INTERHARMONICS IN POWER SYSTEMS

IEEE Interharmonic Task Force, Cigré 36.05/CIRED 2 CC02 Voltage Quality Working Group

Introduction

This paper has been jointly prepared by the IEEE Task Force on Interharmonics and the CC02 (Cigré 36.05/CIRED WG 2) Voltage Quality Working Group for the purpose of summarizing the current state of the art on the subject. This paper is also a starting point for developing engineering guidelines and limits for managing interharmonics in power systems for future inclusion in IEEE 519, IEC-1000 and other relevant standards.

Interharmonics can be thought of as the inter-modulation of the fundamental and harmonic components of the system with any other frequency components and can be observed in an increasing number of loads. These loads include static frequency converters, cycloconverters, sub-synchronous converter cascades, induction motors, arc furnaces and all loads not pulsating synchronously with the fundamental power system frequency [1].

IEEE 519 indirectly addresses interharmonics by discussing cycloconverters which are one of the primary sources of interharmonics on power systems. IEEE 519 does not however, provide any general technical description of the phenomena, methods of measurement, or guidelines for limits. As the sophistication of power electronic interfaces to the power system increases, the frequencies present in the supply current are less likely to be limited to harmonics of the fundamental.

Definition

IEC-1000-2-1 [1] defines interharmonics as follows:

> "Between the harmonics of the power frequency voltage and current, further frequencies can be observed which are not an integer of the fundamental. They can appear as discrete frequencies or as a wide-band spectrum."

Harmonics and interharmonics of a waveform can be defined in terms of its spectral components in the quasi-steady state over a range of frequencies. The following table provides a simple, yet effective mathematical definition:

Harmonic: $f = h * f_1$ where h is an integer > 0
DC: $f = 0$ Hz ($f = h * f_1$ where $h = 0$)
Interharmonic: $f \neq h * f_1$ where h is an integer > 0
Sub-harmonic: $f > 0$ Hz and $f < f_1$

Where f_1 is the fundamental power system frequency

The term sub-harmonic does not have any official definition but is simply a special case of interharmonic for frequency components less than the power system frequency. The term has appeared in several references and is in general use in the engineering community so it is mentioned here for completeness. Use of the term sub-synchronous frequency component is preferred, as it is more descriptive of the phenomena.

The reader may note that if two steady state signals of constant amplitude and different frequencies are linearly superimposed, the resulting time domain waveform is not necessarily periodic even though its components are. An example of such a case is two frequencies that differ in frequency by a non-rational number (e.g. $\sqrt{2}$ or $\sqrt{3}$) – never periodic. A practical example of this situation is the ripple control system used in some countries (e.g. f_1=50, f_2=175) – periodic over 7, 50 Hz cycles. This situation presents interesting challenges when it comes to decomposing such a waveform back into its original steady state components. This will be addressed later when measurement techniques are discussed.

Figure 1 illustrates the waveform produced by a source with the six steady state frequency components shown in Table 1. Clearly, the resulting waveform is not periodic and even appears asymmetric depending on the interval of observation.

Frequency	Magnitude
50	1.0
104	0.3
117	0.4
134	0.2
147	0.2
250	0.5

Table 1 - Frequency Components of Example System

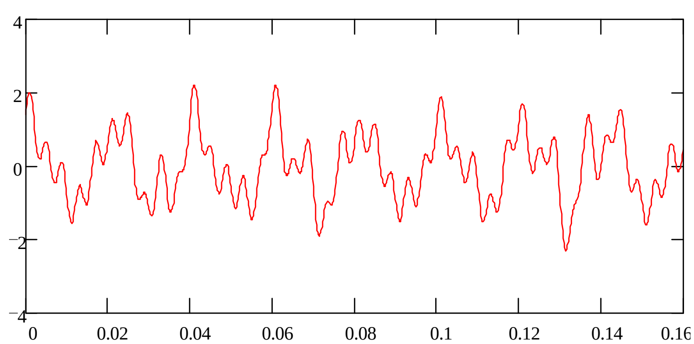

Figure 1 - Waveform With Harmonic and Interharmonic Components

Sources

As mentioned in the introduction, there are a variety of power system loads that result in interharmonic voltages and currents in the power system. Among these sources is the ripple control (power line carrier) system used in many countries. A brief description of other major interharmonic sources follow.

Chief among interharmonic sources is the cycloconverter. Cycloconverters are well-established, reliable units used in a variety of applications from rolling-mill and linear motor drives to static-var generators [2]. Larger mill drives using cycloconverters quoting ranges up to 8 MVA appeared in the 1970's in the cement and mining industries. Today, a 20 MW unit is operating in Australia to drive an ore crusher. Cycloconvertors have also appeared in 25 Hz railroad traction power applications where they are replacing 25 Hz generation and older rotary frequency converters [3].

The currents injected into the power system by cycloconverters have a unique type of spectrum. Unlike the p-pulse rectifier which generates characteristic harmonics [2]:

$$f_i = (p \bullet n \pm 1)\, f_1 \qquad (1)$$

where

f_1 = power frequency
n = 1, 2, 3, …(integers)

cycloconverters have characteristic frequencies of

$$f_i = (p_1 \bullet m \pm 1)\, f_1 \pm p_2 \bullet n \bullet f_o \qquad (2)$$

where:

p_1 = pulse number of the rectifier section
p_2 = pulse number of the output section
m = 0, 1, 2, 3, … (integers)
n = 0, 1, 2, 3, … (integers)
(m and n not simultaneously equal to 0)
f_o = output frequency of the cycloconverter

Figure 2 illustrates a typical input current spectrum of a six-pulse cycloconverter with 5 Hz output frequency.

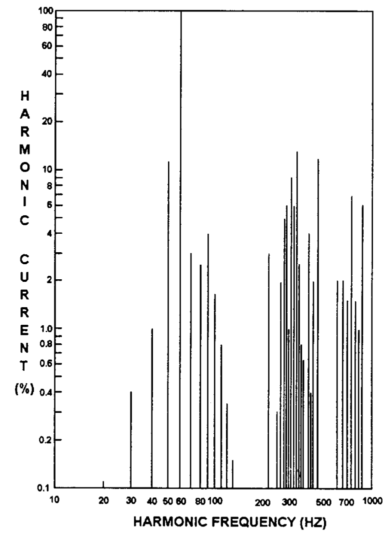

Figure 2 - Typical Cycloconverter Current Spectrum (60 Hz Power System)

Because of load unbalance and asymmetries between phase voltages and the firing angle, non-characteristic frequencies may be present given by the formula in Eq. 3 [2].

$$f_i = (p_1 \bullet m \pm 1) f_1 \pm 2 \bullet n \bullet f_o \qquad (3)$$

Cycloconverters can be thought of as a special case of a more general class of power electronic device - the Static Frequency Converter. Static frequency converters transform the supply voltage into ac voltage of frequency lower or higher that the supply frequency. They consist of two parts, the ac-dc rectifier and a dc-ac inverter. The dc voltage is modulated by the output frequency of the converter and as a result, interharmonic currents appear in the input current according to equations 1 and 2 causing interharmonic voltages to be generated in the supply voltage.

The magnitude of these frequency components depends on the topology of the power electronics and the degree of coupling and filtering between the rectifier and inverter sections. The Cycloconverter is generally the most severe of these devices due to the direct connection between rectifier and inverter common in typical cycloconverter designs, but modern adjustable speed drives may also be of concern.

Another common source of interharmonic currents is an arcing load. This includes arc welders and arc furnaces. These types of loads are typically associated with low frequency voltage fluctuations and the resulting light flicker. These voltage fluctuations can be thought of as low frequency interharmonic components. In addition to these components however, arcing loads also exhibit higher frequency interharmonic components across a wide frequency band.

DC arc furnaces do not normally produce significant interharmonics, except when instability occurs due to interactions between the control system and the filters [4].

Induction motors can also be sources of interharmonics. Induction motors may give rise to an irregular magnetizing current due to the slots in the stator and rotor - possibly in association with saturation of the iron - which generates interharmonics in the low-voltage network. At the normal speed of the motor, the disturbing frequencies are practically in the range of 500 Hz to 2000 Hz, but during the startup period, they may run through the whole frequency range up to their final values.

Induction motors with wound rotor using subsynchronous converter cascades and other doubly fed configurations can also be sources of interharmonics. In a typical doubly fed configuration (Figure 3), the stator is fed from the utility supply, while the rotor is connected to a three phase diode bridge (converter 1) with its DC bus fed from the grid through a three phase thyristor bridge (converter 2). The interharmonics generated by such a device are of two kinds:

- Interharmonics related to the rotor slip frequency, present in the DC link and transferred to the utility supply through the thyristor bridge (sidebands). Their frequencies are given by:

$$(p_2 k \pm 1) f_1 \pm p_1 n s f_1 \qquad (4)$$
$$(k = 0, 1, 2 \ldots \;\&\; n = 1, 2, \ldots)$$

where p_2 is the pulse number of the thyristor bridge (converter 2) and s is the motor slip with respect to the synchronous speed.

- Characteristic harmonics of the rotor diode rectifier bridge, circulating in the rotor windings and coupled through the air gap to the stator. Their frequencies seen from the main supply are normally not an integer of the fundamental; they are given by:

$$(p_1 s k \pm 1) f_1 \qquad (k = 0, 1, 2 \ldots) \qquad (5)$$

where p_1 is the pulse number of the diode bridge (converter 1).

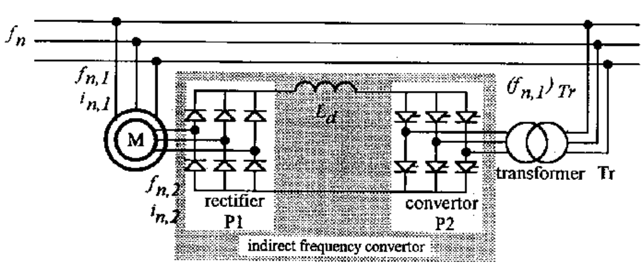

Figure 3 – Subsynchronous Converter Cascade

Another important source of interharmonic currents that is becoming more popular are loads that use Integral Cycle Control. This technique is beginning to replace mechanical contactors and phase control systems [5]. These devices operate by reducing the voltage to zero in increments of one or more integral cycles (or half cycles) in a periodic fashion. This results in an average voltage over the long term less than the power system voltage. Figure 4 illustrates a typical waveform.

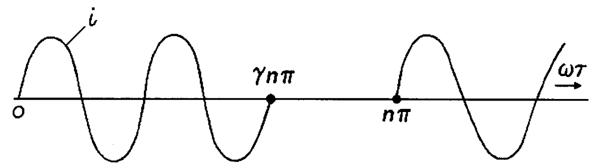

Figure 4 – Integral Cycle Control Waveform

Typical applications are ovens, furnaces, die heaters, and spot-welders. In the United States, three-phase units (600 and 2000 volts) with the capacity for controlling 2-MW furnaces are listed by various manufacturers. The current generated by these systems have a spectrum that is practically lacking in harmonics greater than twice the fundamental (Figure 5).

Impacts

For interharmonic frequency components greater than the power frequency, heating effects are observed in the same fashion as those caused by harmonic currents and will not be discussed further here. In addition to heating effects, a variety of system impacts have been reported. These effects include CRT flicker, torsional oscillations, overload of conventional series tuned filters, overload of outlet strip filters, communications interference, ripple control (power line carrier) interference, and CT saturation.

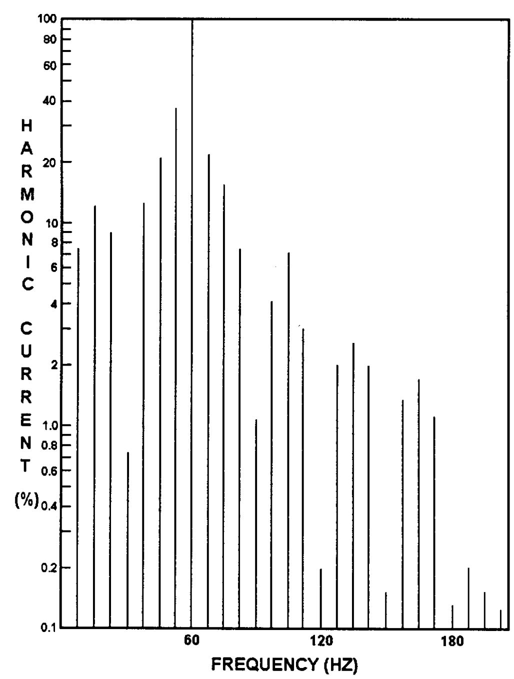

Figure 5 – ICC Spectrum (60 Hz Power System)

Interharmonics that excite torsional oscillations in turbo-generator shafts can be a significant concern. One report [12] showed that one large (775 MW) turbine generator has been put at risk by a current source converter of a type used for slip energy recovery in induction motors. The reported result was torque amplitudes that reached twice the nominal value. With the number of stress cycles greater than 10^6, there was an expectation of a serious reduction in the service life expectancy of certain shaft sections. Reference [13] provides more detail on this phenomena.

One of the more important effects of interharmonics is the impact on light flicker. Since a renewed look at flicker standards and measurements is currently underway within IEEE, interharmonic flicker effects are described here as an example of possible system impacts.

Modulation of a steady state interharmonic voltage on the fundamental power system voltage introduces variations in system voltage amplitude and rms value:

$$u(t) = \sin(2\pi f_1 t) + a \sin(2\pi f_i t) \quad (6)$$

where:

f_1 - fundamental frequency
a - amplitude of interharmonic voltage (p.u.)
f_i - interharmonic frequency
(the amplitude of the fundamental voltage is equal to 1.0 p.u.)
The maximum voltage change in voltage amplitude is equal to the amplitude of the interharmonic voltage, while the changes in voltage rms value is depending both on the amplitude and the interharmonic frequency.

The voltage rms value is given by:

$$U := \sqrt{\frac{1}{T}\cdot\int_0^T u(t)^2\,dt} \quad (7)$$

Where:
the period of integration $T = 1/f_1$

The maximum of the percent deviation of the rms voltage over several periods of the fundamental due to interharmonics can be calculated by combining equations (6) and (7). This is illustrated in Figure 6 for the case of interharmonic voltage distortion of 0.2% of the fundamental voltage.

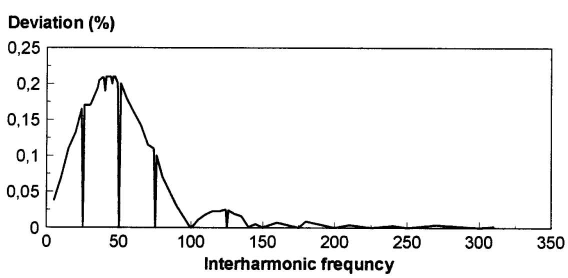

Figure 6 – rms Voltage Deviation with 0.2% Distortion (50 Hz Power System)

As shown in the figure, at interharmonic frequencies higher than twice the power frequency, the modulation impact on the rms value is small compared to the impact in the frequency range below the second harmonic.

A similar analysis can be done relating the peak voltage deviations with interharmonic frequency. The interface between electronic equipment and the AC power system is the DC power supply comprising rectifiers, a capacitor and a regulator. The presence of the rectifiers ensures that only the AC voltage peaks charge the capacitor voltage. Since, from one cycle to another, these peaks always reach the same amplitude, the regulator corrects the fluctuations at the capacitor terminals.

The addition of harmonics to the supply signal does not affect the fluctuation because these harmonics are synchronized with the fundamental of the power system. However, interharmonics, which are not synchronized, do affect the peak amplitude of the AC voltage supply (Figure 7). Consequently, recharging of the capacitor varies from one cycle to another, resulting in an increase in the fluctuation upstream of the regulator and, since this fluctuation is excessive, it affects the operation of the equipment.

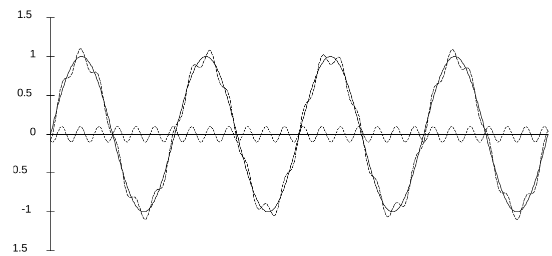

Figure 7 – Peak Voltage Change due to Interharmonic

The distorted waveform illustrated in Figure 8a is calculated as follows:

$$V(t) = V_1 \sin(2\cdot\pi\cdot f_1\cdot t) + V_n\cdot\sin(2\cdot\pi\cdot f\cdot n\cdot t + b)$$

where
V_1 = amplitude of the voltage at fundamental frequency
t = time
f_1 = fundamental frequency (60 Hz)
V_n = amplitude of the interharmonic of order n
n = fractional real number of the interharmonic order

The variation or modulation of the voltage amplitude is calculated from the difference between the maximum and the minimum peak values (V_{max} and V_{min}) recorded over several cycles of the function V(t):

$$\Delta V = V_{max} - V_{min} \quad (9)$$

For interharmonic values of only 5%, the modulation amplitude is as high as 10% up to the seventh harmonic then decreases exponentially. Figure 8 presents the variations ΔV for $½ < n < 30$ (30 to 1800 Hz) and $V_n = 5\%$.

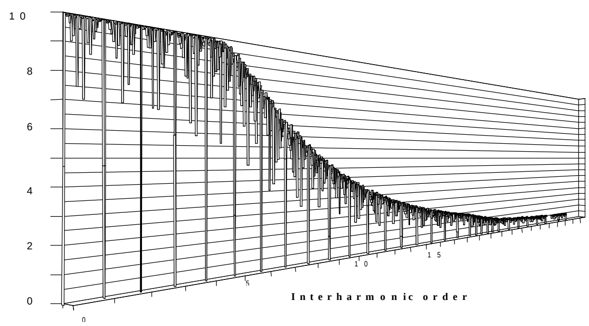

Figure 8 - Modulation in the AC voltage peaks vs. interharmonics

Differentiation between peak and rms deviation impacts can be important since some loads are affected more by peak variations than rms variations. For example, compact fluorescent lamps have been shown to be more sensitive to peak variations than rms variations. Incandescent lamps however, are more sensitive to rms variations. It is interesting to note that the IEC standard flickermeter [6] is sensitive to rms variations as opposed to peak variations.

As interharmonics are a source of voltage fluctuation, the risk of light flicker exists if the level of interharmonic voltages exceeds certain immunity levels. Figure 9 illustrates light flicker sensation thresholds for an incandescent lamp (system frequency - 50 Hz). The threshold represents the level at which a person tested in a laboratory has perceived light flicker.

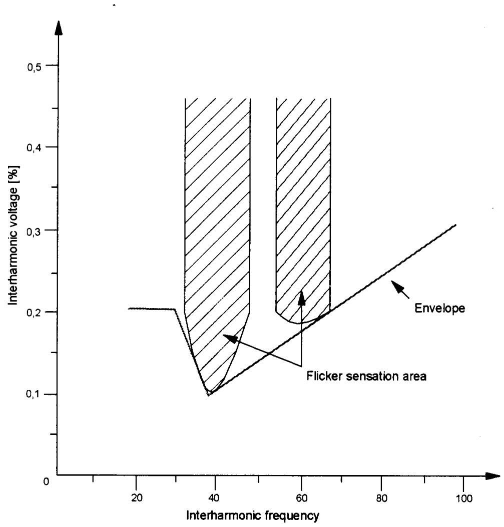

Figure 9 - Flicker Sensation Area - Incandescent Lamp

Note that the visible light flicker effect occurs for frequencies surrounding the fundamental power frequency and odd harmonics. Figure 10 shows the experimental flicker perceptibility threshold for a fluorescent tube (58 W / length = 1500 mm) with two different ballast's (classical inductive ballast and electronic ballast) on a 50 Hz power system.

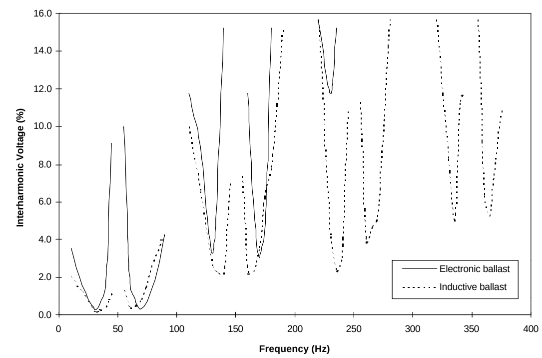

Figure 10 - Flicker Perceptibility Threshold – 58 W Fluorescent

As shown in the figures, the tolerable level of interharmonics increases with frequency. This is due to a decreasing effect of interharmonics on the rms voltage with frequency as well as the influence of the lamp time constant.

Overall, the metal halogen lamp turned out to be more sensitive over the frequency range tested (0 - 800 Hz). In the interharmonic frequency range below 70 Hz, the incandescent lamp showed almost the same flicker sensitivity as the metal halogen lamp, but for the frequencies higher than 70 Hz, the incandescent lamp shows the largest insensitivity of all lamps.

Measurement

The measurement of interharmonics poses some interesting problems for traditional power system monitoring equipment. As discussed earlier, a waveform consisting of just two frequency components that are not harmonically related may not be periodic.

Most power system monitors that perform frequency domain measurements take advantage of the usual situation where only harmonics are present. These instruments use phase locked loop technology to lock on to the fundamental frequency and sample one or more cycles for analysis using the Fast Fourier Transform (FFT). Due to the phase lock, single cycle samples can yield accurate representation of the harmonic content of the waveform as long as there are no interharmonic components.

When frequencies other than those harmonically related to the sampling period are present, and/or the sampled waveform is not periodic over the sampling interval, errors are encountered due to end-effect.

The power industry has been able to extract a lot of information out of measurements made on the power system for harmonic analysis due to the dominance of this special case of the general situation - power system frequency components are dominated by frequency components harmonically linked to the power system fundamental frequency. This special case simplifies accurate measurement of magnitudes and phase angle of these components, determine power flow at these frequencies easily as well as their direction of flow - all things that are much more difficult to do in the general case in the frequency domain.

Identification of interharmonic components need not inherently involve any analysis or association relative to the power supply frequency. This method of signal analysis is analogous to signal analysis techniques used in the communications and broadcast industries. Concepts, limits, standards and measurement equipment have been successfully used in these industries for decades to identify steady state signal levels without the need to phase lock or otherwise reference some arbitrary frequency or dominant signal component.

The method normally used to minimize end-effects and obtain accurate magnitude and frequency information in the general case of spectral analysis involves the use of windowing functions. Windowing functions weight the waveform to be processed by the FFT in such a way as to taper the ends of the sample to near zero. There is considerable art involved in the selection of appropriate windowing functions for different types of analysis, but for the purpose of this discussion, the popular Hanning window will be used.

Figure 11 illustrates the example waveform used earlier (Figure 1) with the Hanning window applied. The resulting spectrum is shown in Figure 12.

Figure 11 - Result of Hanning Window

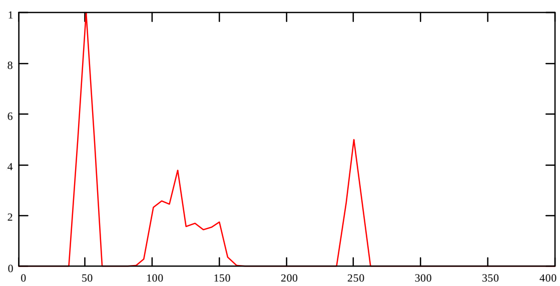

Figure 12 - Result of FFT Analysis of Figure 11

Even with the use of windowing functions, closely spaced interharmonic frequencies are hard to determine due to the resolution of the FFT as determined by the original sampling period (8 50 Hz cycles in this case). It has been shown that the use of the zero padding technique can result in a much more accurate determination of the actual interharmonic frequency component magnitudes and frequencies [7]. Figure 13 shows the results of applying a four-fold zero padding before performing the FFT.

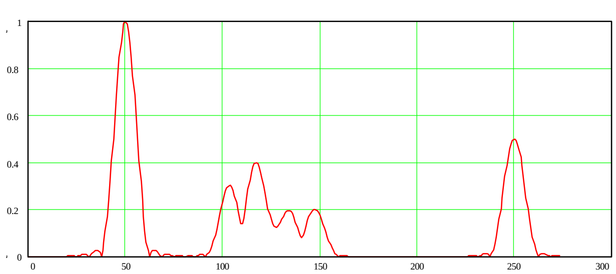

Figure 13 - Result of FFT Analysis of Figure 11 with Four-Fold Zero Padding

Note that the resolution has been improved enough to accurately determine the magnitude and frequency of each component even though the sampled waveform was not periodic and some of the interharmonic components are very close to each other.

The method of measurement just presented is useful for diagnostic procedures where it is desired to characterize a particular waveform in detail. This method may not be appropriate for the general case of monitoring for standards enforcement.

There are many different reasons and purposes for performing any kind of a measurement. These include the evaluation of a specific problem (diagnostic), general surveying of the electrical environment, compatibility testing, and compliance monitoring. In a diagnostic mode, an engineer may be trying to use measurement equipment to identify a particular signal source and its characteristics. Compliance monitoring on the other hand is done without regard to any end-use or source considerations, but rather is simply concerned with evaluating a signal against applicable standards. The former method requires measurement techniques that are flexible and detailed enough to determine the solution to a specific problem. The latter requires simplicity and repeatability. Differing goals such as these often require different measurement techniques and equipment.

A method for simplifying interharmonic measurements is being proposed by the IEC. This method would fix the sampling interval of a waveform to result in a fixed set of spectra for harmonic and interharmonic evaluation. The present proposal would fix the frequency resolution at 5 Hz (10 or 12 cycle sample windows for 50 or 60 Hz systems respectively). Phase locked loop or other line frequency synchronization technique would be used to minimize signals being registered in frequency bins due to end-effect errors. The resulting frequency bin spacing should result in harmonic components being resolved accurately with a minimum of contamination of their frequency bins by interharmonic components.

Interharmonic components that are in between the 6 Hz or 10 Hz bins would spill over primarily into adjacent interharmonic bins with a minimum of spill into harmonic bins. This approach is attractive for compliance monitoring and compatibility testing since compatibility levels can be defined based on the energy registered in the fixed interharmonic bins and the resulting total interharmonic distortion figure rather than relying on precise measurement of specific frequencies. The drawback is that this method may not be suited for the diagnostic mode of monitoring in all cases.

A number of other methods have been reported in the literature and are applicable in a variety of situations. Some of the more interesting methods include the interpolated FFT [8] and the quasi-synchronous algorithm [9].

Analysis

When it comes to defining compatibility levels and limits for interharmonics in power systems, a set of appropriate indices must be defined to facilitate standards development. The use of the proposed IEC method discussed in the measurement section has the benefit of enabling the specification of limits for each of several sets of partial interharmonic groups (as described in the CEA Guide to Performing Power Quality Surveys [10]). The magnitude of each interharmonic group could therefore be an index.

The proposed IEC method defines interharmonic groups. These indices are the rms value of the interharmonic components between adjacent harmonic components. The frequency bins directly adjacent to the harmonic bins are omitted. This relationship is defined by equation (10).

$$X_{IH}^2 = \sum_{i=2}^{8} X_{10n+i}^2 \qquad \text{(50 Hz systems)}$$

(10)

$$X_{IH}^2 = \sum_{i=2}^{9} X_{12n+i}^2 \qquad \text{(60 Hz systems)}$$

Where n is the Interharmonic group of interest and i is the Interharmonic bin being summed.

In harmonic analysis, engineers are used to simplifying indices such as total harmonic distortion (THD) that provide a general indication of the condition of the waveform. Similar indices are possible for waveforms with interharmonic components. The following formulas may be used:

$$THD \equiv \frac{\sqrt{\sum_{h=1}^{n} (V_h)^2}}{V_1} \qquad (11)$$

$$TIHD \equiv \frac{\sqrt{\sum_{i=1}^{n} (V_i)^2}}{V_1} \qquad (12)$$

where h is the total number of harmonics considered, i is the total number of interharmonics considered, n is the total number of frequency bins present, and n=h+i. In this context, subharmonics are considered to be a subset of interharmonics. If it is important to distinguish subharmonics from interharmonics, equation 13 can be used.

$$TSHD \equiv \frac{\sqrt{\sum_{s=1}^{n} (V_s)^2}}{V_1} \qquad (13)$$

$$TIHD = \frac{\sqrt{V_{RMS}^2 - V_1^2}}{V_1} \qquad (14)$$

where s is the total number of frequency bins present below the fundamental frequency. If all three indices are considered, then h is the number of harmonics considered, i is the number of interharmonics considered (greater than the fundamental frequency), s is the number of subharmonics considered, n is the total number of frequency bins, and n=h+i+s.

In some cases, it may be difficult to use existing instrumentation to determine exactly the magnitudes of the interharmonics in (12), including subharmonics as the special case. For these situations, it may be more accurate to specify the rms value of all interharmonics in terms of the rms value of the complete waveform as shown in (14).

The evaluation of (14) depends on the availability the "true rms" value which can only be approximated for non-periodic waveforms. This value may be provided directly by instruments, or it can be calculated using from waveform sample data given the waveform period. Over the time period of interest, most waveforms will be "nearly periodic" in which case the approximation will be acceptable for most applications. Equation (14) is exact for periodic waveforms.

Mitigation

There are a variety of techniques that can be used to mitigate interharmonics. The most common technique is through the use of passive filters. This approach has been used successfully over many years to control interharmonic and harmonic distortion from arcing loads and cycloconverters.

Traditional filtering methods used for harmonic control are not sufficient when interharmonics are present. This is due to the fact that a simple series tuned harmonic filter causes a new parallel resonance at a frequency just below the tuned frequency. When interharmonics are not present this is not a problem, but if they are, significant magnification of the voltage distortion can occur at the parallel resonant frequency. For example, a series tuned fifth harmonic filter has a sharp parallel resonance near the fourth harmonic.

To overcome this problem, filters must be designed with damping resistors to minimize the magnitude of the parallel resonance. Unfortunately, this is expensive and results in additional real power losses in the filter.

Another difficulty with an interharmonic filter design, is that interharmonic producing loads tend to produce frequency components over a wide range of frequencies. This leads to the design of multi-stage filters which adds to the complexity and cost.

Figure 14 illustrates a design recently evaluated for a facility that had a DC arc furnace and cycloconverters. This design uses a third order fifth harmonic filter that provides damping across a wide range of frequencies. The series LC in parallel with the resistor is tuned to the power frequency to minimize losses.

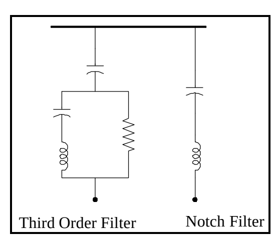

Figure 14 - Minimal Loss Design

In addition to this filter, a traditional notch filter is applied around the 8^{th} or 11^{th} harmonic to control emissions in that range. The parallel resonance produced by the notch filter is reduced due to the damping provided by the third order filter. This effect can be seen in Figure 15 which illustrates the current amplification factor for three design options (the curve of interest is labeled Section 1, Filter Option 3 in the figure). This design has a minimum of components and has low losses.

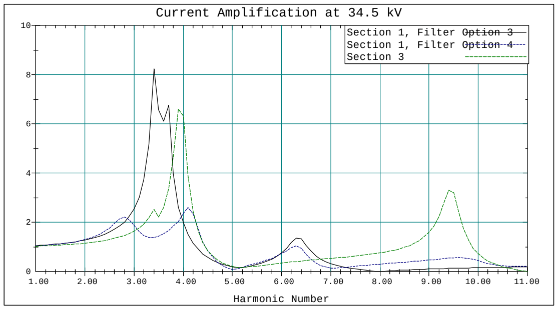

Figure 15 - Current Magnification for Various Designs

Figure 16 shows an alternate design that minimizes the current magnification over a wide range of frequencies. This design is better from a minimization of current magnification point of view, but is much more expensive and lossy. Figure 15 shows the current magnification for this configuration (labeled as Section 1, Filter Option 4).

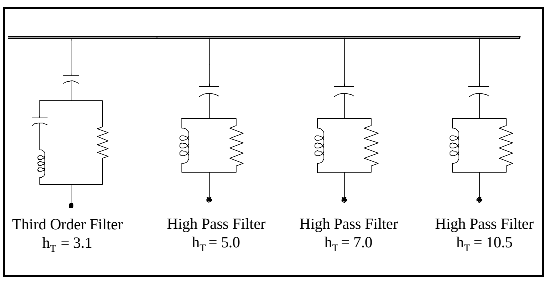

Figure 16 - Minimum Magnification Design

In addition to the use of passive filter schemes described above, a new generation of devices is now becoming available. These devices, commonly referred to as active or dynamic filters, use advanced power electronic techniques to continuously control harmonic and interharmonic levels in real-time. A guide to the application of active power conditioners is expected to be published by Cigré in the near future.

Conclusion

Interharmonics are an important class of power system phenomena that is becoming more prevalent as power electronic load levels increase on the power system.

Interharmonic voltage limits are not well established internationally. An interharmonic voltage limit of 0.2% of the fundamental voltage is given in IEC publication 1000-2-2 [11] based on the following:

- Risk of interference to low frequency power line carrier systems (ripple control)
- Risk of light flicker

The CENELEC Standard EN 50160 gives no values pending more experience. Given this lack of clear standards in this area, more work is needed to gather practical experience necessary to suggest compatibility levels and emission limits to standards setting organizations.

In addition to setting limits, clear measurement protocols must be defined. The revision to IEC 1000-4-7 is expected to address this issue.

References

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