Input Power Quality

Issues and how to specify variable frequency drive for weak input line conditions

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Abstract

The vast majority of input power quality problems experienced by industrial customers can be attributed to voltage sags, harmonics, and transients. Frequently they result in process interruptions. Variable frequency drives are commonly used in the industry due to their energy savings benefits but when properly specified they can withstand and resolve most equipment issues caused by input power disturbances. Although there are many papers written on topic of power quality, this paper provides a holistic overview of the most common input power quality issues, and a synopsis of their impact on industrial process and equipment. The first purpose of this paper is to provide support to engineers when specifying drives for weak input line conditions, and then to identify various mitigation techniques required for low voltage and medium voltage drives.

Index Terms – *low voltage drive, medium voltage drive, voltage sag, transients, input harmonics, mitigation techniques*

I. Introduction

Power Quality is defined by IEEE 1100:2005 [1] as "the concept of powering and grounding electronic equipment in a manner that is suitable to the operation of that equipment and compatible with the premise wiring system and other connected equipment". The term power quality is now widely used, but clear criteria for measuring the quality of power still requires better definition. Typically, input power is considered to be high quality when it has a low level of power disturbances. The electrical power grid is designed to deliver power reliably, which is defined as maximizing power availability to customers. Most power quality issues are outside of the utility control. Many of the power quality problems do not originate from the utility system but may be the result of the facility's own power using equipment or the power use of a neighboring customer.

There are several types of power disturbances that can cause operational problems to industrial facilities. Some of these include surges, transients, sags, harmonic distortion, and momentary disruptions or outages. Almost half of the power quality issues come from voltage sags/swells and short interruptions caused by them. The next most common problems are harmonic distortion followed by transients [4].

It is not possible to avoid power line disturbances completely, but there are options for mitigating voltage and current deviations. With the knowledge to identify and mitigate power quality events, process reliability can be significantly improved.

II. Input Power Quality Problems Definition and Impact

A. Voltage Sag, Undervoltage Conditions and Interruptions

The power utilities are responsible for delivering voltage within the range of +/-10% of nominal value. Voltage sags are a temporary decrease in the voltage level below normal range. In case of 60Hz power system, the drop typically lasts at least 0.5 cycles to 30 cycles (8 milliseconds to 0.5 second) (figure 1). In the United States, typical voltage sag is 6-10 cycles (100-167 milliseconds) in duration and drops to less than 70% to 60% of nominal voltage in magnitude. The majority of voltage sags that occur are single phase (68%), followed by two phase (19%) and three phase (13%) [5]. Undervoltage conditions happen when this decrease in the voltage level extends for minutes or hours, as opposed to short-term voltage sag (figure 2).

A momentary interruption occurs when a supply voltage decreases to less than 10% of nominal for a period of time not to exceed 1 minute. These Interruptions are measured by duration since the voltage magnitude is always less than 10% of nominal. Typical duration for interruptions is 30-120 cycles (0.5-2.0 seconds) and depends on recloser fault clearing time [2].

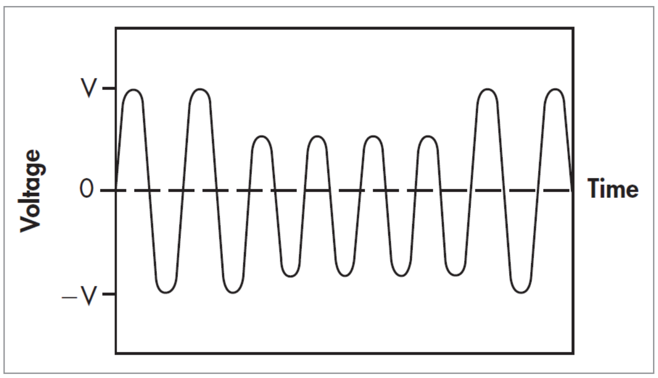

Figure 1. Voltage Sag

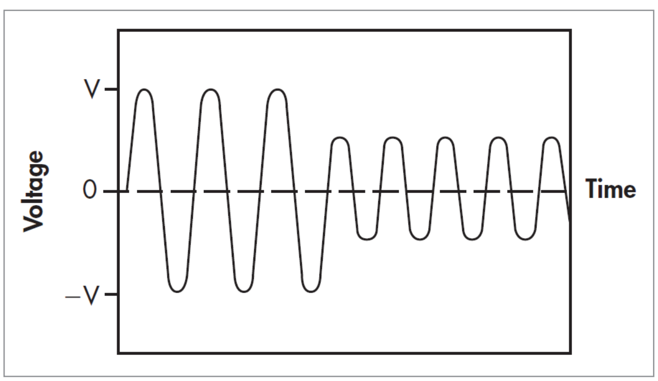

Figure 2. Undervoltage

A short voltage dip in the power supply can bring a process down within a second. A typical electric customer in the U.S experiences 40 to 60 sag events per year with those events resulting in the voltage dropping to between 60 to 90% and lasting several cycles to more than a second [5]. The impact of voltage sag, undervoltage and interruptions is typically related to loss of revenue such as flawed or off spec product or loss of revenue due to downtime that cannot be made up. The duration and severity of the sag depends on the following conditions:

- Distance to a fault
- Impedance of system upstream of the fault
- Feeder impedance
- Transformer connections between faulted system and customer electrical system bus
- How fast upstream protection device can clear the fault

B. Input Harmonics

A harmonic is a component of a periodic wave having a frequency that is an integer multiple of the fundamental power line frequency. The fundamental frequency is the lowest frequency in the waveform, generally the repetition frequency. For example, in the US distribution system, 60Hz is the fundamental referred to as the 1st harmonic, then the 2nd harmonic is 120Hz; the 3rd harmonic is 180Hz, etc. When the higher frequencies are added to the fundamental, it will result in a distortion of the fundamental waveform (figure 3).

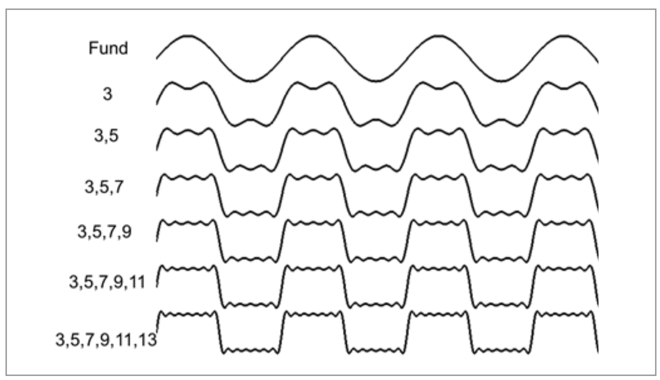

Figure 3. Square Wave Harmonic Content

The primary reason for harmonic distortion is non-linear loads. A load is considered "non-linear" if its impedance changes with the applied voltage. Due to this changing impedance, the current drawn by the non-linear load is also non-sinusoidal in nature, even when it is connected to a sinusoidal voltage source. Such loads draw non-sinusoidal currents from the power supply which, in turn, causes distortion in the voltage waveform at the point-of-common coupling (PCC). This distortion may impact other customers or equipment connected to the same power supply. Examples of the non-linear loads include:

- Non-incandescent lighting
- Dimmers
- Computers
- Uninterruptible power supplies
- Telecommunications equipment
- Static VAR compensators,
- Any device with a solid state AC to DC power converter
- AC or DC motor drives

The major impact of voltage and current harmonics is the increase of machine heating due to rise in iron losses, and copper losses: both are frequency dependent and increase with increased harmonics. The following are examples of equipment failure and misoperation caused by presence of harmonics in power system:

- Power Factor Capacitors Failure
- Erratic electronic equipment operation
- PLC lockups
- Overheating (motors, cables, transformers)
- Motor vibrations
- Audible noise in transformers and rotating machines
- Nuisance circuit breaker operation
- Voltage regulator malfunctioning
- Generator regulator malfunctioning
- Timing or digital clock errors – i.e. the farm feeds the chickens twice as often

In comparison with utility power supplies, the effects of harmonic voltages and harmonic currents are significantly more pronounced on generators (esp. stand-alone generators used a back-up) due to their source impedance being typically three to four times that of utility transformers.

IEEE 519-2014, "Recommended Practices and Requirements for Harmonic Control in Electric Power Systems," is the standard for harmonics in North America. Within this standard, recommended limits are provided for individual harmonics and total distortion. The goal is to limit harmonics at Point on a Public Power Supply System Coupling, defined as the utility/customer connection point, focusing on current distortion limits for the user and on voltage distortion limits for the supplying utility [3].

IEEE 519-2014 defines levels for Total Current Demand Distortion (TDD(I)). Most manufacturers' measure and show cumulative amount of harmonic distortion or Total Harmonic Current Distortion (THD(I)). IEEE requires distortion measured at 100% load at this point THD equals to TDD. Table I shows IEEE 519 recommended levels of Individual Current Harmonic Order, Odd Harmonics [3].

Table I. Individual Current Harmonic Order, Odd Harmonics (Percent)

ISC/IL	< 11	11 ≤ h < 17	17 ≤ h <23	23 ≤ h <35	35 ≤ h	TDD
< 20)	4.0	2.0	1.5	0.6	0.3	5.0
20 < 50	7.0	3.5	2.5	1.0	0.5	8.0
50 < 100	10.0	4.5	4.0	1.5	0.7	12.0
100 < 1000	12.0	5.5	5.0	2.0	1.0	15.0
> 1000	15.0	7.0	6.0	2.5	1.4	20.0

I_{SC} = maximum short-circuit current at PCC

I_L = maximum demand load current (fundamental frequency component at PCC

The above limits as per IEEE 519 apply to a distribution system with zero voltage imbalance and negligible pre-existing voltage distortion.

In order to prevent or correct input harmonic problems that could occur within an industrial facility, an evaluation of system harmonics should be performed if:

- A plant is expanded and significant non-linear loads are added: >20% of installed kVA.
- Power factor correction capacitor banks or line harmonic filters are added at the service entrance or close by.
- A generator is added in the plant as an alternate stand-by power source.
- The utility company imposes more restrictive harmonic injection limits to the plant.

C. Transients

Lightning strikes and utility capacitor switching are the most common events that cause transients in utility system. Voltage transients are sudden, one-shot, sub-cycle voltage disturbances of tens to hundreds of microseconds in duration and could be over 1000 V (figure 4).

Impulsive Transient is defined by IEEE 1159 as a sudden, non–power frequency change in the steady-state condition of voltage, current, or both that is unidirectional in polarity either primarily positive or negative [2]. It is normally a single, very high impulse like lightning. Impulsive transients are frequently referred to as surges and caused by lightning strikes. The strike can produce large amount of energy transfer with very short rise and decay times. These types of transients can have a 5ns rise time and have duration of less than 50ns.

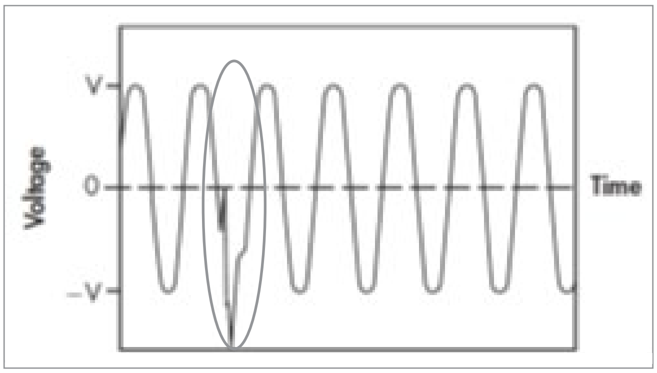

Figure 4. Impulsive Transient

On average, between 40 and 80 thunderstorms hit the areas along the Gulf Coast each year, while California and some states along the Canadian border have an average of fewer than 5 per year. It is easy to understand that surge protection of electrical equipment differs site to site but should not be dismissed during equipment evaluation. Transients caused by lightning are typically the most damaging ones. Lightning is not the only source of impulsive transients, other sources include:

- Line switching of heavy loads, large motors starting directly on line, or by operation of vacuum circuit breakers
- Welding equipment
- Clearing line short circuit faults
- Poor grounding

Oscillatory Transient (High Frequency Oscillations) is described as a sudden, non–power frequency change in the steady-state condition of voltage, current, or both that has both positive and negative polarity values (bidirectional) [2] (figure 5). Capacitive load switching is the most common cause of oscillatory transients. Shunt capacitors are applied on transmission systems, distribution feeders and at substations. They adjust the line voltage for differences between daytime and night time loading and may be switched on a daily basis. Energizing these capacitors causes a transient voltage between the capacitor and the power system inductance.

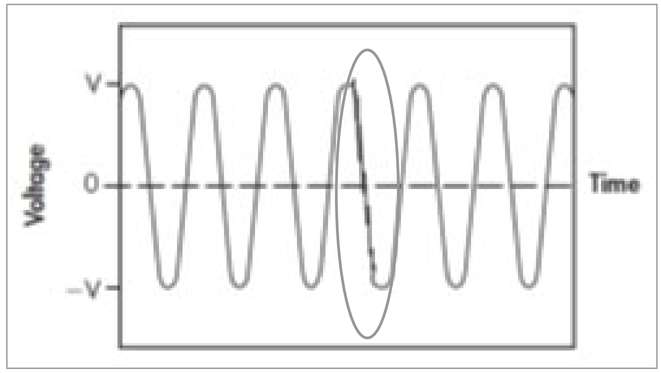

Figure 5. Oscillatory Transient

These transients can pass through the service transformer, feeders, and converter front-end of the drive directly to the dc link bus, where it will often cause a dc link overvoltage trip resulting in process interruption. They also can shorten the life of input diodes on drives reducing equipment life.

Whether a process stays online during a power quality event depends on the site specific equipment operating envelope and tolerances. Variable frequency drives (VFDs), when properly specified, can withstand and resolve most equipment issues caused by input power disturbances.

III. Low Voltage and Medium Voltage Drive Basic Operation and Definition

Advances in drive development give users many more options when selecting drive technology VFDs can be applied in low voltages (LV) in applications up to 2500 HP and medium voltage (MV) drives down to as low as 150 HP. The output voltage of a LV drive is typically less than 750 Volts, while MV drives are typically available in output voltages up to 13.8 kV.

There is an overlap in power range where both LV and MV drives can be applied. The motor crossover from low voltage to medium voltage is in the 200 to 500 HP range. This creates cases when a customer considers both low voltage and medium voltage drives. The solution will often depend on multiple criteria; the list below includes but is not limited to:

- Available Input Power: stiff or weak
- Available site distribution: low or medium voltage
- Frequency of power quality issues
- How critical the application is
- Cost impact of interruption

There are several VFD circuit configurations or topologies available in the market place for both low voltage and medium voltage solutions. This paper will examine the two most commonly used configurations: 6 pulse 2 level diode bridge low voltage inverter (figure 6) and a multilevel H-Bridge medium voltage inverter (figure 7). A variable frequency drive controls the speed of an AC motor by varying the frequency supplied to the motor. The drive also regulates the output voltage in proportion to the output frequency to provide a relatively constant ratio of voltage to frequency, as required by a motor to produce adequate torque.

There are three steps in a basic voltage source drive operation. Power first goes into the rectifier, where the 3-phase AC is converted into a DC voltage. Next a DC capacitor smooths and holds the DC voltage at a constant level for the inverter. The last step is when the inverter takes the DC voltage and converts it back to AC voltage by using IGBTs to create a PWM output voltage. These basic steps are the same for LV and MV drives. The multilevel H-Bridge medium voltage inverter circuit consists of 2 level diode bridge low voltage inverters connected in series to produce MV output (figure 7).

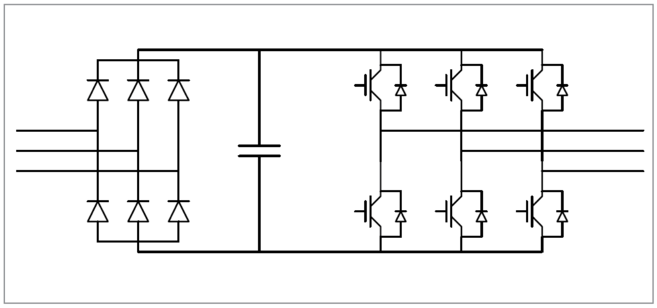

Figure 6. 6 Pulse 2 Level Low Voltage Inverter

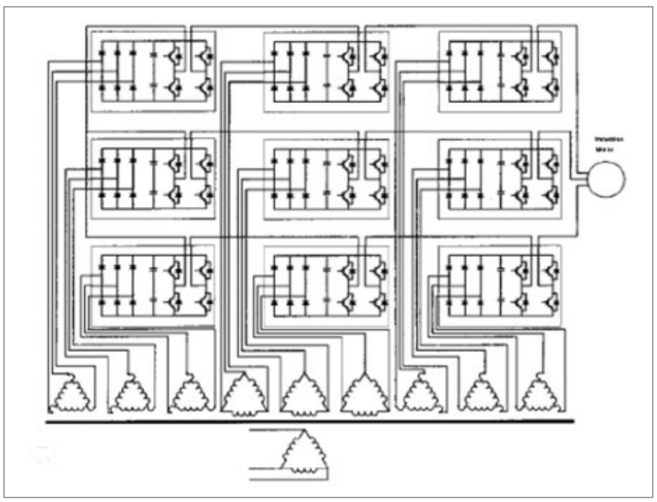

Figure 7. Multilevel H-Bridge Medium Voltage Inverter

IV. Drive Performance during Input Power Quality Issues and Mitigation Techniques

While it is the utility's responsibility to provide a good quality supply system, with correct specifications, application design and parameter settings help to minimize or avoid damage to equipment from input line issues. This section will review low voltage and medium voltage drive performance capability during common power quality issues described in this paper and mitigation techniques.

A. Voltage Sag, Undervoltage Conditions and Interruptions VFD Performance and Mitigation Techniques

Voltage sags cause a decrease of the DC Bus voltage in the VFD. During very brief sags it may be possible to supply the energy from the DC Bus capacitor. During longer sag periods, the DC Bus voltage will drop to a lower level. If this falls below the DC Bus trip voltage then the inverter will trip. Usually, most of the damage caused by voltage sag to equipment occurs after the sag has cleared. There are large voltage and current transients present in the system as it returns to normal. At this time the drives' DC Bus voltage is low due to the sag, and once full voltage is available, the DC Bus capacitor would draw a large current as it recharges.

At full speed, a low voltage 6 pulse 2 level VFD can provide regular operation for dips between 90% (most manufacturers) and 85% of nominal voltage. After the voltage gets below the manufacturer's specified levels for normal operation, the VFD starts to drop its maximum output down from 100%. The drive continues to operate but at a lower torque and speed level during these conditions. AC drives have considerable capability to ride through voltage sag, because they store energy on their dc bus capacitors and can make use of the energy stored in the load's inertia.

When the input voltage drops below VFD's tolerance level, the drive switches to ride-through mode. The torque will be reduced to zero or even small negative values in order to support the dc-link with energy. This prevents large inrush currents and voltage overshoots when the input voltage comes back and also keeps the induction motors magnetized [6]. The technique is known as kinetic recovery or buffering. The advantage is that the VFD doesn't have to trip and is able to re-accelerate the motor immediately after the distortion is cleared. The crucial point is that the rotational mass does not drop under the mechanical system's minimum speed or even come to a stop during the dip.

The voltage sag tolerance and ride through of momentary interruptions of the LV VFD depend on the amount of capacitance available in the DC link. The tolerance level varies from manufacturer to manufacturer and ranges from 90% to 75% of nominal input voltage. The LV drive monitors line voltage at the dc bus. Its control and fan power is derived from that bus as well. This allows VFD to operate during line voltage sag as long as the dc bus holds up. The more capacitance a drive has, the more tolerant it is to voltage sags.

At full speed, a multilevel H-Bridge medium voltage inverter provides regular operation for dips down to 90% of nominal voltage. After that the VFD output power is rolled-back linearly from 100% power at 90% of input voltage down to 50% power at 65% of nominal input voltage. Output power is reduced by limiting the available motor torque. The VFD can operate continuously in this mode. When the input voltage falls below 65%, then the power is quickly reduced to a slightly negative value (regenerative limit) (figure 8). This limit forces the drive to absorb power from the motor and maintain the DC bus voltages in case the input voltage recovers during MV ride-through. The limit is implemented as an inverse function of speed in order to maintain constant power flow to the DC-bus.

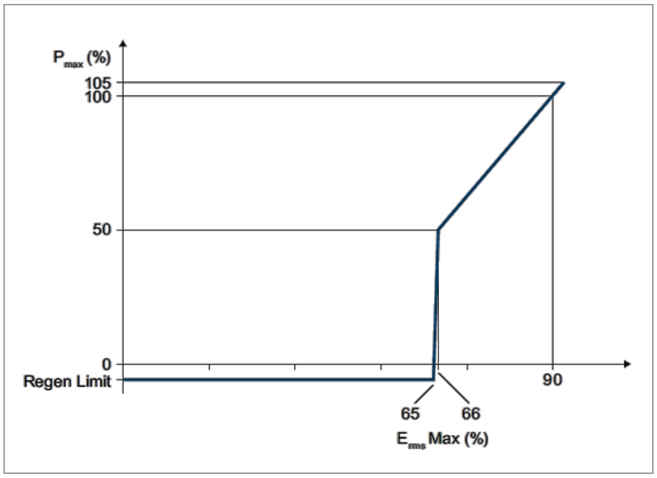

Figure 8. Drive Power (Pmax) as a Function of Input Voltage Magnitude (Erms)

The voltage sag tolerance and the duration of ride through of momentary interruptions of the Multilevel H-Bridge medium voltage inverter depends on the amount of capacitance in DC link. Depending on the manufacturers' design implementation, some MV inverters in this configuration are capable of operation down to 65% of nominal input voltage while others only down to 80%.

The multilevel H-Bridge medium voltage inverter by design has significantly more capacitance compared to 6 pulse 2 level low voltage inverter and as such can provide a longer power loss ride through. When the input voltage falls below 65% (or other limit defined by manufacturer), the multilevel H-Bridge medium voltage inverter will ride-through without tripping up to 500 milliseconds. During ride-through the motor voltage is maintained but no torque is produced until the input VFD voltage is re-established. The drive provides only magnetising current to a motor leaving energy stored in the DC link to generate output voltage. Automatic restart into spinning load is possible with no load or line disturbance as long as the motor flux is present.

Most medium voltage VFDs require a separate low voltage input for control and auxiliaries provided by the customer and are backed up by UPS. In the case where a UPS is not available the manufacturer has the option to incorporate a UPS into the drive design to ensure smooth performance during voltage sag and undervoltage conditions. Table II provides overview of LV and MV VFD input voltage sag, undervoltage and momentary interruptions capabilities.

Table II. VFD Performance Comparison

	6 pulse 2 level low voltage inverter	Multilevel H-Bridge medium voltage inverter
Continuous Input Line Tolerance	+110% and 90/ 85%*	+110/120%* and 90%
Voltage Sag	85% to 75% of nominal voltage*	80 to 65% of nominal voltage*
Undervoltage (Brownout)	Depending on load's inertia 0.5 to 5 seconds*	Independent of load's inertia Continuously - drive can operate with reduced motor torque*
Momentary interruption	15-16 milliseconds at full load*	80-500 milliseconds at full load*

**Defined by manufacturer*

B. Input Harmonics VFD Performance and Mitigation Techniques

The input harmonics produced by the VFD semiconductors in steady state condition of operation are called dominant or characteristic harmonics and expressed in Equation (1) as:

$$h = np \pm 1 \quad (1)$$

where

h	order of harmonics;
n	an integer 1, 2, 3, ... ;
p	number of 6 pulse rectifiers

The VFD harmonic spectrum depends on the number of pulses; the harmonic spectrum looks different for a 6-, 12- or 18-pulse VFDs. In balanced system even harmonics and harmonics divisible by 3 are not generated by 3 phase diode bridges. The harmonic spectrum (dominant harmonics) based on number of VFD pulses:

- 6 Pulse: 5, 7, 11, 13, 17, 19, 23, 25, 29, 31, 35, 37...
- 12 Pulse: 11, 13, 23, 25, 35, 37...
- 18 Pulse: 17,19,35,37...

The above mentioned characteristic harmonics are for an ideal steady state operation of the drive and assuming the power supply network is symmetrical and free from harmonics. In the real world conditions, the supply networks or connected equipment never follow the ideal environment and therefore, the actual measured harmonics would not be exactly as calculated from Equation (1).

Generally, the magnitude of the harmonics decreases as the harmonic order increases: lower harmonic orders have the higher magnitudes (figure 9). Other factors that impact magnitude of the harmonics include:

- The percentage of the total power system capacity compared to VFD capacity
- The stiffness or short circuit capacity of the power system supplying a VFD
- Whether or not the VFD is electrically isolated from other sources of harmonics
- The installation practices for a VFD

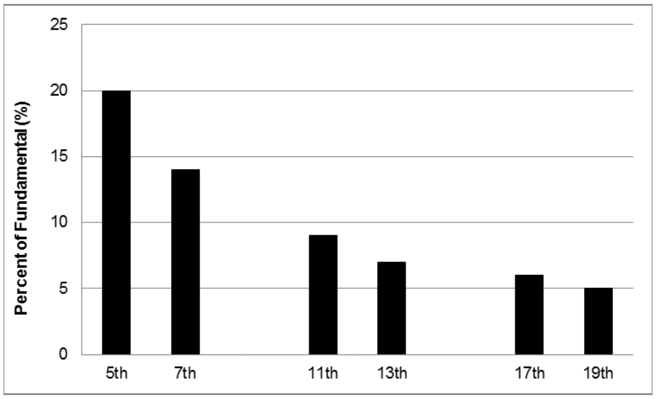

Figure 9. Theoretical harmonic magnitude (per unit) quasi square wave

One of the possible effects of input harmonics is power factor capacitors failure. When the harmonic spectrum exhibits abnormal magnitudes (figure 10), it is a good sign of harmonic resonance. Typically it is caused by interaction with power factor correction capacitors. Due to their lower impedance, capacitors are more susceptible to higher order harmonics. At a given harmonic frequency in any system where a capacitor exists, there will be a point where the inductive and capacitive reactances are equal. This point is called the parallel resonant point. Every system with a capacitor has a parallel resonant point [7]. If not protected from harmonic stress, the capacitor lifetime will be shortened.

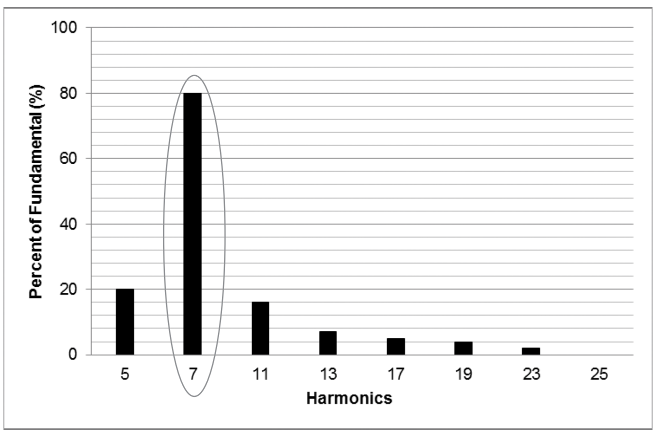

Figure 10. Exhibit of abnormal harmonic spectrum magnitudes

There are solutions available to mitigate the harmonic issues created by low voltage and medium voltage drives. When evaluating various alternatives, the preferred method will depend on the user's objectives as well as the severity of harmonics contributed by internal loads. The typical list includes but not limited to:

- Increase number of pulses
- DC Choke
- Line reactors
- Passive harmonic filters
- Active harmonic filters

Increasing the number of pulses in a drive has a direct impact on the current distortion factor and thus on the harmonics in the power system. Drives with 12- or 18- pulse configurations extend the first characteristic harmonic from 5th in 6-pulse configuration to the 11th or 17th respectively.

The benefit of the 12 pulse solution is that it almost completely cancels 5th and 7th harmonics and the 18-pulse almost completely cancels 5th, 7th, 11th, and 13th harmonics [8]. In order to make the 12- or 18-pulse option work correctly, a phase shift transformer is required.

In ideal conditions 5th and 7th harmonics would be 0 (a perfect cancellation) for 12- and 18-pulse systems, in the real world, the perfect cancellation is not achievable due to transformer limitations and tradeoffs. In order to achieve harmonic cancellation, the individual 3-phase sets of voltages must meet two criteria:

- The voltages must all have the same amplitude;
- The voltages must be phase shifted by 60/n where n is the number of 6-pulse rectifiers. For example, for an 18-pulse system n=3 and the phase shift is 20 degrees so we have one set at -20, one set at 0 and the third set at +20 degrees.

To meet these constraints the transformer turns numbers have to be chosen according to a trigonometric formula, and this usually results in a non-integer number of turns. It's not practical to have fractional turns, so the nearest integer number of turns is chosen. This causes errors in the amplitude and phase, which degrade the accuracy of the harmonic cancellation. Despite of imperfect cancellation, the level of 5th and 7th harmonics for both 12- and 18-pulse system is very small compared to 6 pulse configuration (table III).

Table III. Typical Values of Harmonic Currents for Different Types of Front Ends

Harmonic order (h)	6-pulse* (stiff source)	12-pulse*	18-pulse*
5	80.0%	3.7%	0.6%
7	58.0%	1.2%	0.8%
11	18.0%	6.9%	0.5%
13	10.0%	3.2%	0.4%
17	7.0%	0.3%	3.0%
19	6.0%	0.2%	2.2%
23	5.0%	1.4%	0.5%
25	2.5%	1.3%	0.3%
ITHD	101.5%	8.8%	3.9%

**Relative short circuit ratio of the power system is assumed to be between 20 to 50*

When a preferred solution is 6-pulse diode bridge system, the input harmonics mitigation solution would depend on customer specifications. In many cases, if not clearly specified, the solution would be manufacturer's default option which may or may not meet all requirements of a site and a load.

A DC choke is comparable to an equivalent AC-side line reactor, although the % ITHD is somewhat less. The DC choke provides a greater reduction primarily of the 5th and 7th harmonics but not so much for higher order. This option provides the most economical solution; it is integral to the VFD design and provides less voltage drop than an equivalent line reactor. The limitation of the DC choke is its impedance that is typically fixed by design and not field selectable.

A Line Reactor is a 3-phase series inductance on the line side of a drive. If a line reactor is applied on all VFDs, it is usually possible to meet IEEE guidelines depending on the stiffness of the line and the value of line reactance. It is the most common solution used by low voltage drive manufacturers. It is located between the drive and the power supply. Table IV shows the impact of reactor size on the reduction of current distortion: 3% and 5% reactors are the most commonly used [8].

Table IV. Effect of Line Reactors on Current Distortion

Harmonic order (h)	Reactor Size	
	3%	5%
5	40%	32%
7	15%	9%
11	5%	4%
13	4%	3%
17	4%	3%
19	3%	2%
23	2%	1.5%
25	2%	1%
THD	43.6%	33.9%

* *Relative short circuit ratio of the power system is assumed to be between 20 to 50*

The line reactor does reduce the harmonic noise, but it also reduces the voltage going to the drive. This reduced voltage might be a problem when the drive is used at maximum load and maximum speed. The motor can become voltage starved. This might require the VFD to be a size larger to avoid nuisance tripping. Line reactors greater than 5% are not recommended due to voltage drop, ex: a 3% line reactor will lead to an output voltage drop of somewhat less than 3% when passing full rated current. The larger the reactor the large the drop it will generate.

A passive harmonic filter is typically an inductor connected in series with capacitors. It is also known as a tuned filter because it will absorb whatever harmonic it is designed to filter out based on the values of the inductor and capacitor(s), typically the 5th or 7th harmonics. It is a relatively low-cost solution. There are several benefits that a passive filter provides compared to the DC choke or the line reactor. The first one is the ability to install a single filter to compensate for multiple drives. Depending on design, the other is the ability to provide power factor correction [9].

One of the limitations of this solution is that it cannot absorb other harmonics that it is not designed to, and it cannot adapt to changes in the electrical system. Therefore, if other harmonic frequencies need to be filtered, additional passive filters tuned to absorb those frequencies will have to be added. If a passive filter is determined to be the best solution for a facility, a harmonic study of the facility will need to be performed in order to design a filter to suit your needs.

Active filters have similar benefits to passive filters such as power factor correction and a single unit can compensate for several VFDs. The key differentiation is its dynamic response. Active filters are a great solution when the offending harmonic frequencies are changing throughout the day. The active filter injects equal and opposite currents to cancel harmonic currents. It cannot be overloaded. If the network's harmonics are greater than what the filter can correct for, the filter will supply its maximum harmonic-canceling current. If further reduction is necessary, multiple units can be connected in parallel to increase compensation. The disadvantage of this solution is higher cost compared to the other methods, its size and complexity [8].

While low voltage drives require additional measures to improve input harmonics, multilevel H-Bridge medium voltage inverter as a minimum has 18-pulse diode front end configuration with built-in phase shifting isolation transformer due to its topology requirements (figure 7). Regardless whether it is low voltage or medium voltage VFD the 18-pulse solution meets IEEE 519 requirements.

C. Voltage Transients

During a voltage transient event the VFD's DC bus capacitors attempt to charge to the peak of the transient line voltage, possibly resulting in an overvoltage fault or possibly damage to the input diode front-end. When overvoltage trips occur at the same time of day it may be caused by input line transients. For example, if it happens early in the morning, transients are the result of capacitors being switched in response to increased load demand. The smaller the VFD and lighter the load, the more susceptible they are to overvoltage tripping due to capacitor switching transients.

For the low voltage drives, AC line reactors provide some protection against the oscillatory transient caused by capacitor switching. Reactors provide some voltage drop as well as a limit to surge current. The required reactance depends on the source impedance, transient magnitude and trip level of the drive. A 3% reactor based on the drive's kVA rating normally is enough. If a VFD is designed with the dc link choke it does not provide protection against transients. The drive would need additional equipment such as metal oxide varistors (MOV) to protect against these [9].

In the case of impulsive transients neither the input line reactors nor the dc link choke provides any significant surge protection. In such cases a MOV is necessary for protection against line-to-ground surges regardless of whether a dc link choke or an input line reactor is used [10].

Since the multilevel H-Bridge medium voltage inverter requires a phase shifting isolating transformer it provides galvanic isolation from the input line transients. This transformer has a BIL rating based on input voltage; higher rating is available on request if required by the environment. The transformer is rated for traveling wave voltage surge capability by the impulse test. The Impulse test is most common and consists of applying a full-wave voltage surge of a specified crest value to the insulation of the equipment involved. This rating can be increased if the customer site requires it. In addition to the BIL test, the transformer has surge arresters to limit the magnitude of impulse waves. The transformer is protected from the excessive peak voltage by lightning arrestors.

V. Conclusion

In order to ensure that equipment meets your site requirements, it is recommended to conduct a site power survey and work with a drive manufacturer to create a cost/benefit analysis to ensure the VFD designed for your specific needs that may significantly differ from other site locations. Working with the electric utility provider when unexplained process interruptions occur will better assist the facility in finding and correcting problems. The utility provider has the ability to generate a report that can help to determine the severity of the events that can affect your plant. It also makes it easier to consider the cost impact of poor input power quality on your process, and in turn, justify the investment needed to improve immunity through the industrial facility.

The goal of this paper is to provide an overview of the more popular options available, their benefits and limitations that should be considered when addressing input power quality issues. The solution for how to protect a drive or other equipment from voltage sags, harmonics and transients is often site dependent and the whole system should be taken into account when evaluating each drive proposal.

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VII. VITA

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