# ZENER ELECTRIC PTY LTD

**ACN 001 595 428**

APPLICATION NOTE: IM 10002 **Revision -, June 1996**

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## **Topic:** Mains Harmonic Disturbance and Variable Speed AC-Drives

### Introduction

Most common industrial variable speed drives (VSD's) for AC motors have an effect on the supply system because of the design of the drive input circuitry. However the degree of this effect in producing harmonic noise at levels of concern is largely determined by *characteristics of the supply* such as the supply rating and fault level and the level of existing harmonics. In other words harmonic effects are largely site dependent.

It is critical for distribution authorities and end-users to realize that compliance with the Australian Standard AS2279.2 ('Disturbances in mains supply networks - Part 2: Limitation of harmonics caused by industrial equipment') cannot be demanded or determined for any VSD unless the fault level of the supply and existing harmonic levels are both specified. [1]

With this site information it is then possible to evaluate harmonic reduction requirements and ensure the design of the VSD installation will meet the specifcations. Voltage harmonics introduced to the supply by a VSD are dependent on drive size and on the circuit options offered by the drive manufacturer to manage harmonics. Zener Electric's VSC 2000 drives employ a significant DC bus choke as a standard feature which is highly effective in reducing harmonics, other forms of electrical "noise" such as RFI and for improving power factor.

Installation of basic VSD's without added filtering components should be absolutely trouble free from the supply harmonic point of view if the total drive rating is no more than 4% of the supply rating. This proportion can be increased to about 35% if existing harmonics are low and suitable circuit options are specified.

### Variable Speed Drive Inverters

AC variable speed drives vary the speed of standard induction motors by changing the frequency and the magnitude of the three-phase voltage supplied to the motor. In currently available drives this is done by converting the incoming AC power to DC and then reconstructing variable frequency AC voltages from this intermediate DC link.

The first step is called AC-to-DC rectification and the second DC-to-AC inversion. The rectification step is usually accomplished by diode rectifier circuits. The inverter stage uses power transistors in various forms.

A standard rectifier input inverter shown in Figure 1 has a large capacitance in the DC link which acts as a constant voltage source for the output inverter.

[1] Reference extensively used for this Application Note is 'Supply Harmonics caused by AC Variable Frequency Drives', Motor and drive technical note - number 1, Pacific Power Center for Energy Efficiency , G J Sanders & P M Dalton

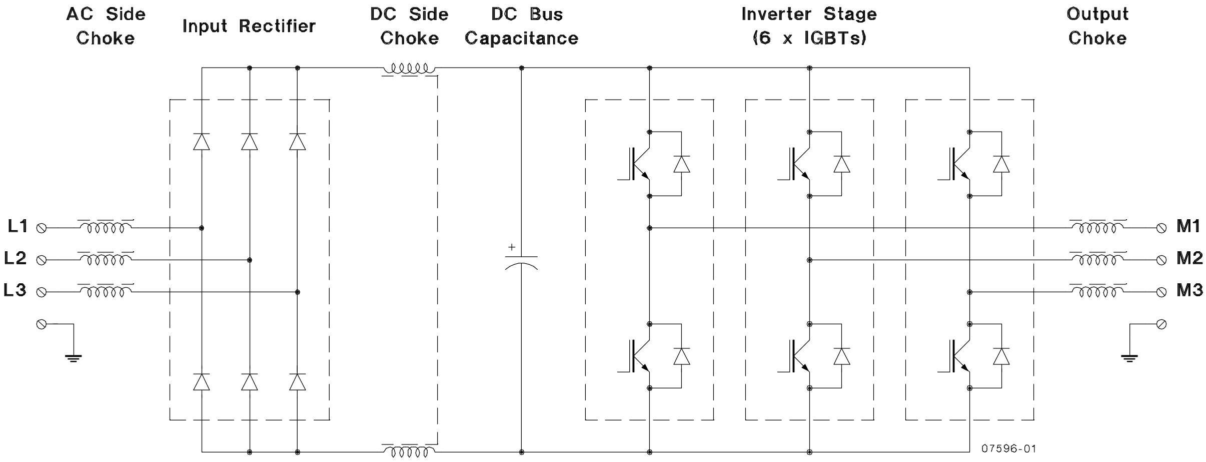


**Figure 1:** Power circuit of a Variable Speed Drive Inverter showing the DC-side choke, DC bus capacitor, input rectifier and inverter output stage and AC-side input and output chokes.

The input on the supply side (L1, L2, L3) "sees" a bridge rectifier feeding a very large capacitor bank (thousands to tens of thousands of microfarads) with a relatively constant current drain proportional to the load on the motor. Optional components around the rectifier and capacitor are shown in the Figure 1. These AC-and DC-side chokes are absent on smaller drives. When fitted, their function is to smooth the input current waveform through the rectifier and reduce the harmonic distortion in the supply.

## Drive Rating in Relation to Supply Capacity

The most important single factor in assessing whether an AC drive will cause unacceptable voltage harmonics in the supply is the drive rating in relation to the supply capacity. Supply capacity is usually measured by the "Fault Level" which is the three phase product of open circuit voltage and the (hypothetical) short circuit current.

The fault level is the main parameter of the supply system used in protection calculations. It is usually measured in kVA or MVA and sometimes referred to as Short Circuit VA or SCVA. In a city or large town the fault level of the 415V supply is typically 10 to 20 MVA, while in country regions it may be only 2MVA. Fault level is a measure of the series impedance of the supply. For a system with a 3-phase line-to-line source voltage U and source impedance Z in each line,

$$\textbf{Fault Level} = \frac{3 \times U^2}{Z} \quad \text{(kVA)}$$

The series impedance Z = R + jX where R is the resistive component and X is the reactive component of the supply, usually inductive. In a city or large town Z is dominated by the series reactance of the final distribution transformer and the fault level is typically 20 to 30 times the rating of this transformer. In a more remote country region the impedance of the high voltage feeder may dominate and Z may be almost resistive. Sometimes the fault level of a supply can be specified by the impedance with values for R and X or L.

## Point of Common Coupling

In practice it is usually the supply authorities concern over the harmful harmonic effects that a VSD may have on an adjacent customer that determines the need for compliance with standards. The location at which harmonic measurements are specified is therefore at the point of common coupling (PCC) which is the point at which the nearest adjacent user is connected to the supply network.

## Short Circuit Ratio

The convenient and fundamental measure of drive size in relation to supply capacity is the short circuit ratio defined as,

$$\textbf{Short circuit ratio} = \frac{\textbf{Supply Fault Level (kVA)}}{\textbf{Drive DC bus rating (kVA).}}$$

This usually lies in the range 20 to 500.

The drive DC bus rating (kVA) can be estimated from the motor load L (kW) and the motor efficiency (E%).

Approximately,

**Drive DC bus rating = 103 x L(kW) / E(%)   kVA**

where the factor 103 takes into account an average efficiency of the inverter stage of the drive. Motor efficiencies vary with motor size. Good average figures are shown below.

| **Motor Rating** | **Efficiency (%)** | | |
|---|---|---|---|
| kW | lower | median | upper |
| 1.1 to 7.5 | 73 | 76 | 85 |
| 11 to 90 | 86 | 89 | 92 |
| >110 | 92 | 94 | 96 |

**Table 1:** Motor efficiency at various ratings

Using these values we can then determine the short circuit ratio to establish the likely level of harmonic disturbance. Graphs or tables of harmonic distortion versus short circuit ratio give a percentage figure for the harmonics. Harmonics of interest with AC drives are the 5 th and the total harmonic distortion (THD).

Graphs showing the 5th and total harmonic voltage distortion percentages as a function of short circuit ratio are shown in Figures 2 (a through d). These are sourced from the reference document [2]. The graphs shown are for the case of an inverter with input rectifier and a large DC-side choke, and for the same inverter without a DC choke.

Each graph also shows the reduction in harmonic levels made by adding AC-side chokes, with values X = Xs, 2Xs and 4Xs where Xs is the supply reactance at the PCC.

From these graphs we can determine theoretical values for the 5th harmonic and THD which will be generated by the drive when it is installed in a supply location PCC which results in a particular short circuit ratio as determined previously.

[2] p 4, Pacific Power, G J Sanders & P M Dalton op. cit.

## Example

What would be the approximate short circuit ratio for a drive supplying a 55kW motor operated at 80% of its rated load in a supply with 10 MVA fault level? What would be the 5th and total harmonic levels if the drive was supplied with a substantial DC side choke?

## Solution

| | |
|---|---|
| Motor load is | = 0.8 x 55 |
| | = 44 kW |
| Estimated motor efficiency | |
| | = 91% |
| Drive DC bus rating | = 103 x 44/91 |
| | = 49.8 kVA |
| **Short circuit ratio** | = 10 MVA / 49.8 kVA |
| | = **200** |

From the graphs, if a DC choke is used but with no AC choke (X/Xs = 0), the 5th harmonic would be 0.5% and the THD 1.3%. (Figure 2a and 2b). If AC chokes were used such that X/Xs = 4, then 5th harmonic would be 0.5% and the THD 1%.

From the graphs for a drive without a DC choke and no AC choke (X/Xs = 0) the 5th harmonic would be about 1.8% and the THD about 3.1% (Figure 2c and 2d). If AC chokes were used such that X/Xs = 4, then 5th harmonic would be about 1.0% and the THD 1.3%.

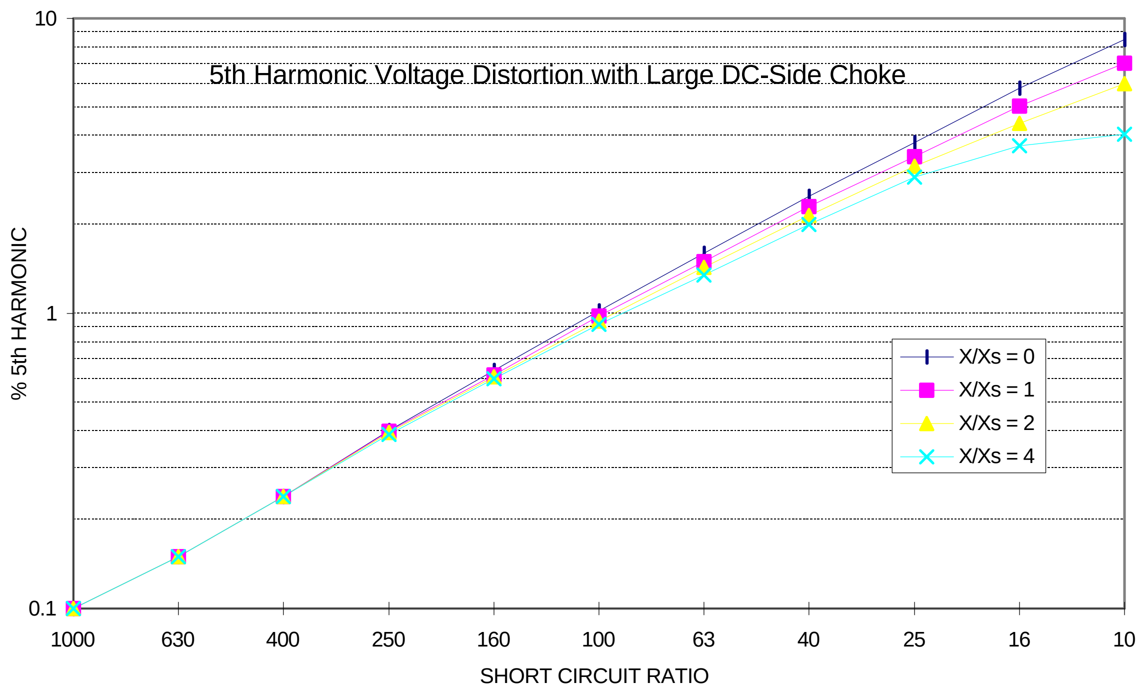


**Figure 2(a):** Percentage of 5 th harmonic voltage distortion for a variable speed drive <u>with</u> a large DC-side choke. The effect of AC-side chokes (reactance X) are also shown for various sizes of X. Xs is the supply reactance.

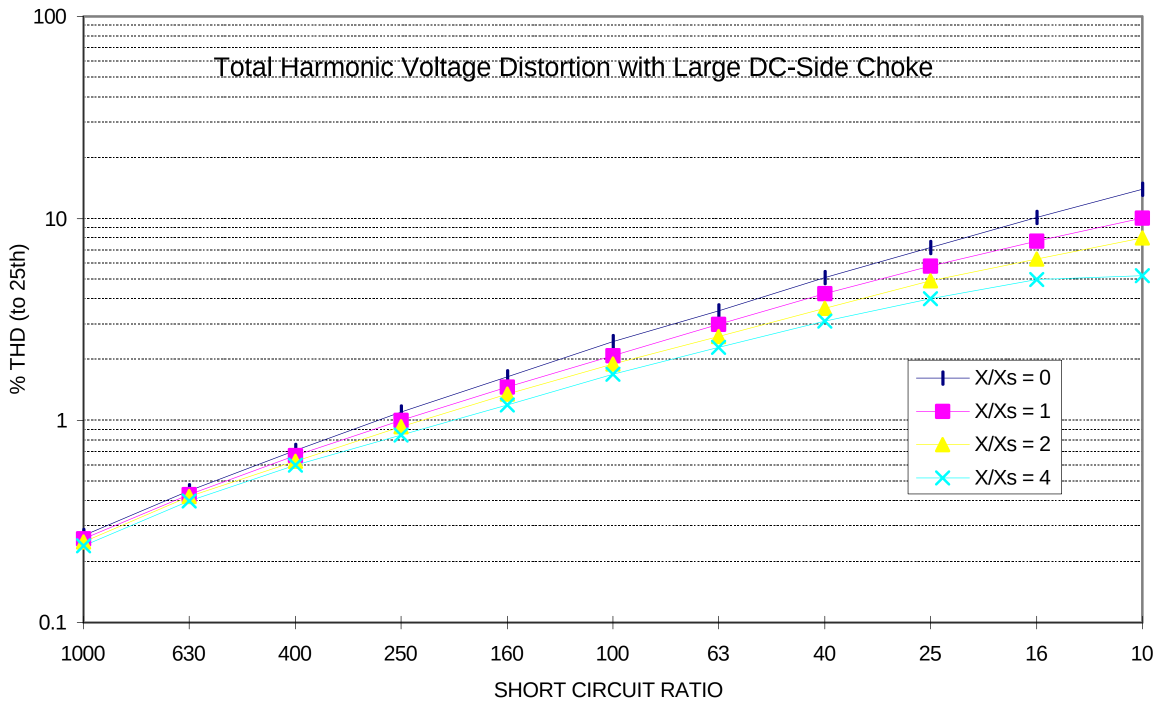


**Figure 2(b):** Percentage of total harmonic voltage distortion for a typical variable speed drive with a large DC-side choke. The effect of AC-side chokes (reactance X) are also shown for various sizes of X. Xs is the supply reactance.

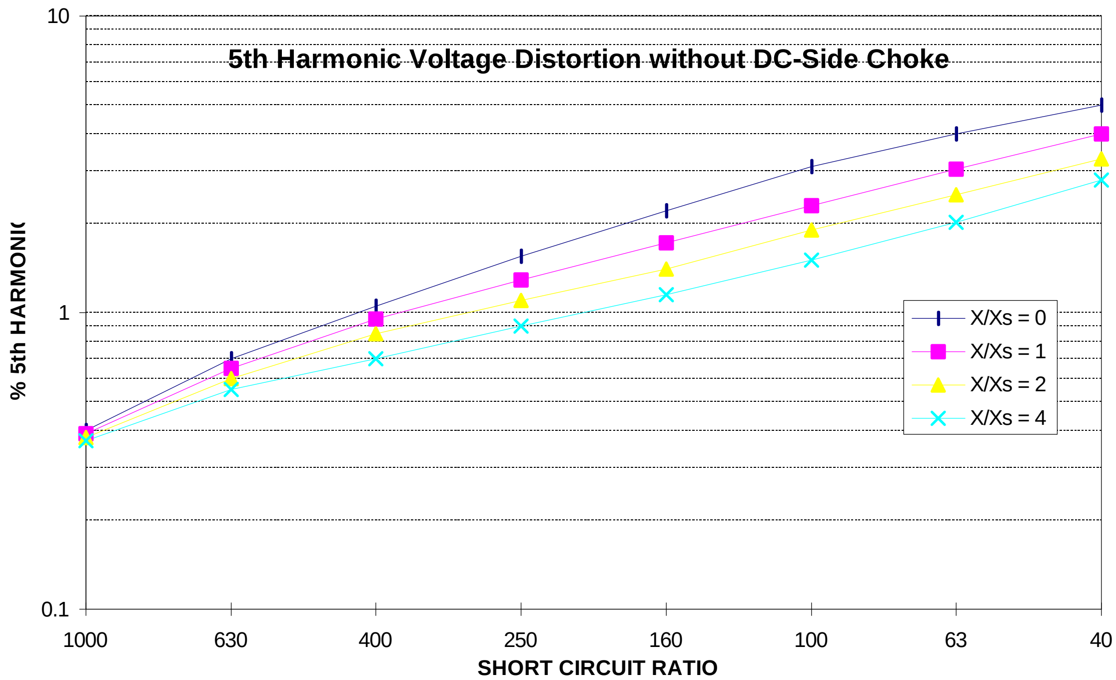


**Figure 2(c):** Percentage of 5 th harmonic voltage distortion for a typical variable speed drive without a DC-side choke. The effect of AC-side chokes (reactance X) are also shown for various sizes of X. Xs is the supply reactance.

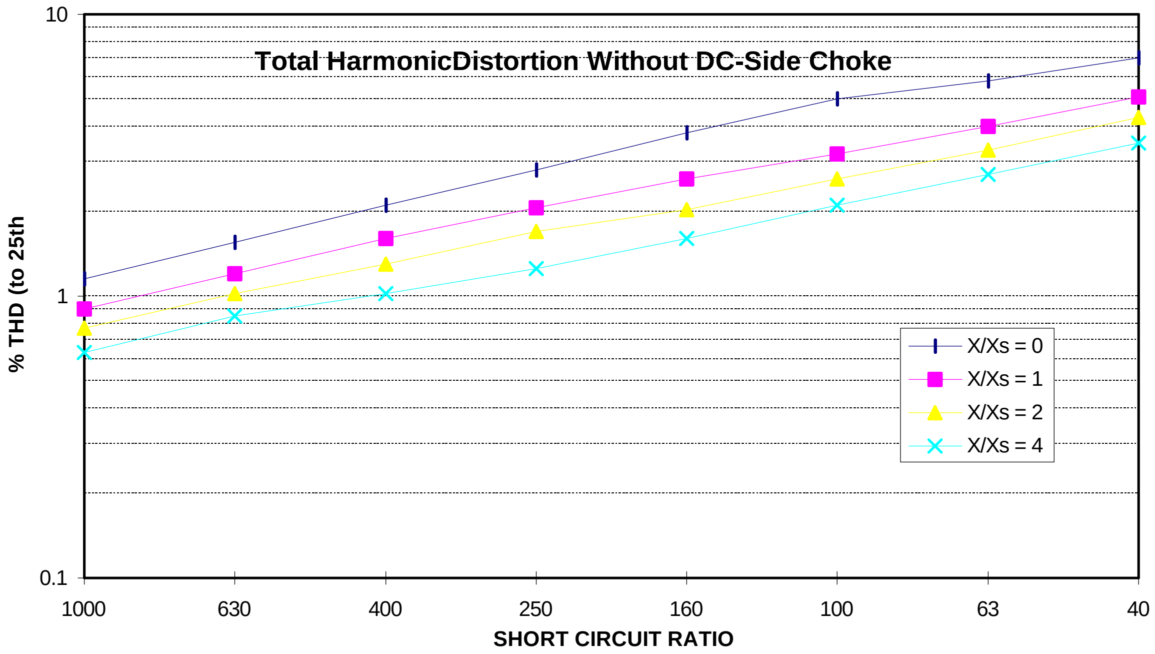


**Figure 2(d):** Percentage of total harmonic voltage distortion for a typical variable speed drive without a DC-side choke. The effect of AC-side chokes (reactance X) are also shown for various sizes of X. Xs is the supply reactance.

## Applying Australian Standard AS2279.2 - 1991 for typical industrial AC drives

The majority of potentially troublesome industrial drives where the short circuit ratio is less than 300 are covered by the "Stage 2 limits" (Clause 5.3) in AS2279.2-1991.

The standard allows for the 415V supply to have voltage distortion up to 4% for any odd harmonic and up to 5% THD. These are overall limits due to all connected equipment. Individual installations are allowed to cause a much lower level of distortion. Limits for even harmonics are 2% but even harmonics are not created in balanced 3 phase systems such as Zener 3 phase drives.

From Clause 5.3, the Standard allows the following:

(a) If the largest existing odd voltage harmonic is 3% then equipment which produces no more than 1% of any odd harmonic voltage can be connected.

(b) If the largest existing odd harmonic is 1% then equipment double the size of that which produces 1% of any odd harmonic may be connected.

The equipment on which the Standard data is based is such that doubling the size of the equipment in relation to the supply SCVA virtually doubles the largest odd voltage harmonic.

**Note that a knowledge of both the fault level and existing harmonics is necessary before Stage 2 limits can be analyzed. If the connection of load cannot be justified from stage 2 considerations, it may still be possible to connect the load after detailed examination of existing harmonic current and voltage conditions and the conditions resulting after the new load is connected.**

## General guidelines for connection of VSDs

Very often the fault level is not known. If the rating of the distribution transformer is known then the fault level in a city of a large town can be guessed to be 15 to 25 times the transformer rating. On this basis we can estimate the size of the largest VSD (motor rating as a proportion to the supply rating) which can be connected to the supply in a city of a large town without causing harmonics in excess of the Standard.

Estimates are shown in Table 2. They are based on an average motor efficiency of 90% and a fault level equal to 20 times the distribution transformer rating. Final values are rounded down to the nearest %.

| LARGEST EXISTING HARMONIC $U_n$ | DC-SIDE CHOKE | AC REACTANCE ADDED (Xs IS THE SUPPLY REACTANCE) | | | |
|---|---|---|---|---|---|
| | | X = 0 | X = Xs | X = 2Xs | X = 4Xs |
| 1%<$U_n$<3% | NONE | 4% | 4.5% | 5% | 8% |
| 1%<$U_n$<3% | SUBSTANTIAL | 17% | 18% | 18% | 19% |
| $U_n$<1% | NONE | 9% | 13% | 18% | 24% |
| $U_n$<1% | SUBSTANTIAL | 36% | 37% | 38% | 41% |

**Table 2:** Estimated maximum AC drive rating as a percentage of supply rating with and without a DC choke and for different values of added AC reactance X. (Note: Xs assumed to be 20 x (supply rating)/$U^2$) If the supply impedance (reactance) is specified as inductive, Xs can be calculated as Xs = 2 $\pi f$L, where $f$ is the supply frequency.

As Zener VSC 2000 drives have a substantial DC-side choke as standard, you should refer to those figures. It is interesting to note the obvious effectiveness of the DC-side choke for reducing harmonic effects. Note that AC-side chokes will cause a small additional voltage drop in the inverter DC bus under load. For the worst case in Table 2 (X = 4Xs and motor rating 41% of supply rating) this additional voltage drop in the DC bus with AC-side chokes is about 5%.

## Multiple Drives and Load Diversity

Because input circuits are virtually standard, harmonics from multiple drives will tend to add algebraically. AS2279.2 allows a “diversity factor” of only 0.9 in dealing with rectifier input equipment. It is important to estimate the largest simultaneous load on multiple VSDs in order to assess harmonic performance. A single VSD with rating equal to this largest simultaneous load should give almost identical harmonics to those produced by the multiple drives.

## Effect of Harmonics on Power Factor

The Power Factor (PF) of a balanced three-phase load is commonly defined by:

$$\mathbf{PF = Real\ Power / (\sqrt{3}\ V_{rms} I_{rms}).}$$

Harmonics in the AC line current tend to increase the rms line current without contributing to real power. Where harmonic currents are large, cable and transformer sizes may need to be increased.

If substantial DC-side chokes are fitted the Power Factor of an AC drive is close to 0.95. If however neither DC-side nor AC-side chokes are fitted the harmonic currents are much larger and the power factor is significantly lower.

## Obtaining network information

To determine the need for any of these measures it will be necessary to have information on the supply such as the supply rating, fault level or supply impedance and level of existing harmonics at the point of common coupling. This information can be obtained from the electricity distributor in the district by contacting the nearest Customer Supply Office.

The Network Planning Engineer should be able to give details on rating of supplies, fault levels and advice on series impedances. For detailed information on harmonics it may be necessary to have a survey carried out by a group such as Testing and Certification Australia, however this will not be a free of charge service.

With this information the graphs and other information given in this paper can be used to predict harmonic levels and the need for filters, or Zener Electric can make an exact analysis of harmonic levels via a CAD circuit simulation to predict harmonic levels for a range of frequencies and the total harmonic distortion.

## Conclusion

Harmonic disturbance with AC variable speed drives is a real concern, but is dependent on several things other than just the drive itself such as:

- the characteristics of the supply such as rating and fault level and the ratio of the drive rating to the rating of the supply,
- the level of existing harmonics in the supply at the point of common coupling,
- the number of drives to be used on the same supply.

Problems with harmonics can be minimized by appropriate design of the AC drive input circuitry. The inclusion of a substantial DC bus choke is a highly effective approach to reduce harmonic disturbance. AC chokes can also be added but with the limitation of voltage drop that is introduced.