

**Power Line Harmonics
and Installation Considerations
For AC and DC Drives**

Application Note

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Title	Power Line Harmonics Considerations for DC Drives and AC Drives				

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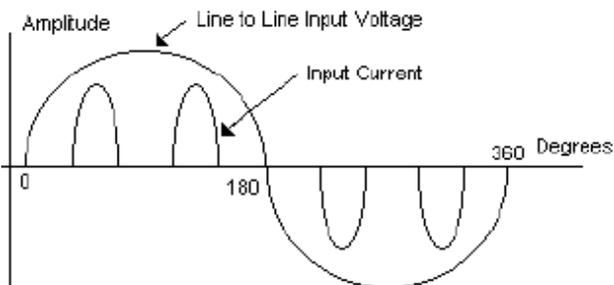
Power Line Harmonics and Installation Considerations For AC and DC Drives

This paper discusses the differences between DC and AC drive rectifiers and compares several harmonic mitigation methods for AC drives. DC drive Retrofit considerations are also discussed.

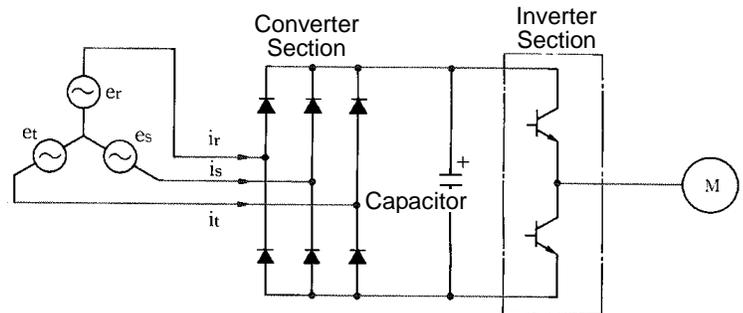
It is known that harmonic currents on an AC power line can be caused by the rectifier switching circuits in inverters. Harmonics are defined as currents or voltages with frequencies that are integer multiples of the fundamental power frequency. This harmonic current of AC drives can be controlled by adding an AC line reactor (ACL) or a DC link reactor (DCL) to the power circuit.

Yaskawa F7 Drives provide a built-in bus choke above 30HP as well as 12-pulse rectification above 30HP which can reduce input current harmonic distortion by over 90%. Yaskawa F7 drives 25 HP and below offer an optional DC Link choke. The Yaskawa F7 drive meets or exceeds generally accepted power quality standards. Phase-to-phase, phase-to-neutral, short circuit and ground fault protection are provided in the F7 drive. These features are useful when retrofitting a SCR based DC drive.

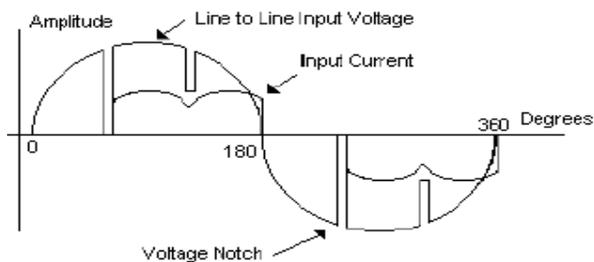
Diode Rectification – Pulsed Current, Increases Current Distortion



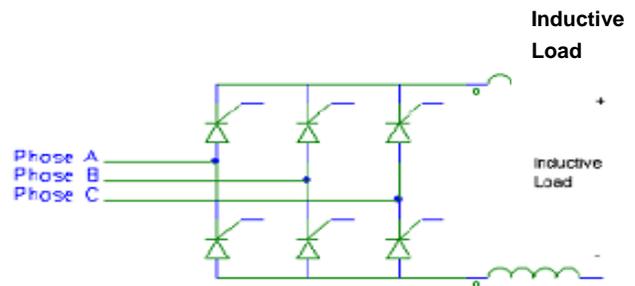
AC Drive - Diode Rectifier



SCR Rectification - Line Notching, Increases Voltage Distortion



DC Drive - SCR Based



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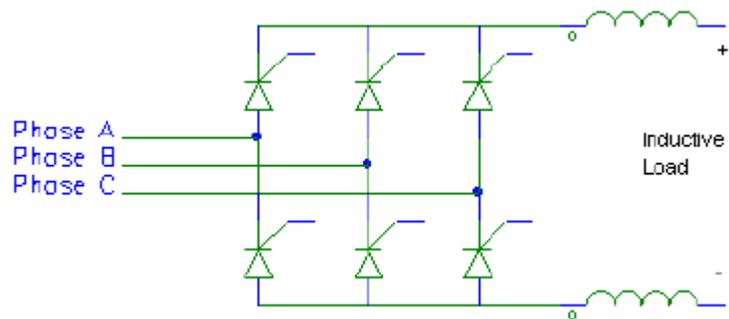
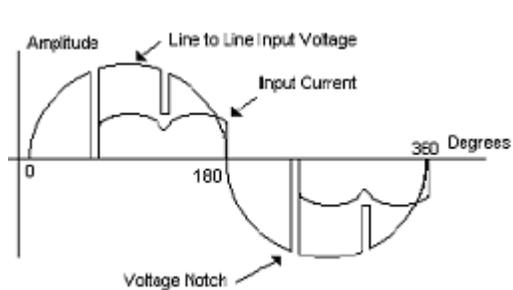
DC DRIVES

DC Drives and SCR Power Conversion

SCR power conversion and Diode power conversion sections effect voltage and current harmonics differently. Also, system impedance has a large impact on voltage and current harmonics present in the power system.

SCR Front End Of A DC Drive

DC drives for the most part, utilize Phase Controlled Converters, referred to as Silicon Controlled Rectifiers (SCRs), in the input rectifier stage.



Basic Schematic for DC Drive (SCR Diode Bridge)

In this application, the line current will be relatively square in shape, which is generally the case for DC drives that usually have a DC link choke.

Reactance located on the AC side of the SCR bridge will have a relatively small effect on total current distortion but, may drop the total voltage distortion considerably. In this situation, the total voltage distortion levels will be relatively high and may effect low voltage equipment.

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AC DRIVES

Diode Front End Of An AC Drive

In most AC drives, the input rectifier utilizes a diode bridge. This power conversion scheme eliminates line voltage notches, but does pull pulses of current from the utility line when the diode conducts. The DC circuit utilizes capacitors to provide additional filtering for the DC bus voltage. If possible, these capacitors would charge (draw current) instantaneously. Circuit inductance is the only limiting element that opposes instantaneous current flow.

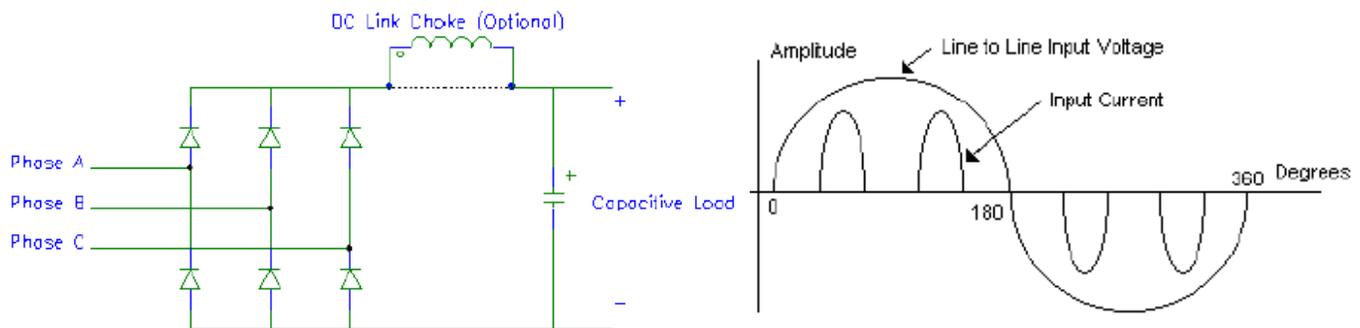


Diagram 2: Basic Schematic for AC Drive (Diode Bridge)

With little or no inductance in the circuit, the current drawn from the AC line will appear as two separate rounded pulses every 1/2 cycle. This type of waveform is commonly known as the rabbit ear waveform. The DC Link Choke reduces the peak currents the capacitors draw to charge.

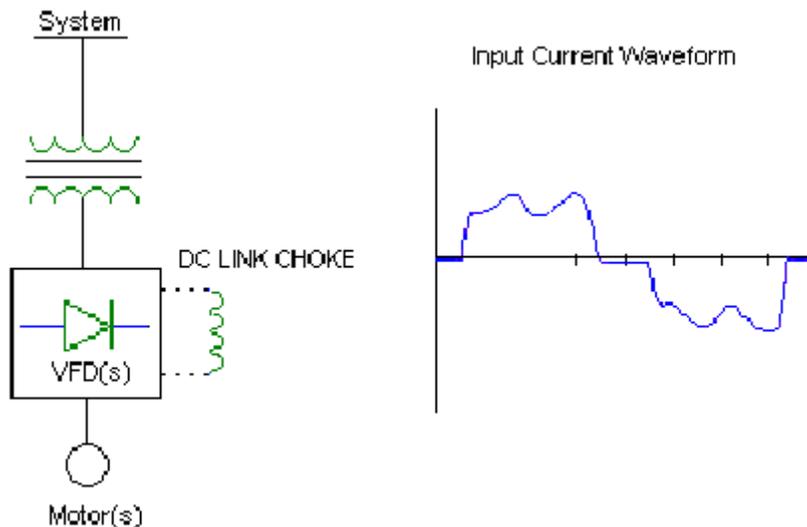
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Variable Frequency Drive with DC Link Choke

A DC Link Choke is simply an inductor located in the ripple filter circuit, placed before the drive's DC Bus Capacitors. DC choke bus connections are available on Yaskawa drive models <30HP. The result being lower peak currents as depicted by the following waveform measured at the input terminals of the VFD.

One Line Diagram and Input Current Waveform



A DC Link Choke will typically reduce current distortion by approximately 40 - 60%. This may or may not have a quantifiable impact on the measured voltage distortion. In the specification process, it is typical to substitute a DC Link Choke in place of a three phase input reactor. Consequently, this same technology is being used in other equipment such as lighting ballasts and smaller power supplies to control harmonics.

The least expensive countermeasure for controlling harmonics is a DC Link Choke.

A 3% input reactor will reduce the current distortion by approximately the same percentage as a DC Link Choke (40 - 60%).

A reactor simply adds impedance to the system which will slow down the di/dt of the current flow into the drive capacitors. The result is a lower current distortion level. This is the same as having a high impedance transformer in the system.

It is important to note that there is a point of diminishing returns regarding impedance and current distortion levels. Through laboratory testing, after 7% input impedance, the distortion levels do not drop much lower. An input reactor may be 2 to 3 times the cost of a DC Link Choke.

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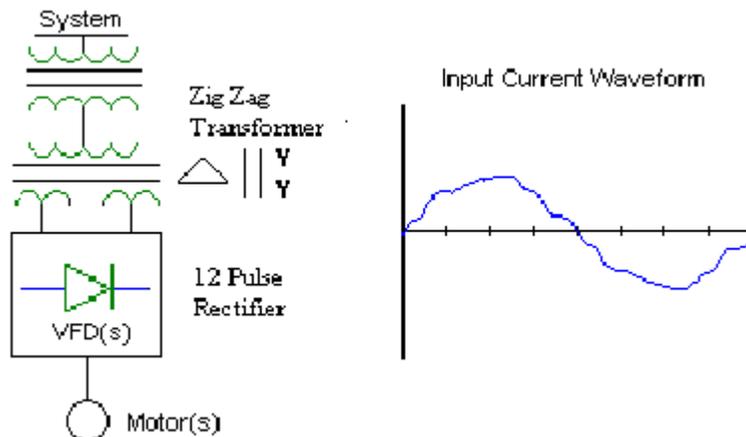
A 12-PULSE TRANSFORMER

12-Pulse Transformer (Harmonic Cancellation)

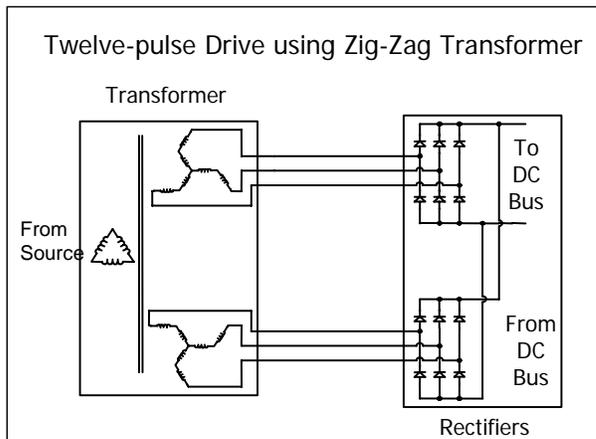
Many Yaskawa Drives, including F7 have designed the flexibility of using two 6-pulse rectifiers in parallel to virtually eliminate power harmonics through phase manipulation. One 6-pulse rectifier just needs to be shifted by 30° in respect to the second 6-pulse rectifier.

Phase manipulation is a result of converting power through a specifically designed transformer called a 12-pulse transformer. This transformer is different from auto transformers and phase shift transformers because the impedances on the secondary side are properly balanced. The transformer effectively eliminates the 5th and 7th harmonics in the core of the transformer. Since the 5th and 7th harmonics contribute to approximately 90% of the harmonic spectrum very high density packaging of drives to transformer size can be achieved. The result being a pure sine wave as depicted by the following waveform measured at the input terminals of the transformer.

One Line Diagram and Input Current Waveform



By utilizing the 12-pulse input transformer and a Yaskawa Drive, the end user can reduce current distortion levels by ~90%. The 12-pulse transformer configuration will meet the most strict power quality specifications such as IEEE519 -1992.



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THE EFFECT OF SYSTEM IMPEDANCE

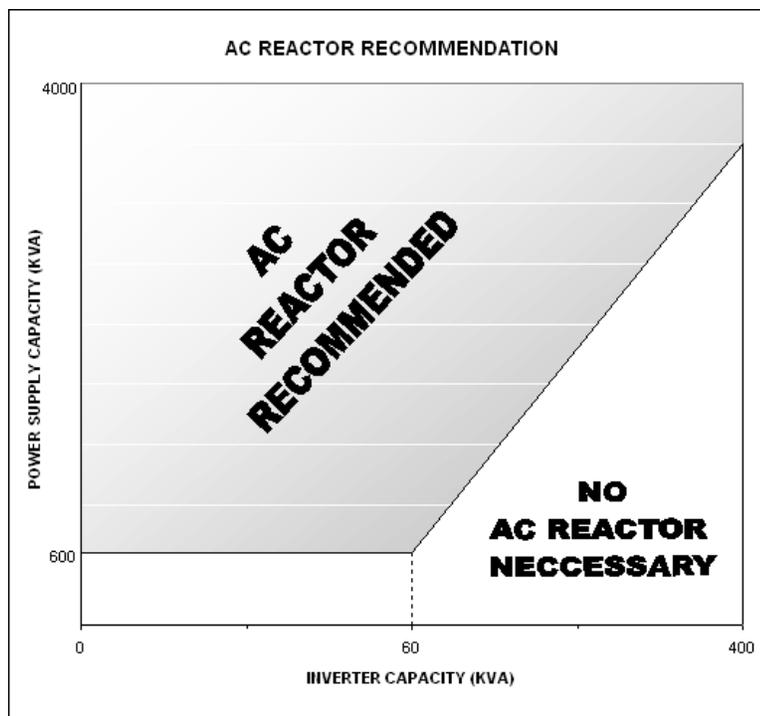
As far as AFDs are concerned, the most important circuit element which influences the amount of harmonic current present in the distribution system is the amount of system impedance and where it is located. System impedance is the amount AC reactance in a power distribution system. Reactance opposes instantaneous current change, thus effecting how devices, such as capacitors in an adjustable frequency drive, draw current or charge. If a power distribution system has a relatively high impedance (between 5%-10%), the total current distortion will be relatively low because the current waveform is more sinusoidal. Likewise, if a power distribution system has a relatively low impedance (between 2% - 5%), the total current distortion may be relatively high.

A fourier analysis may show current distortion levels between 20 - 110% with the resultant voltage distortion levels of 1.5 - 4%. These values are entirely dependent on the system characteristics including amount of impedance and preexisting distortion levels. If the transformer impedance is very high the current distortion will be relatively low (soft system). If the transformer impedance is very low, the current distortion will be relatively high (stiff system).

NOTE: Current distortion varies with system characteristics.

The figure below suggests that if the power supply capacity is 10 times the size of the drive capacity, then a line reactor is recommended to add impedance to the system.

NOTE: In most cases a more cost effective DC Link Choke will suffice unless there exists a 10:1 capacity mismatch between the power supply and the AFD.



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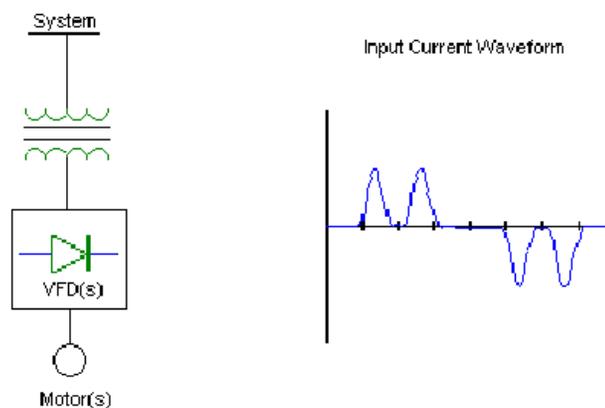
CONSIDERATIONS WHEN REPLACING DC DRIVES WITH AC DRIVES

The following chart highlights some differences between AC drives and DC drives, key points being that power factor and line notching are not concerns with AC diode rectified drives.

INPUT CONVERTER COMPARISON

	(Yaskawa F7) Diode Rectifier Bridge	(DC drive) SCR Phase Controlled
Displacement Power Factor	~Unity	Power factor is based on speed
Line Notching	No	Yes
DC Output Voltage	Fixed	Variable
Reliability	Highest	Medium
Complexity	Low	Medium

Retrofitting drives that incorporate SCRs in the power conversion section with drives that incorporate diodes to rectify the incoming voltage waveform will eliminate voltage notching. This can be accomplished with no additional hardware. The following waveform of an AC drive would be expected if the current waveform was measured at the input terminals of a diode rectified VFD.



Single Line Diagram and Input Current Waveform

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HANDLING TRANSIENTS FROM LIGHTNING , CAPACITOR SWITCHING AND SCR BASED DRIVES

AC line reactors serve a role in reducing transient voltages to the input of AC Drive rectifiers when supply capacity exceeds the branch requirement by 10:1. Power line transients may be mitigated by existing branch circuit impedance >1% if the supply capacity is less than 10:1 between drive and supply.

Transient line voltages can be a result of switching power factor correction capacitors, lightning strikes or a non-isolated SCR based drive on the branch circuit. Transients can shorten the life of input diodes on AC drives. The switching of SCR's generates voltage transients that can damage the diode bridge input of an AC drive if sufficient impedance is not provided between diode rectifier (AC drive) and SCR converter (DC drive) drive systems (See Figure 3.1). An AC line reactor may also be employed if the installation is subject to frequent line disturbances and the power source is greater than 10 times the capacity of the AC drive circuit. The AC line reactor is useful in protecting the diode bridge of an AC drive when line transients are a concern.

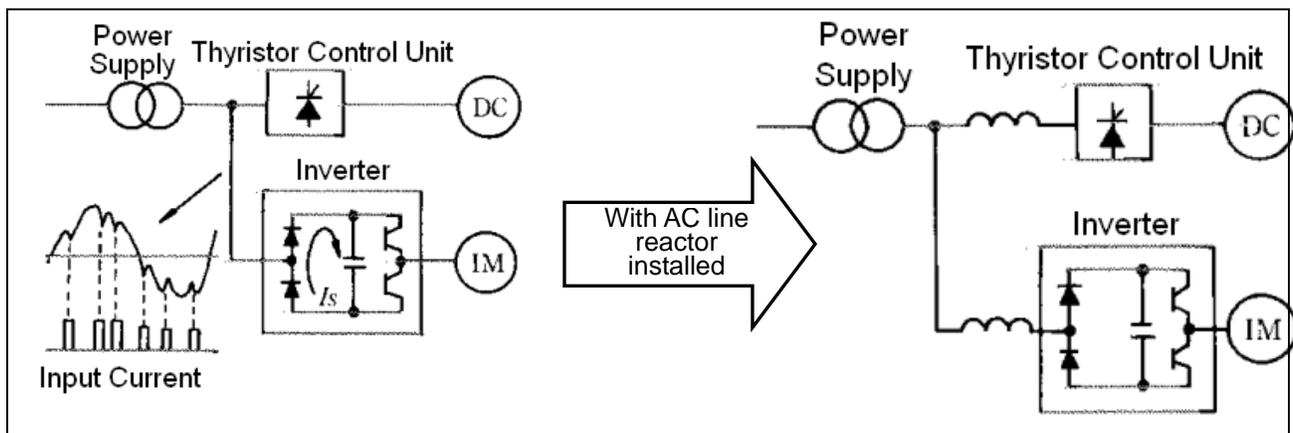


Figure 3.1 DC Drive on same branch as AC Drive

Transient Surge Suppressors

Transient suppression commonly known as MOV's (metal oxide varistors) are typically employed in most AC Drive products. Effective at snubbing transients, these devices have a specified energy handling capacity and useful life. MOV's provide some protection however, caution should be used if relying on MOV's as the sole source of transient protection. This is because the energy in lightning transients or power factor capacitor switching transients is often unknown.

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ISOLATION TRANSFORMERS

Isolation transformers are commonly used with DC drive applications. There are several reasons why DC drive manufacturers have recommended the use of these transformers.

- Ground fault protection
- Protection from three phase supply transients

Ground Fault Protection

Isolation transformers have been used by AC and DC drive manufacturers for ground fault protection in the past. The rationale is that if one of the drive outputs becomes grounded there will be no path for the fault current to flow with a "Floating" system feeding the drive. In effect, a isolation transformer provides ground fault protection. The Yaskawa F7 Drive uses a "Zero Sequence" ground fault protection scheme. If there is a leakage current flowing through a ground path, the inverter will protect itself via a fault trip condition. This type of electronic ground fault protection eliminates the requirement for external ground fault protection in the form of isolation transformers. In addition, the use of transistors on the output section of the inverter, means that if a fault current (exceeding the OC trip level of the inverter) occurs, the gate drive signal will turn the device off, interrupting the fault current.

Thyristor (SCR) based drives (AC and DC) cannot be turned off simply by removing a turn-on signal. These drives must wait for the thyristor to become reverse biased and for the current through the device to fall below the minimum holding current level. This problem means that the device cannot be turned off easily in the event of a fault condition. This makes the use of an isolation transformer a common recommendation among the manufacturers of SCR based DC drives.

Yaskawa F7 AC drives do not require the use of isolation transformers to provide ground fault protection.

Protection Of The Drive From The Three-Phase Supply

Drives that have a thyristor based (phase-controlled) AC to DC converter need to limit the commutation current when one SCR turns off and another turns on. This commutation condition produces a momentary line-to-line short circuit through the input thyristors. Many drive manufacturers recommend the use of isolation transformers to add impedance between the drive and the incoming power supply to limit this commutation current. Since Yaskawa inverters use a diode bridge AC to DC rectifier, this commutation problem does not occur. Another common reason used to justify the use of isolation transformers on DC drives is the protection of the drive from input transients. Yaskawa drives use MOV protection on the input of the inverters that protect from this type of line-to-line transient. As a result, Yaskawa F7 drives typically do not require the use of isolation transformers.

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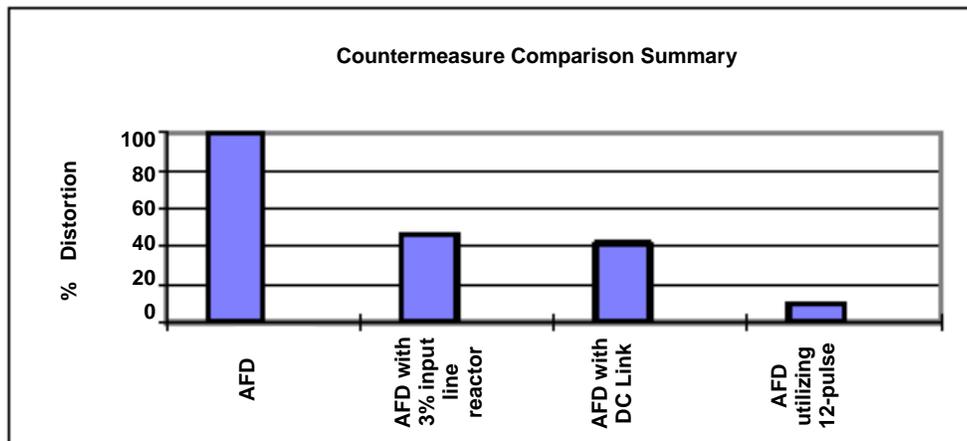
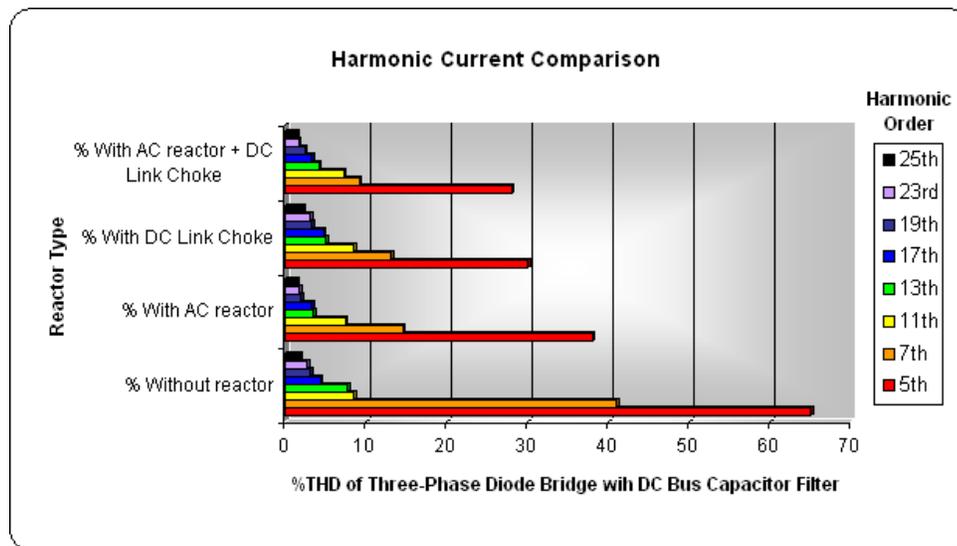
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HARMONIC CURRENT COUNTERMEASURE COMPARISON DC CHOKE and AC REACTOR

The following chart is a visual comparison of the various harmonic countermeasures as it relates to current distortion. These relationships can be used for estimating the reduction in total current distortion (ITHD) as compared to standard VFDs. If estimated ITHD is 75% of the fundamental, installing a 3% three phase input reactor or DC Link Choke should drop ITHD to 38%, ($75\% \times 0.48 =$).

Understandably, this is a rough estimate, but may be useful when quoting some VFD jobs.

The following chart shows the harmonics ratio for each harmonic order with the fundamental wave at 100% in a three-phase diode bridge with DC bus capacitor filter.



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A COMPARISON SUMMARY OF DC LINK REACTORS AND THREE PHASE REACTORS

The following shows the comparison of characteristics between AC reactor and DC Link Choke when used for prevention of harmonics or power factor improvement. AC reactors or DC chokes may be employed singly or together. Harmonic mitigation is easy with the Yaskawa F7 Drive, since models of F7 22 kW or more incorporate DC Link Choke as standard. If reactors are not sufficient to suppress effects the effects of harmonics, use 12-phase rectification or sine-wave converters. For the details, contact your Yaskawa representative.

Comparison between AC Reactor and DC Link Choke

	Harmonic Current Distortion Ratio at Inverter Primary Side	Power Factor at Inverter Primary Side	Size and Price per Unit	Voltage Drop by Reactor	Common Input Reactor for Multiple Drives Possible
Without reactor	Approx. 75 to 95%	Approx. 60 to 80%	—	—	—
With AC reactor	Approx. 35 to 45%	Approx. 80 to 90%	Medium (Due to 3 phase windings)	Approx. 3% (Installed at AC input side)	YES *3
With DC Link Choke	Approx. 30 to 40%	Approx. 85 to 95%	Small (Due to single-phase winding)	1% or less (Installed at DC side) *2	NO *4
With AC reactor +DC Link Choke	Approx. 30 to 35%	Approx. 90 to 95%	Large (Due to use of two reactors)	Approx. 3 to 4%	Possible with only AC reactor
12-Pulse Input	Approx. 10%		Large (Due to use of phased transformer)	Approx. 3 to 4%	NO

*1 The above data values are for 3-phase power supply and given at motor load ratio 100%.

*2 A DC Link Choke is attached on the inverter DC bus bar and operates only for harmonic components, resulting in reduced of voltage drop.

*3 Installed only when all Drives on the branch circuit share the load equally.

*4 Each DC Link Choke must be attached DC bus terminals provided on each Drive.

*5 Models of Yaskawa Varispeed F7 22 kW or more, Varispeed G7 of 18.5 kW or more, and VS-616G5/P5 18.5 to 160 kW have built-in DC reactors. DC Link Chokes must be mounted optionally on other models of smaller capacities or VS-606V7 and VS mini J7.

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CONCLUSION

The construction and protective features of the Yaskawa inverters with built-in DC Link Chokes eliminate the need for isolation transformers. Knowing harmonic distortion and using appropriate filtering on a system wide approach, insures a more reliable, cost effective solution. A DC Link Choke is just as effective at reducing harmonic current as a AC line reactor. Today many existing solid-state DC drives (most prevalent in the early 80's), electromechanical and fluid drives are rapidly being replaced by AC variable speed technology. High-maintenance DC drives and motors have been eliminated on extruder and other applications through the installation of Flux Vector AC drives, which closely match DC performance while eliminating maintenance.

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3. Yaskawa Electric Corporation, "Comparison between AC Reactor and DC Reactor," *Document # E-P-01-GP-06*, July 2002.
4. Yaskawa Electric Corporation, "Application of AC Reactors," *Document # E-R-02-GN-01*, March 2000.