

Methods for Mitigating Voltage Sag Impact On Variable-Frequency Drives

Background

Thanks to the precise controllability of motor speed and to the energy savings potentials, applications of variable frequency drives (VFDs) are no longer limited to pumps and fans. VFDs are becoming an integral part of the equipment in many continuous process applications such as blow-molding, paper machinery, extrusion presses, winders/unwinders, and other applications. However, with this widespread use of VFDs, the impact of momentary voltage disturbances on process operation is becoming an issue of concern for end-users. The type of momentary voltage disturbance that is the most frequent cause of disruption of VFD-related industrial processes is the voltage sag, also loosely called glitch or bump by plant people. What was before a minor irritant for plant operators, noticeable only in flickering lights, now may cause the entire plant production to stop due to tripping of VFDs, resulting in thousands of dollars loss associated with down-time, loss of product, and in some cases, damage to equipment. The purpose of this Power Note is to provide an understanding of the different solution options that are available to end-users who are using VFDs as a stand-alone unit for single applications (i.e., fans, pumps), or integrated into a process equipment.

Understanding the Electrical Environment

A voltage sag is a momentary (0.5 to 30 cycles) decrease in the rms voltage magnitude, usually caused in the utility distribution or transmission system by faults such as animal contact, tree limb incident, lightning strike, or caused within a customer facility by starting large motor loads. A voltage sag is primarily characterized by its magnitude and duration, as shown in *Figure 1*. Due to utility fault clearing practices, most the voltage sags are less than 20 to 30 cycles in duration. The magnitude of the sag depends on the available fault current, system impedance and distance from the fault. In most cases, the magnitude of the sag is down to 60 to 70% of nominal voltage. A typical customer site will experience 7 to 8 times more voltage sags than momentary interruptions. Also, the majority of the faults in the utility system involve single-line-ground faults and, depending on the customer transformer connection, only one or two phases will be affected by the voltage sag.

The first step in mitigating VFD trips related to voltage sags is to determine the nature of the voltage sag that is causing the problem and keeping a log of the VFD fault codes. Imprecise terms such as glitch, or bump are not adequate to characterize the disturbance. Yet, characterizing the disturbance is the first step to develop a cost-effective solution strategy. The utility may be able to provide assistance to the customer in selecting the proper voltage monitoring instrument to characterize the voltage sags impacting the plant.

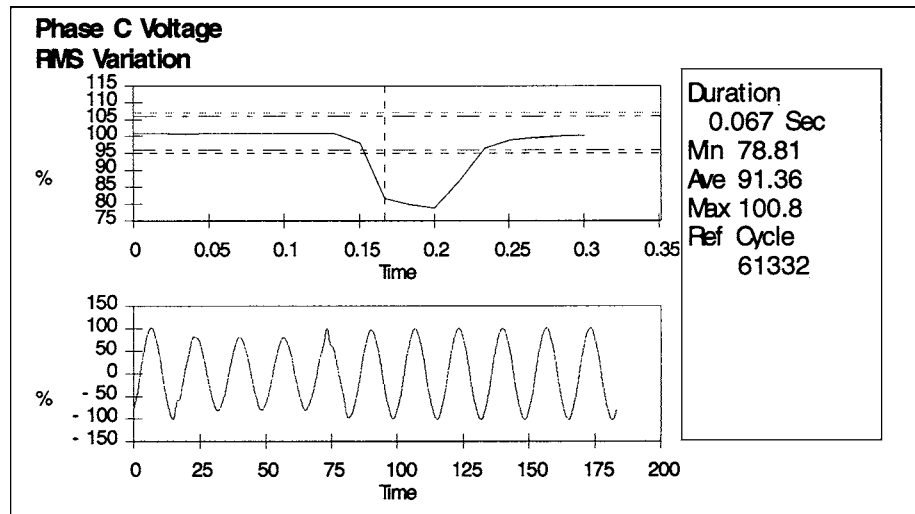


Figure 1 – Typical recording of a sag event by a power quality monitor

Options for Increasing the Ride-Through of VFDs

Non-Energy Storage Option

Reducing the trip level or increasing the time-delay of VFDs

VFDs are typically programmed by the manufacturer to trip instantly, and in some cases for a voltage sag of only 90% of nominal. This sensitive trip setting is usually selected by the manufacturer to protect the electronic components of the VFD. However, in many cases, there is room for relaxing this trip level or introducing time delays into the trip sequence without sacrificing the VFD integrity. This level of parameter change usually requires the manufacturer to provide access to the factory level parameters, which generally cannot be changed by the customer. In many cases, just lowering the trip level to 70% will significantly reduce the number of times the VFD will be affected by voltage sags. After the customer has obtained a log of typical duration and magnitude of voltage sags affecting the VFD, the manufacturer should then be contacted to determine whether a change of trip level or introduction of a time delay will reduce the number of nuisance tripping of VFDs during voltage sags.

Ride-Through Using 'Flying Restart'

The ability of a VFD to start into a spinning motor without tripping on an overcurrent fault is known as 'Flying Restart' capability. A majority of VFDs built after 1990 provide this as a programming parameter that can be enabled by the customer (*Figure 2*). In this method, when the voltage sag causes the VFD to reach its undervoltage trip level, the drive will shut off the inverter section and thus remove power from the motor instead of tripping. The motor will coast down during the duration of the sag and, as soon as the voltage recovers, the VFD will start into the still-spinning motor and ramp up to set speed. How much the motor speed will drop depends on the inertia of the load and the duration of the sag. However, since mechanical time constants are usually much longer than electrical time constants, a 10 to 15-cycle power loss to the motor will not cause appreciable speed change for many processes. In these cases, enabling the 'Flying Restart' option is the most cost-effective way of solving the voltage sag problem. The

customer will need to consult the drive manufacturer and the system integrator to determine how much speed/torque reduction the process can withstand without having to trip the process.

445 Flying Start
(FLYING START)
Value:
On (Enable)
* Off (Disable, Factory pre-set)
Function:
This function makes it possible to “catch” a motor, which because of an AC line drop-out is spinning freely
Description of Data Value:
Select Disable if this function is not required
Select Enable if the VFD is to be able to “catch” and control a spinning motor

Figure 2 – Typical example from drive instruction manual for enabling the flying (re)start

Ride-Through Using Load Inertia

This option, which is also provided by some manufacturers of VFDs, uses the energy stored in the mechanical load to keep the DC bus voltage from dropping down to the trip level. This is accomplished by running the inverter section during a voltage sag at a frequency slightly below the motor frequency, causing the motor to act as a generator. Similar to the flying restart option, the motor speed will drop while it is acting as a generator, however the advantage is that the motor is never disconnected from the drive. This option works best for those high-inertia loads that are allowed to slow down without interrupting the process.

Ride-Through Using Boost Converter

A Boost Converter can be used to provide ride-through to VFDs during undervoltage condition. Essentially, a boost converter uses the voltage remaining on the AC line during an undervoltage condition and the remaining available energy to maintain the DC bus voltage above the trip level. *Figure 3* shows the diagram of a commercially available voltage sag ride-through device using the boost converter topology. The unit converts the incoming AC voltage to DC using a rectifier, and then uses one or more inductive chopper sections to boost the DC bus voltage during a voltage sag and thus maintain its voltage above the trip level.

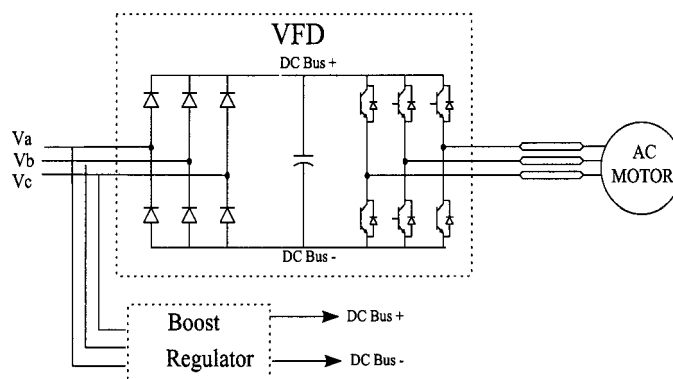


Figure 3 – Typical configuration for enhanced ride-through by a boost converter

Boost converters typically provide a ride-through capability for a 50% voltage sag on all three phases for 30 cycles, or ride-through capability for a voltage sag down to 37%, 37% and 67% of nominal in the respective phases for 30 cycles. Ride-through capability for deeper sags or for momentary interruptions can be provided by using energy storage options, such as battery or capacitors, with the boost regulator. These units are sized based on load kW rating and are available from sizes of 1 kW to 300 kW at a cost of \$100 to \$200 per kW.

Energy Storage Option

Energy storage for DC Bus

The principal energy storage element in a VFD is the DC bus capacitor. Typically the size of the DC bus capacitor ranges from 100-200 μ F/hp for smaller drives and 40-60 mF/hp for drives up to 500 HP size. This amount of capacitance usually will provide a ride-through from a couple of milliseconds to 10 ms for smaller drives under full load. However, since most of the voltage sags are much longer in duration than 10 ms, additional energy storage is required to provide ride-through for sags of longer duration.

A simple formula to calculate the amount of capacitor required to provide a ride-through for t seconds for a 460-V VFD is given by $C = I_{fl} \times t/60$, with C in farads and I_{fl} = full load current in amperes under rated load condition. For example for a 50 hp VFD supplying a motor load with full load current of 35 A, the amount of capacitance required for 0.5 s ride-through is $35 \times 0.5/60 = 0.291$ F. Obviously, the use of capacitors becomes impractical in size and cost as the power of the VFD increases. On an energy per volume basis, a battery has a much higher ratio than capacitors. In addition to the cost of the energy storage device itself, accessories such as enclosures, fuses, bus bars, fans and charging circuits are required for installing a DC bus energy storage system. Providing energy storage option for DC bus requires approval from manufacturers as in many cases connecting an energy storage system to the DC bus of VFDs may void the manufacturer's warranty.

Power Conditioning for AC Line

This is the most simple yet the most expensive solution. The cost may range from \$500 to \$1000 per kW and this in many cases will be more expensive than the drive system itself. Uninterruptible power supplies, magnetic synthesizers, motor-generator sets can be used for conditioning the AC line input to the drive so that the VFD does not see the voltage sag.

In some cases, where drives are integrated throughout the facility, a facility level power conditioning may prove to be more economical than fixing the problems at individual drive or component level. Contact your local utility to discuss possible options of facility-wide power conditioning that can be used for protecting the entire process from voltage sags, momentary interruptions, or other power quality problems.

Conclusions

Solving voltage sag related VFD tripping problems requires a coordinated approach where the customer, the utility, the manufacturer, and the system integrator all have specific roles to play. The problems is best tackled by following a systematic approach as outlined below:

1. Maintain a log of process upsets, with date, time, and fault codes, using a suitable power quality monitor to record the magnitude and duration of voltage sags at the equipment terminals if possible. Contact your local utility to determine if the characteristics and frequency of voltage sags that would be typical for the site are available.
2. Provide information to the VFD vendor on the full load current drawn by the load and the type of load, and request information on duration and depth of voltage sag that the VFD can tolerate under rated load condition. If the difference between the level of tolerance and the actual sags is within 5% to 50%, determine if the trip level can be reprogrammed by the manufacturer.
3. If the process does not require a precise speed and torque control, contact the VFD vendor to determine if enabling a flying restart option, or a ride-through by load regeneration option is available for the specific drive under consideration -- or if the option can be retrofitted to the existing VFD.
4. For processes that must maintain precise speed or torque control, where the typical voltage sag depth is less than 50% of nominal voltage for three-phase sags, or 37%, 37% and 67% for individual phases, the most cost-effective solution is using the boost converter circuit topology.
5. If the voltage sag depth is greater than the operating range of boost converters, and a precise speed and torque control is required, for a VFDs of less than about 15 hp, then a battery or capacitor type energy storage option for DC bus is suitable.
6. If the number and sizes of VFDs and the interconnection of other sensitive loads within the process make an individual component level solution too expensive or technically not feasible, then a facility-level power conditioning option should be looked into and a cost benefit analysis should be conducted.
7. Another system approach to this problem is to address the issue of overcurrent protection at the drive supply breaker. It is important that any overcurrent protection devices used will respond to true rms values because VFDs do draw non-linear currents, harmonics. Fuses and circuit breakers generally do not prevent all types of single-phasing conditions. Therefore, electronic phase-failure or voltage-unbalance relays may be required in addition to fuses or circuit breakers. VFDs will not tolerate sags, either single phase or three phase. In addition to nuisance tripping, there is the possibility of component failure. External relaying can overcome deficiencies in the drive itself for protecting the drive against sags. The more economical approach is to choose a drive that has this protection built-in. One advantage to using external protection is that you would know exactly what caused a trip if the drive diagnostics are lacking.