Press Release

Technical Paper:

Reducing adjustable frequency drive (AFD)-caused harmonics at partial-load conditions

The need for controlling the level of harmonic current in power distribution systems is widely recognized as an important factor in selecting and applying adjustable speed drives and other non-linear load equipment. This paper explains the benefits of a new built-in harmonic mitigation technique for pulse width modulated (PWM) AC adjustable frequency drives (AFDs).

Line Harmonic Basics

Harmonic Currents are Component Parts of a Distorted Sine Wave Current

Figure 1 uses a simple single-phase example to illustrate the operation of a capacitor filtered rectifier circuit. The capacitor is charged to the peak line voltage. The capacitor discharges as current is supplied to the load. Line current flows to recharge the capacitor only while the peak of the line voltage waveform is greater than the capacitor voltage. Only the source resistance limits the peak current.

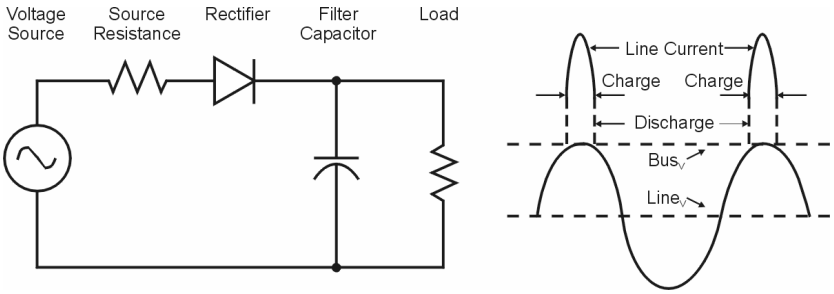

Figure 1 – Capacitor Filtered Rectifier Circuit

A three-phase rectifier is generally similar to the single-phase example, but there are three voltage sources, six diodes and six pulses of current per cycle. The source impedance is mostly inductive and additional inductance is often added inside the drive or in series with the source. The total impedance shapes both the height and width of the current pulses.

Figure 2 shows a simplified line current waveform for a typical three-phase drive including the fundamental and the 5th and 7th harmonic current components. The non-sinusoidal or "distorted" current waveform is the sum of its component parts.

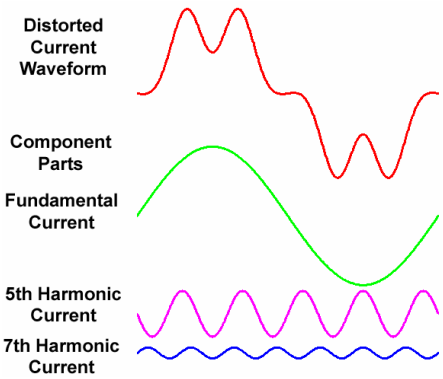

Figure 2 – Distorted Waveform and Harmonics

Reasons for Limiting Harmonics

IEEE Standard 519-1992 explains the reasons for limiting harmonics and recommends limits to be applied in various situations. The harmonic currents drawn by a load cause extra heating in all of the power distribution equipment that supplies the load. Harmonic voltages are generated by the action of the harmonic currents flowing in all of the impedances in the system from the utility generating and transmission system and the substation and distribution transformers to the branch circuit protective devices and wiring. Harmonic voltages cause additional harmonic currents to flow in equipment that does not ordinarily draw harmonic currents. Harmonics can interfere with the operation of some sensitive equipment.

(For more detailed information about harmonics, refer to ABB publications Fact File TD2 EN, *Reducing harmonics caused by variable speed drives,* and Technical Guide No. *6, Guide to Harmonics with AC Drives.*)

Harmonic Mitigation Alternatives

Line Chokes and DC Bus Chokes are the Most Common Harmonic Mitigation Alternatives

The terms *choke*, *reactor* and *inductor* are generally used interchangeably to mean a circuit component that provides a desired value of inductance. Inductors offer very little resistance to continuously flowing DC current, but the flowing current causes a magnetic field that stores energy and opposes any increasing or decreasing current. Either line chokes or DC bus chokes may be provided by the drive manufacturer as a built-in standard feature or made available as a built-in optional feature. Line chokes are also available as accessory items. See Figure 3.

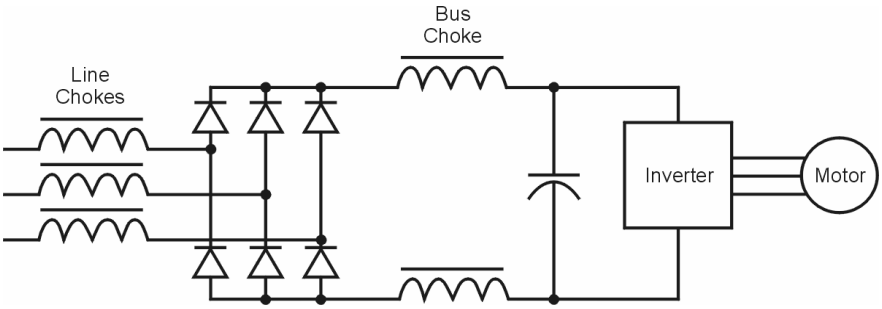

Figure 3 – AFD with Line Chokes and Bus Chokes

Note that two bus chokes are shown in Figure 3. Providing chokes in both the positive and negative sides of the bus is a key element of the protective functions described at the end of this article.

Swinging Choke

What is a Swinging Choke?

The swinging choke is an inductor that has an inductance value that is inversely proportional to its operating current. Over a substantial portion of the normal operating current range, the inductance decreases as the current in the choke increases. A conventional or *linear* choke has a fixed inductance value that changes very little as the operating current varies in the normal operating range. See Figure 4.

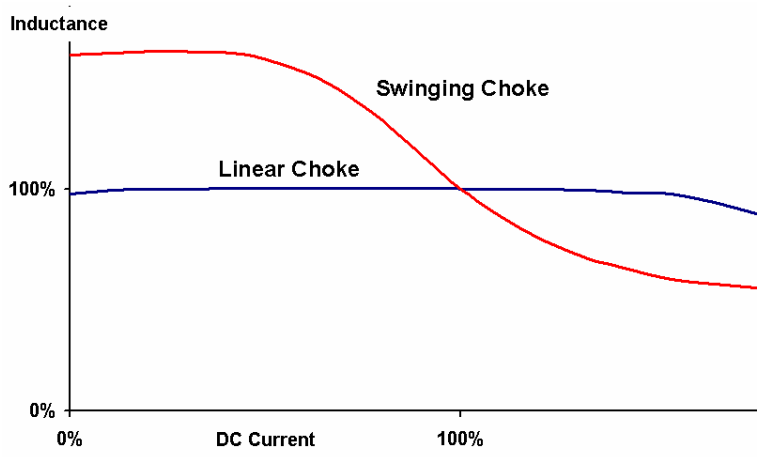

Figure 4 – Swinging Choke Percent Inductance

As it is applied, the ABB swinging choke is comparable to a 5% linear choke in terms of the effective impedance at 100% rated current, but comparable to a 3% linear choke in terms of the copper windings and iron core used.

(For additional information, refer to U.S. Patent 6,774,758, available at www.uspto.gov.)

What Does a Swinging Choke Do?

Used as a line choke or DC bus choke in an AFD, the swinging choke reduces harmonic current just as a linear choke does. The main objective of using a swinging choke is to provide further harmonic reduction when the drive is operating below its rated horsepower. This further harmonic reduction is provided with no increase in drive cost, physical size or weight compared to a similar drive equipped with a conventional choke. See Figures 5 and 6.

Figures 5 and 6 compare the total RMS value of the drive's input harmonic currents to the rated input current marked on the drive's nameplate. This is a measure of the harmonic current added to the power distribution system when the drive is operating.

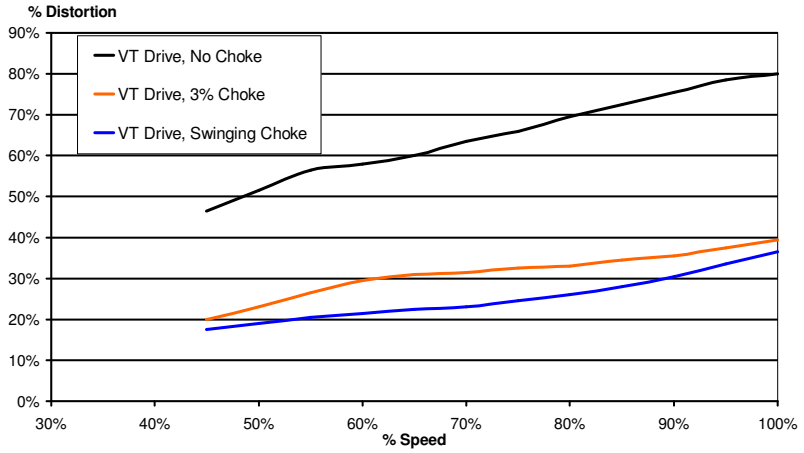

Figure 5 – Variable Torque Drive Harmonic Current (Percent of Rated Input Current)

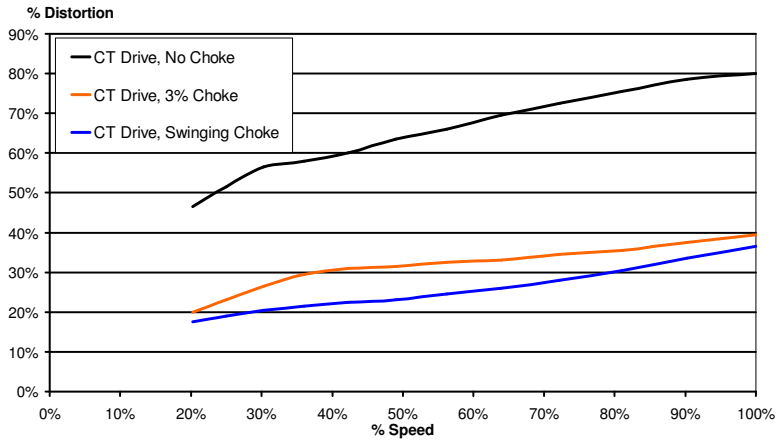

Figure 6– Constant Torque Drive Harmonic Current (Percent of Rated Input Current)

What are the Advantages of a Swinging Choke?

Advantages of Swinging Choke vs. Conventional Choke

- Compared to a standard linear choke, the swinging choke provides superior line harmonic current reduction when the drive's output power is less than or equal to rated output.
- The effective inductance value of a swinging choke at full load is higher than the value of a linear choke of the same physical size, weight and cost.
- The efficiency of a swinging choke is higher than the efficiency of a linear choke of the same inductance value.

Some Design Advantages of a Built-in Choke Are Gained Internally

Incorporating an AC line or DC bus choke in the basic design of the drive allows the designer to utilize the choke to the maximum advantage. The choke offers benefits in the following areas of design:

- DC bus filter capacitor selection
- Short circuit and ground fault protection
- Protection from line voltage transients
- Radio frequency noise suppression
- Increased overall drive efficiency and reduced internal heat dissipation

Some of the internal design benefits of a built-in choke are passed directly to the customer; others help make it possible to provide a built-in choke as a standard feature at a competitive price.

Customer Benefits Provided by a Built-in Swinging Choke

Limiting Harmonic Distortion

A Choke Reduces the Level of Harmonics Generated by Each Drive

Some benefit is gained by reducing the level of harmonics generated by each piece of equipment connected to the user's power system even when an analysis shows that the system can tolerate some harmonic generating equipment without taking additional measures to limit the harmonics.

Limiting Harmonic Currents

Reduces the Drive's Total RMS Input Current

The swinging choke assures that the drive's input current will never exceed the output current supplied to the motor. The rated input current marked on the drive's nameplate is the same as the rated output current. This means that there is no need to oversize the branch circuit wiring, disconnecting means and protection to comply with the National Electrical Code. See Figure 7.

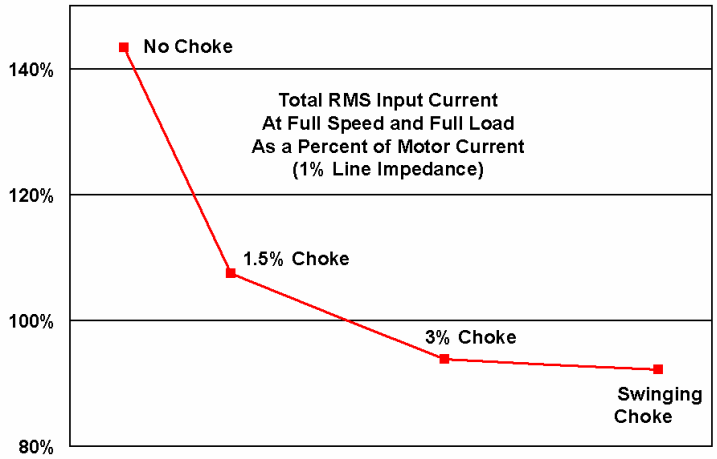

Figure 7 – Input Current / Output Current Ratio

Limiting the harmonics generated by an individual piece of equipment frees power system capacity for adding future equipment.

When each piece of new equipment includes this simple, cost-effective, built-in feature, the user reduces the risk of needing to retrofit harmonic limiting measures in the future.

Harmonic Mitigation Objectives
IEEE 519 addresses two issues

Limiting Harmonic Currents
At the Utility Metering Point

The standard recommends limits for the harmonic current distortion caused by any individual electric utility customer as measured at the point where the utility grid and customer owned equipment meet. This point, called the point of common coupling (PCC) is typically the utility metering point. This PCC is on the utility side of all transformers and other equipment, which serve only the customer under study. The harmonic current distortion (total demand distortion) limits are intended to protect the utility and preserve the utility's ability to provide undistorted power to other customers.

Limiting Harmonic Voltages
Inside the Customer's Plant

The standard also recommends limits for the harmonic voltage distortion caused by individual equipment or groups of equipment measured at the point or points on an owner's facility distribution system where other existing equipment is connected. This portion of the standard is applied at one or more points of common coupling inside the customer's facility. The voltage distortion limits are intended to protect the user's power distribution system and connected equipment from harmful effects of harmonics.

Harmonic Studies

When a harmonic study is undertaken, the demand current and harmonic current contributions of adjustable speed drives should be based on the maximum continuous brake horsepower (BHP) required to drive the connected equipment. For fans and pumps, this would be the BHP at the maximum flow design point.

(A Microsoft Excel spreadsheet harmonic analyzer tool is available at www.abb-drives.com. Click *ABB Product Documentation* in the list of *Popular Pages* and scroll down to *-14 Software*.)

The Swinging Choke Advantage

Since the design point BHP is nearly always less than the nameplate horsepower of the selected motor, the harmonic contribution of the drive can nearly always be based on an operating point that is less than the maximum rated output power. Since the harmonic limiting effectiveness of the swinging choke increases when the operating point is less than maximum power, a drive with a swinging choke has an advantage over a similar drive with a comparable linear choke.

Other Protective Functions

Electromagnetic Compatibility

In addition to reducing harmonics, chokes provide other benefits in assuring that the drive will operate in its installation environment while neither causing nor experiencing electromagnetic interference (EMI). EMI is any interference with normal equipment operation caused by abnormal energy entering equipment either by conduction though wiring connections or by radiated wave reception. Radiated EMI is also called radio frequency interference (RFI). Chokes help filter out any high frequency noise that might otherwise be emitted from the drive through the power lines.

Line Voltage and Current Transient Protection

Chokes help protect the drive from voltage transients on the power lines. Chokes are particularly effective in protecting the drive from current surges that can occur when the utility switches power factor correction capacitors.

Ground Fault and Short Circuit Protection

Chokes contribute to a drive's ground fault and output short circuit protection design. Chokes limit the rate of rise and maximum prospective value of fault current. Effective 4/25/06, UL 508 requires the drive's maximum short circuit current rating to be marked on the nameplate. The 2005 edition of the National Electrical Code includes a similar requirement. Built-in chokes help make it possible to provide a 100,000 amp output short circuit rating as a standard feature at a competitive price.

Dual DC Bus Chokes and AC Line Chokes Provide Similar Benefits

All of the benefits described are provided by either AC line chokes or DC bus chokes. When DC bus chokes are provided, two chokes are required, one in the positive side and one in the negative side. Dual DC chokes are required to provide impedance between the AC line and any path to ground. Impedance in the ground path is needed for ground fault and EMI protection.

Summary

We have presented a brief introduction to harmonic distortion with an explanation of some reasons and methods for limiting harmonics. We have described a swinging choke, the key component of a recently patented method for limiting harmonics generated by an adjustable frequency drive. We are confident that you will agree that the swinging choke provides valuable benefits when it is used as a built-in component of a drive's rectifier circuit

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