

How adjustable speed drives affect power distribution

Application Note

Adjustable speed drives (ASDs) can be both a source and a victim of poor power quality.

ASDs as victim loads

Although ASDs are usually depicted as the culprit in the PQ scenario, there are ways in which they can be a victim load as well.

Capacitor switching transients

High-energy (relatively low-frequency) transients that are characteristic of utility capacitor switching 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 over-voltage trip. Input diodes could also be blown out by these transients.

Voltage distortion

If high-voltage distortion shows up as excessive flat-topping, it will prevent dc link capacitors from charging fully and will diminish the ride-through capability of the drive. Thus a voltage sag which would not normally affect a drive will cause the drive to trip on undervoltage.

Improper grounding will affect the internal control circuits of the drive, with unpredictable results.

ASDs as culprit loads

A drive can definitely be a “culprit load” and have a major impact on system PQ. But before we talk of problems, let’s put in a good word for the positive effects of drives on PQ. First of all, they offer built-in soft-start capabilities. This means there will be no

inrush current and no voltage sag effect on the rest of the system. Secondly, if the drive is of the PWM type, with a diode converter front-end, the Displacement Power Factor is high (commonly > 95 % at rated load) and more or less constant throughout the range. This means that drives can reduce energy usage and correct for DPF at the same time. It’s a good thing too, because drives and PF correction capacitors don’t mix. Caps are vulnerable to the higher frequency harmonic currents generated by drives, since their impedance decreases as frequency increases.

The type of drive has a major impact on the PQ symptoms, because of the different converter designs (converters or rectifiers turn ac to dc and are the first stage of the drive). There are two major types of converter design.

Line-side measurements on ASDs

Measurement	Look for
Voltage waveform	<ul style="list-style-type: none"> • Voltage notching (SCR converters) • Flat-topping
Harmonic spectrum	Harmonic orders and amplitudes, before and after filter application
Displacement PF	For PWM drives, DPF should remain high even at low speeds (it will typically decrease slightly)
Voltage unbalance	Less than drive manufacturer specs, or current overload trips can result. The drive may have a higher limit for unbalance than the motor.

SCR converter with Voltage Source Inverter/ Variable Voltage Inverter (VSI/VVI) drives

Commonly called six-step drives, they use SCRs (Silicon - Controlled Rectifiers) in their converter front-ends (the following discussion applies to CSI, Current Source Inverter drives, which also use SCRs). VSI and CSI drive designs tended to be applied on larger drives (> 100 HP). SCR converters control the dc link voltage by switching on (or “gating”) current flow for a portion of the applied sine wave and switching off at the zero-crossing points. Unlike diodes, SCRs require control circuits for gate firing.

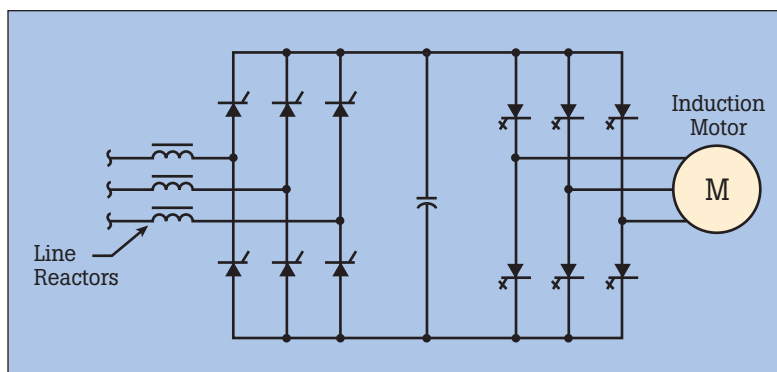


Figure 1. Voltage Source Inverter (VSI) ASD.

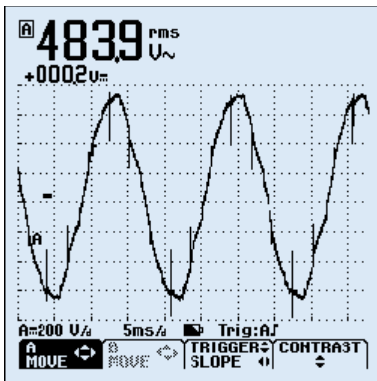


Figure 2. Voltage notching.

For the SCR converter, there are three main issues that affect line-side PQ:

- Commutation notches. SCR switching or commutation is such that there are brief moments when two phases will both be “ON.” This causes what is in effect a momentary short circuit that tends to collapse the line voltage. This shows up as “notches” on the voltage waveform. These notches cause both high V-THD and transients. The solution is to place a reactor coil or isolation transformer in series with the drive’s front end to clean up both problems.
- Displacement Power Factor declines as drive speed decreases. This is not as serious a problem as it sounds, because the power requirement of the drive-motor-load decreases even more.
- Harmonic currents, typically the 5th and 7th, are generated by VSI drives.

Diode converter with Pulse Width Modulation (PWM) drives

The other and more common converter design uses diodes and is used in the PWM drive. The diodes require no switching control circuitry. One of the main trends in the industry has been the proliferation of PWM drives, mainly due to the continued development of fast-switching, efficient IGBTs (Insulated Gate Bipolar Transistors) used in the inverter section of the drive (inverters turn dc to ac). For all practical purposes, PWM drives are the industry standard.

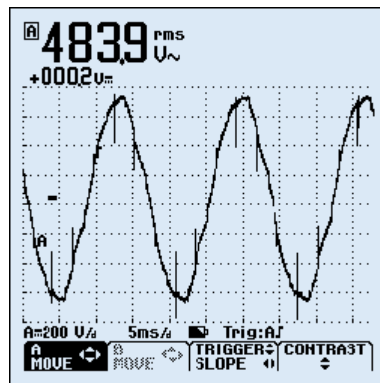


Figure 3. Typical ASD harmonic waveform.

For the diode converter, the main PQ issue is harmonics. The actual harmonic orders being generated depend on the number of diodes in the front end. For three-phase conversion, a minimum set of six diodes is required. This “six-pulse” converter will generate 5th and 7th harmonics.

If a 12-pulse converter were used, the 11th and 13th harmonics will be generated instead of the 5th and 6th – and, very importantly, for the same load, the amplitude of the 11th and 13th would be considerably less than the 5th and 6th. Therefore, the THD would be less. The vast majority of drives, however, are six-pulse PWM style, which is one reason we see so much 5th harmonic on the system.

Harmonics solutions

There are a number of solutions to mitigating drive-generated harmonics:

Harmonic trap filters (Figure 5)

These are typically LC networks connected in parallel at the source of the harmonics (in other words, at the drive input). They are tuned to just below the 5th harmonic (typically 280 Hz) and will tend to sink both 5th and much of the 7th harmonic. Obviously, they must be sized to the harmonic-generating load.

Phase-shift transformers

This can be as simple as a delta-wye transformer feeding one drive(s) and a delta-delta feeding another drive(s). There is a 30 degree phase shift effect between these two configurations, which effectively results in cancellation of harmonics at the closest upstream PCC (Point of Common Coupling). The cancellation effect is optimal when both loads are more or less equal.

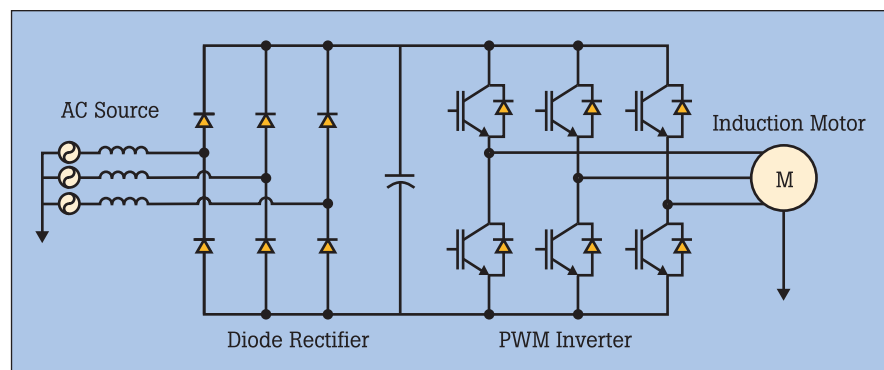


Figure 4. Pulse Width Modulated (PWM) ASD.

12-pulse converter

If the delta-wye/delta-delta are packaged together (delta primary, delta and wye secondary) and each secondary feeds one of two paralleled six-pulse converters, a 12-pulse front-end is created with all the benefits mentioned above. 18-pulse designs are also available. Because of the extra cost, this type of solution tends to only get used on high HP loads.

Active filters

This relatively new technology is based on an elegant concept – using power electronics to solve the problems created by power electronics. It senses the instantaneous ac sine wave; it then actively cancels the harmonics it detects by generating equal and opposite polarity harmonics, thus recreating the sine wave.

Commercial packages might provide voltage regulation as well.

Active PF correction

Another recent solution is for manufacturers to offer converter front ends using fast switching technology that generates a minimum amount of harmonics and has near unity power factor (both Total PF and DPF).

There is room for discussion on which approach to harmonic mitigation might prove most effective and economical in a particular situation. However, what is often overlooked by the end-user, and what should be clear from the information in this section, is that the total cost of a drive system should include both the cost of the drive itself and the harmonic mitigation (whether part of the drive or installed separately).

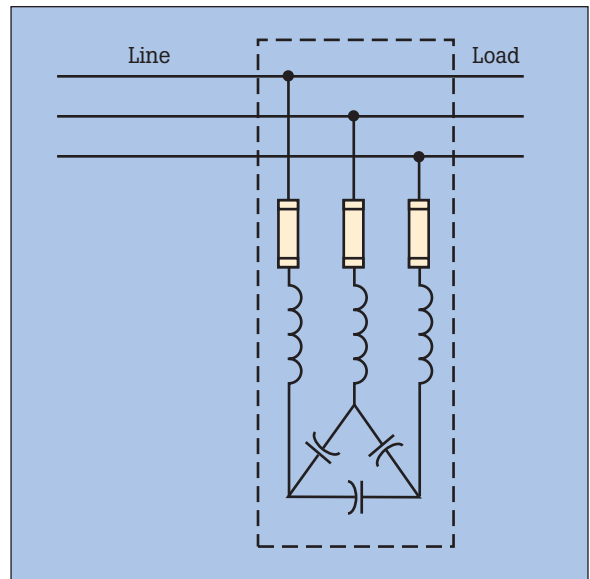






Figure 5. Harmonic trap filter.

Why True-rms

True-rms test tools are necessary for accurate measurements of distorted waveforms. For more information, see the Fluke application note *Why True-rms*, document number 1260729.

A comparison of average-responding and true-rms multimeters

Waveform	Description	Multimeter Reading	
		Average-sensing DMM	True-rms DMM
	Sine wave	Correct	Correct
	Square wave (flat-top voltage)	10 % high	Correct
	Current to single phase diode rectifier	40 % low	Correct
	Current to 3 phase diode rectifier	5-30 % low	Correct

Power system resonance

Hot vibes can result when harmonics and capacitors get together

Is it possible to install “Power Factor Correction Capacitors” and have PF get worse? It certainly is, and a starting place to understanding this puzzle lies in the distinction between Displacement PF (DPF) and Total Power Factor (PF). The penalty for not understanding the difference can be blown capacitors and wasted investment.

Total PF and Displacement PF are the same in one basic sense: they are the ratio of Real Power to Apparent Power, or Watts to VA. DPF is the classic concept of power factor. It can be considered as the power factor at the fundamental frequency. Total Power Factor, abbreviated to Power Factor (PF), now includes the effects of fundamental and of harmonic currents (it is also referred to as True PF or Distortion PF, Figure 7). It follows that with the presence of harmonics, PF is always lower than DPF and is also a more accurate description of total system efficiency than DPF alone.

Strictly speaking, the term “Power Factor” refers to Total PF, but in practice can also be used to refer to DPF. Needless to say, this introduces some confusion into discussions of power factor. You have to be clear which one you’re talking about.

Displacement power factor

Lower DPF is caused by motor loads which introduce the need for Reactive Power (Volt-Amp Reactive or VARs). The system has to have the capacity, measured in Volt-Amps (VA) to supply both VARs and Watts. The more VARs needed, the larger the VA requirement and the smaller the DPF. The cost of VARs is accounted for in a power factor penalty charge. Utilities often levy additional charges for DPF below a certain level; the actual number varies widely, but typical numbers are 0.90 to 0.95.

To reduce VARs caused by motor loads, power factor correction capacitors are installed. Upstream system capacity, both in the plant and at the utility level, is released and available for other uses. (Figure 6)

Historically, this has been the gist of the PF story: a relatively well-known problem with a relatively straightforward solution.

Harmonics and capacitors

Harmonics have had a dramatic impact on our approach to Power Factor correction. The motor and capacitor loads described above are all linear and for all practical purposes generate no harmonics. Non-linear loads such as ASDs, on the other hand, do generate harmonic currents.

Take a plant which is step-by-step putting adjustable speed drives on its motor loads. ASDs generate significant harmonic currents (5th and 7th on six-pulse converter drives). Suddenly the fuses on existing PF correction caps start blowing. Since these are three-phase caps, only one of the three fuses might blow. Now you’ve got unbalanced currents, possibly unbalanced voltages. The electrician replaces the fuses. They blow again. He puts in larger fuses. Now the fuses survive, but the capacitor blows. He replaces the capacitor. Same thing happens. What’s going on? Harmonics are higher frequency currents. The higher the frequency, the lower the impedance of a cap ($X_C = 1/2\pi fC$). The cap acts like a sink for harmonic currents.

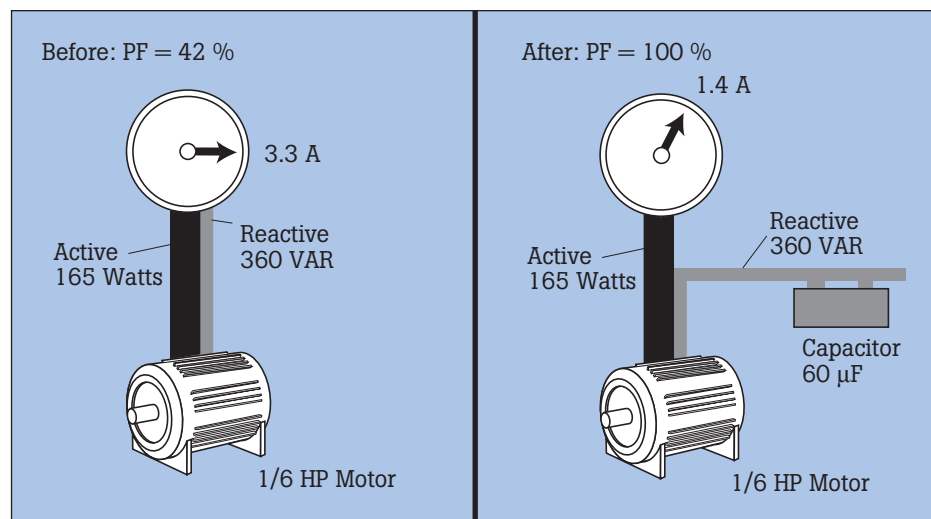


Figure 6. Capacitor corrects Displacement Power Factor (DPF).

Power system resonance

In a worst-case scenario, the inductive reactance (X_L) of the transformer and the capacitive reactance (X_C) of the PF correction cap form a parallel resonant circuit: $X_L = X_C$ at a resonant frequency which is the same as or close to a harmonic frequency. The harmonic current generated by the load excites the circuit into oscillation. Currents then circulate within this circuit which are

many times greater than the exciting current. This so-called “tank circuit” can severely damage equipment, and it will also cause a drop in power factor. Perversely, this resonant condition often appears only when the system is lightly loaded, because the damping effect of resistive loads is removed. In other words, we have what the audio buffs call a “high Q” circuit. (Figure 8)

Imagine coming to work on a Monday and seeing the insulation on your cables melted off. How can this happen over a weekend when there was hardly any load on the system? Has Ohm’s Law been overruled? Not quite. Your power system just spent the weekend tanked out on the Harmonics. It was quite a party, but now comes the clean-up.

Start with harmonics mitigation

The correct solution path starts with measuring and mitigating the harmonics generated by the drives. Harmonic trap filters would generally be called for. These trap filters are installed locally on the line side of the drive. Their effect is very much like the traditional PF correction cap, in two senses: they reduce DPF as well as PF, and also they localize the circulation of the problem harmonics (generally the 5th). Harmonics mitigation and traditional DPF correction should be addressed as one systems issue. In other words, manage Total PF, not just DPF.

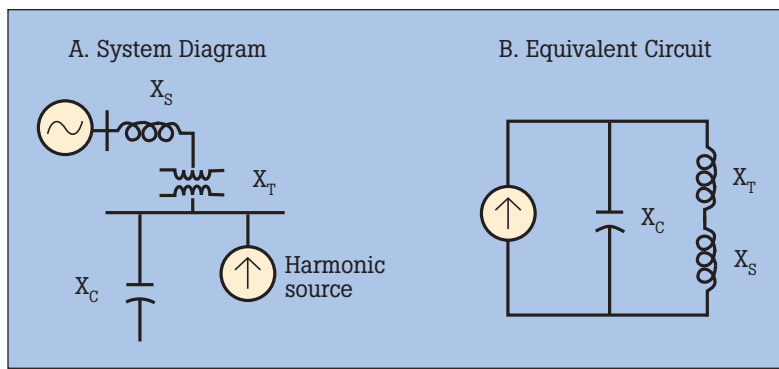


Figure 8. Resonant circuit when $X_C = (X_T + X_S)$

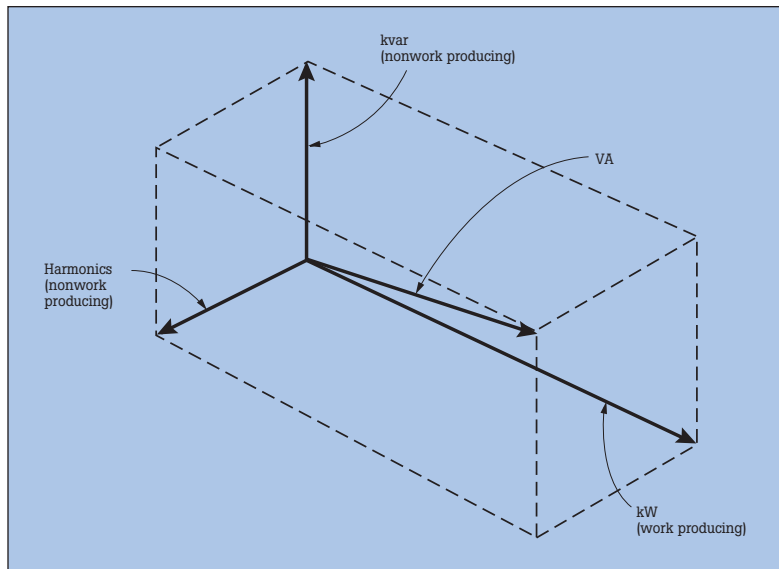


Figure 7. Total Power Factor increases with harmonics.

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