run thru various iterations of harmonic mitigation methods finding the best technical solution and one that is most cost effective. This can later be followed up by using metering devices to fine tune the solution after installation.

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