# Interharmonics

## *Definition*

IEC-1000-2-1 [1] defines interharmonic 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.

## Sources

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. They 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]:

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

where

$f$ = power frequency
$n = 1, 2, 3, \ldots$(integers)

cycloconverters have characteristic frequencies of

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

where:

$p_1$ = pulse number of the rectifier section
$p_2$ = pulse number of the output section
$m = 0, 1, 2, 3, \ldots$ (integers)
$n = 0, 1, 2, 3, \ldots$ (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.

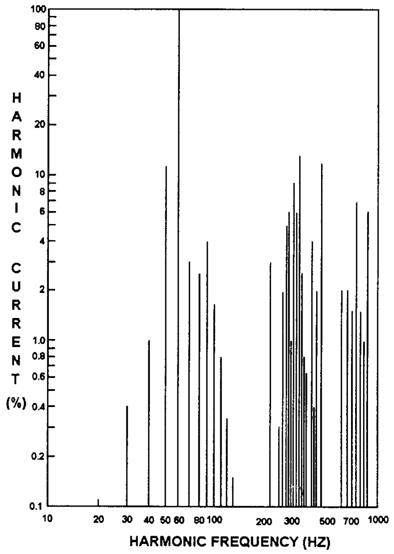


Figure 2 - Typical Cycloconverter Current Spectrum (60 Hz Power System)

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.

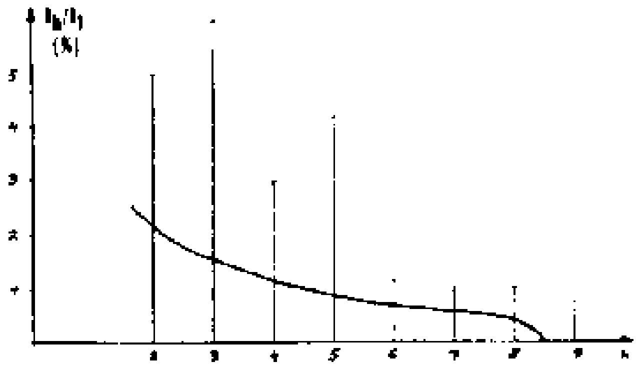


Figure 3 – Example of AC Arc Furnace Interharmonics

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

Other sources of interharmonics include [xx]:

- Induction motors (wound root and subsynchronous converter cascade)
- Integral cycle control (heating applications)
- Low frequency power line carrier (ripple control)

## *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, overload of conventional series tuned filters, overload of outlet strip filters, communications interference, and CT saturation.

One of the more important effects of interharmonics is the impact on light flicker. Modulation of a steady state interharmonic voltage on the fundamental power system voltage introduces variations in system voltage amplitude and rms value:

$$u(t) = \sin(2\,\mathrm{pi}\, f\, t) + a \sin(2\,\mathrm{pi}\, f_i\, t) \qquad (6)$$

where:

f - 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:

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

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 7 for the case of interharmonic voltage distortion of 0.2% of the fundamental voltage.

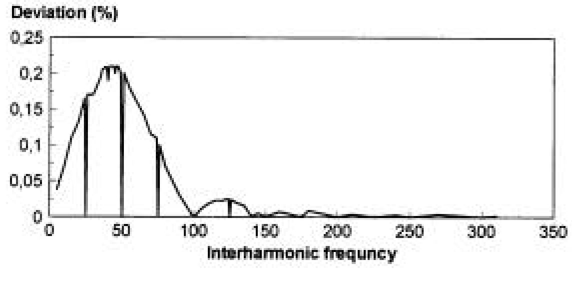
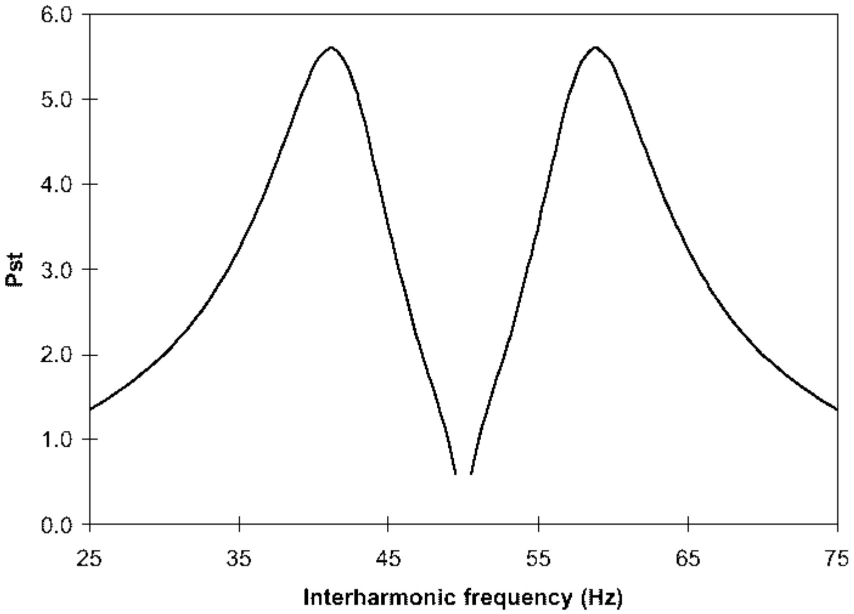


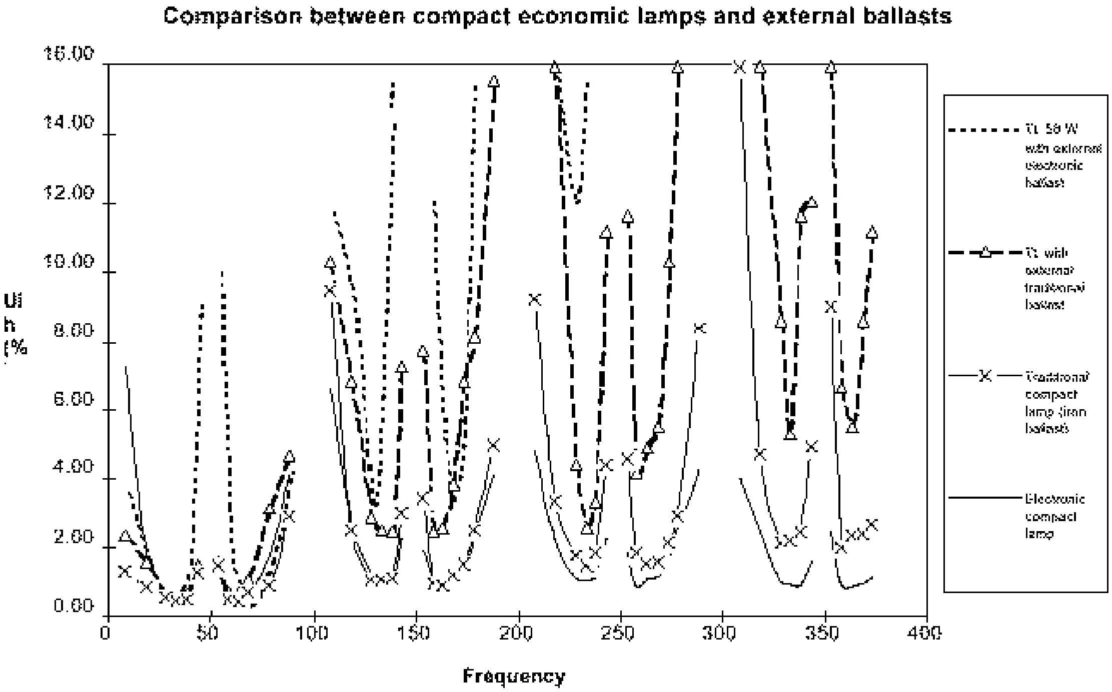
Figure 7 – rms Voltage Deviation with 0.2% Distortion
(50 Hz Power System)

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.

The IEC flicker meter is used to measure light flicker indirectly by simulating the response of an incandescent lamp and the human eye-brain response to visual stimuli. When this algorithm is used to calculate the flicker level that would be produced due to a 1% interharmonic component near fundamental frequency, high levels of flicker (> 5 Pst) can be observed as shown in Figure xx.



Field tests of various lamps supplied by voltage containing varying levels of interharmonic distortion were done[xx]. Figure xx illustrates the results of these tests. The figure clearly indicates that these lamps produce visible light flicker even when there is no significant change in the overall RMS value of the waveform as shown in Figure 7. This is due to the changes in peak voltage over time due to the intermodulation of the harmonic and interharmonic components. This is evident in Figure xx in that the most visible flicker occurs at around +/- 8 Hz of a power system harmonic. This is due to the fact that the eye is most sensitive to 8 Hz variations in light intensity[xx].



In addition to light flicker, the following impacts may be of concern:

- Excitation of sub-synchronous condition in turbo-generator shafts
- Interharmonic currents cause interharmonic voltage distortion according to the system impedance in the same manner as for harmonics and has similar impacts and concerns.
- Interharmonics can interfere with low frequency power line carrier control signals.
- Series tuned filters commonly applied on power systems to limit 5th through 13th harmonic voltage distortion and comply with the existing 519 cause parallel resonance (high impedance) at interharmonic frequencies (e.g. 250 Hz for a 5th harmonic filter). Filter designers expect this bandwidth to be clear of intentional signals. Interharmonic currents/voltages at these frequencies can be magnified. Filter failure and/or loss of life can result.

## Measurement

IEC 61000-4-7 established a well disciplined measurement method for harmonics. This standard has recently been revised to clarify aspects of the older version and add methodology for measuring interharmonics. The reader is referred to the standard for details, but key to the measurement of both harmonics and interharmonics in the standard is the utilization of a 10 or 12 cycle sample window upon which to perform the Fourier transform. The result is a spectrum with 5 Hz resolution for both 50 Hz and 60 Hz systems. The standard further defines ways of combining individual 5 Hz bins to produce various groupings and components for which limits and guidelines can be referenced to. Figure xx illustrates these groupings:

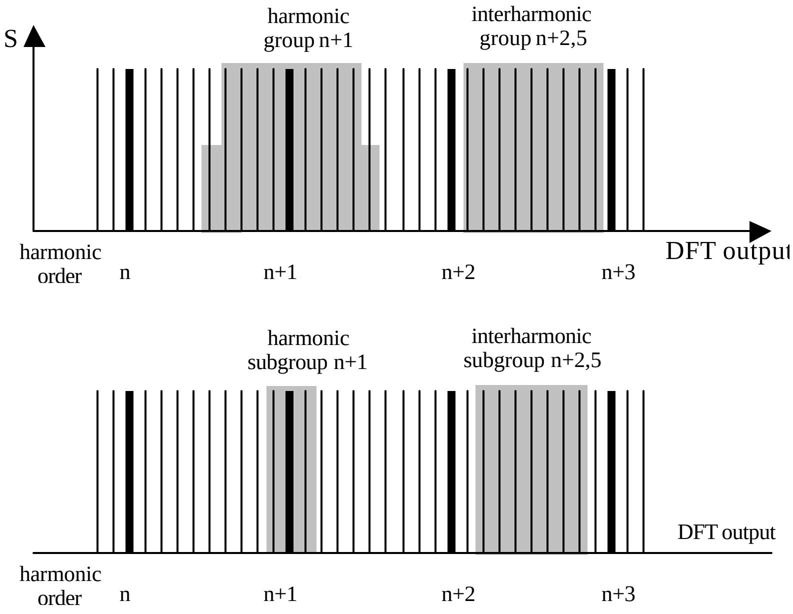


Figure xx – Ilustration of harmonic and interharmonic groups and sub-groups
(here represented for a 50Hz window)

From these definitions, measurements can reported for each interharmonic group, as well as a figure for total interharmonic distortion and normalized to the fundamental, overall r.m.s. value or a declared value (e.g. average maximum demand load current $I_L$). These quantities then form the basis for defining limits.

## Limits

Interharmonic currents present the same problems with heating and inductive interference as do harmonic currents. Therefore it is recommended that interharmonic currents be limited in the same manner as harmonic currents in IEEE 519-1992 Table 10.1.

The present state-of-the-art for interharmonic limits revolves around the theoretical and observed impact of interharmonic voltage distortion as described in this document. As such, there has only been experience in defining voltage distortion limits. Presently, the IEC limits interharmonic voltage distortion to 0.2 % for the frequency range from DC to 2 kHz.

IHTF Chairman's recommendations:

- Adopt the IEC limit of 0.2% for frequencies less than 140 Hz to address flicker of incandescent lamps and fluorescent lamps with reasonable gain factors.
- Limit individual interharmonic component voltage distortion to less than 1% above 140 Hz up to some frequency yet to be determined (e.g. 800 Hz) to protect low frequency PLC, address sensitivity to light flicker within 8 Hz of harmonic frequencies, and account for resonances created by harmonic filters.
- For higher frequencies, limit interharmonic voltage component and total distortion to some percentage related to proposed frequency dependent harmonic voltage limits (e.g. say 1/5) to protect higher frequency PLC and filter resonances. Alternatively, define a linear limit curve with increasing slope as is done in the UK's G5/4. This recognizes the reduced impact on light flicker with increasing frequency.

## References

[1] CEI/IEC 1000-2-1:1990, “Electromagnetic Compatibility”, Part 2: Environment, Sect. 1: Description of the environment – Electromagnetic environment for low-frequency conducted disturbances and signalling in public power supply systems. First Edition, 1990-05

[2] B. R. Pelly, “Thyristor Phase-Controlled Converters and Cycloconverters”, John Wiley and Sons, New York, 1971.

[3] R. F. Chu and J.J. Burns. “Impact of Cycloconverter Harmonics”, IEEE Transactions on Industry Applications, Vol. 25, No. 3, May/June 1989, pp. 427-435.

[4] L. Tang, D. Mueller, “Analysis of DC Arc Furnace Operation and Flicker Caused by 187 Hz Voltage Distortion”, Presented at IEEE-PES 1993 Summer Meeting July 18-22, 1993, Vancouver, BC.

[5] W. Shepard, “Thyristor Control of AC Circuits”, Bradford University Press, England, 1976.

[6] CEI/IEC 868, “Flickermeter”, Functional Design Specification, First Edition, 1986.

[7] X. Dai, R. Gretsch, “A Fast and Accurate Method to Measure Interharmonics in Power Systems”.

[8] P. Langlois and R. Bergeron, “Interharmonic Analysis by a Frequency Interpolation Method”, Proceedings of the Second International Conference on Power Quality, pp.E-26:1-7, Atlanta, US, Sep 1992.

[9] X. Dai. et. al., “Quasi-synchronous Sampling Algorithm and its Application – 2. High Accurate Spectrum Analysis of Periodic Signal”, Conference Record of IEEE IMTC/93, Los Angeles, US, pp. 94-98, May 1993.

[10] CEA Guide to Performing Power Quality Surveys

[11] CEI/IEC 1000-2-2:1990, “Electromagnetic Compatibility”, Part 2: Environment, Section. 2:Compatibility levels for low-frequency conducted disturbances and signalling in low-voltage power supply systems. First Edition, 1990-05

EPRI Power Electronics Applications Center, Lamp Flicker Predicted by Gain-Factor Measurements, Brief n°36, July 1996 [Magazine Article]

IEC, 61000-4-15 - CEM - Part 4 : Testing and measurement techniques – Section 15 : Flickermeter – Functional and design specifications, November-1997 [International standard]

E. Gunther et. al. - Interharmonics in Power Systems, Cigre 2000

UIE Working Group, Flicker Measurement and Evaluation, Disturbances, 1992 [Report]

W. Mombauer, Flicker-Simulation & Minimalisation, Forschungsgemeinschaft für Hochspannungs - und Hochstromtechnik e.V., Mannheim [Conference Paper]

W. Mombauer, Flicker caused by interharmonics, etzArchiv, Bd.12 H.12, 1990 [Magazine Article]

UK G5/4 harmonic standard

IEEE 519-1992

IEC 61000-4-7 Second Edition (at CDV stage as of this writing)