Network 2 is made with 3 Network 1 units, connecting all neutral conductors together.

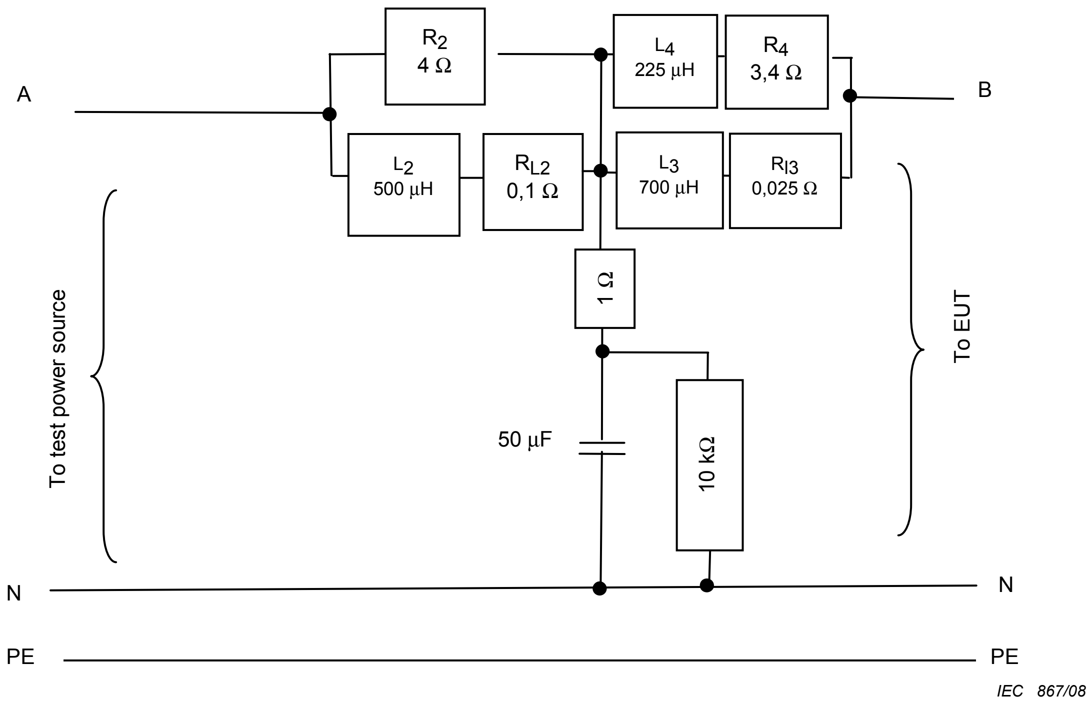


Figure B.3 – Artificial mains network for 16-A current and below

NOTE If an AC power source is used, its inductance and resistance should not exceed 160 µH and 0,1 Ω.

B.5 Performance requirements

The uncertainty of the whole measurement (measuring instrument including shunt or CT) shall not exceed ±10 %of the measured current when tested with a single-frequency signal. The instrument manufacturer shall specify the measuring range over which this ±10 %uncertainty applies.

The total uncertainty of the measurement including the AMN should not exceed ±15 % of the applicable group value $Y_{B,b}$.

NOTE The power source should fulfil the operating requirement of the EUT. Provided the applicable frequency, voltage, and adequate power rating are available, the low voltage public supply voltage may be used as the test voltage source. Alternatively, a suitable power source may be used.

If a current shunt is used at point B, it should have a value of a maximum of 0,02 Ω.

The AMN should present to the EUT an impedance characteristic measured between B and N, with A connected directly to N, within ±5 % of the characteristic shown in Figure B.4 in the range 2 kHz to 9 kHz. Component tolerances should therefore be selected so as not to exceed this tolerance when subjected to EUT current, temperature and frequencies under operating conditions. Physical layout, packaging, and temperature control of the AMN should be designed with these tolerance requirements in mind.

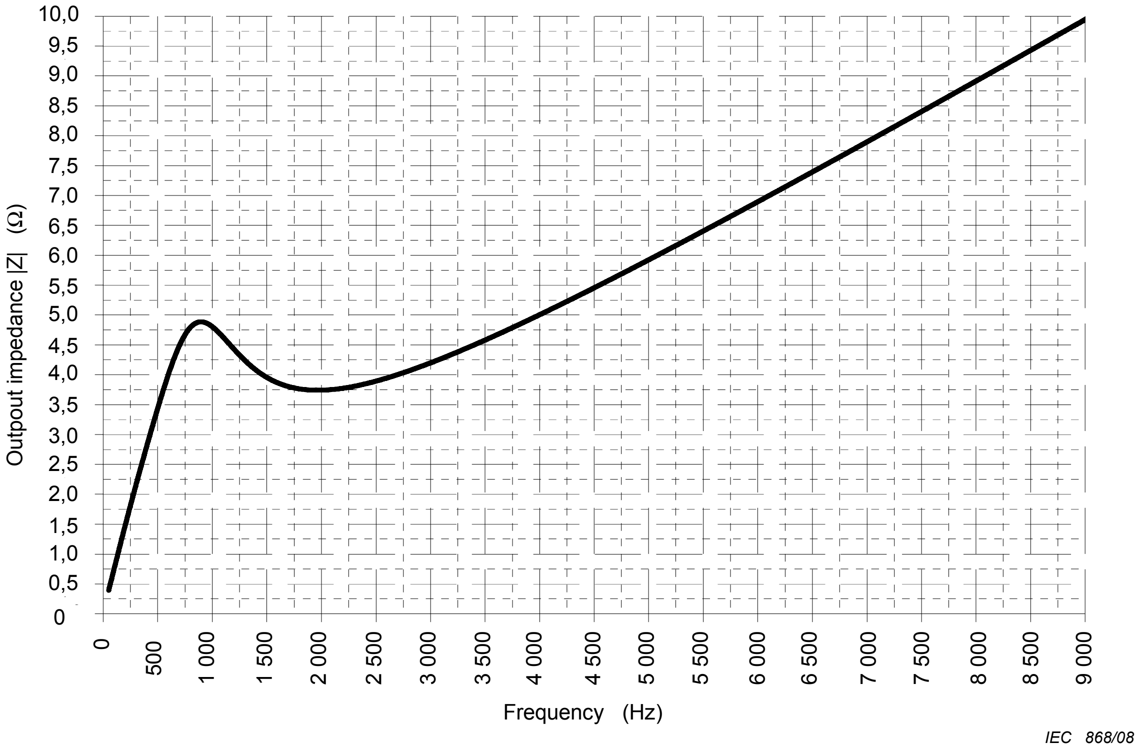


Figure B.4 – Artificial mains network impedance viewed by the EUT

At 2 050 Hz and 2 450 Hz, the output impedance are respectively 3,745 051 and 3,868 689. Output impedance for frequencies f above 3 kHz is obtained by the following equation.

$$|Z| = \sqrt{8{,}819 + 1{,}23 \times 10^{-7} \times f^{2} \ln(f)}$$

Annex C
(informative)

Technical considerations for grouping method

Measurement methods defined in this standard follow from careful consideration and balancing of competing objectives (for example, measurement bandwidth and frequency resolution). In certain cases, the need for defining a practical measurement results in compromises rather than the achievement of the ultimate in precision in characterising the signal in question. Considerations for resolution of several particularly difficult issues are documented in this annex.

NOTE In this standard, voltage and current values are r.m.s. unless otherwise stated.

C.1 Power equivalence of time and frequency domain representations of signals

Parseval's relation, also known as the Rayleigh energy theorem, defines the equivalence of signal power (or energy) expressed in the time domain to signal power (or energy) expressed in the frequency domain.

$$\int_{-\infty}^{+\infty} [g(t)]^2 \, dt = \frac{1}{2\pi} \int_{-\infty}^{+\infty} |G(j\omega)|^2 \, d\omega \qquad \text{(C1)}$$

where

$g(t)$ is a time function;

$G(j\omega)$ is the complex Fourier transform of the function; and

$\omega = 2\pi f$.

NOTE Since the power is proportional to the square of a voltage or current the squared signal is understood to be the "power" of the signal. For example, if $g(t)$ is assumed to be the time function of a voltage, the physical dimension of the left-hand side of the equation (time domain) would be V^2 s ("energy"). The Fourier transform presents the spectral density of the voltage and, in the example, $G(j\omega)$ would have the dimension V/Hz or V s, i.e. the right-hand side yields also the dimension V^2 s ("energy").

If the function is not periodic, its spectrum is continuous, but if it is periodic it can be represented in a time window T_w, i.e. the infinite repetition of the time window would yield the total function $g(t)$. The Fourier transform of this now time-limited signal is no longer continuous but consists of spectral lines at a frequency distance of $f_w = 1/T_w$. The product of the window time T_w and the squared r.m.s. value, G_k^2, of the (complex) line at the frequency $f = k \times f_w$ represents approximately the "energy" of the continuous spectral density integrated over $f - f_w/2$ to $f + f_w/2$. The "energy" sum contributed by all spectral lines is equivalent to the "energy" of the time function within the window. Dividing the "energy" by the window time T_w yields equation (C2):

$$\frac{1}{T_W} \int_{-T_W/2}^{+T_W/2} [g(t)]^2 \, dt = \sum_{k=-\infty}^{\infty} |G_k|^2 \qquad \text{(C2)}$$

where

the left-hand side corresponds to the average "power" of the time function within the window; and

the right-hand side to the total "power" of all lines within the spectrum.

A characteristic of the Fourier transform is that the spectral lines at negative frequencies are conjugate complex to the lines at the same positive frequencies, i. e. the "power" spectrum is symmetrical about the frequency f = 0. By folding the negative part of the spectrum over the positive one, equation (C2) is simplified:

$$\frac{1}{T_W}\int_{-T_W/2}^{+T_W/2}[g(t)]^2\,dt = G_0^2 + 2\sum_{k=1}^{\infty}|G_k|^2 \qquad \text{(C3)}$$

The definition of the amplitude c_k of the Fourier components according to equation (3) of the standard is related to $T_w/2$, not to T_w (except c_0 which is related to T_w), i.e. c_k = 2 × G_k or $C_k = \sqrt{\mathbf{2}} \times G_k$. Equation (C3) can therefore be rewritten:

$$\frac{1}{T_W}\int_{-T_W/2}^{+T_W/2}[g(t)]^2\,dt = c_0^2 + \sum_{k=1}^{\infty}|C_k|^2 = \sum_{k=0}^{\infty}|C_k|^2 \qquad \text{(C4)}$$

In practice, the number of coefficients in the sum has to be limited: k = 1 … K. If the signal is "band-limited" to frequencies $f_K \leq K \times f_w$, no "power" is associated with coefficients of order $k > K$, and they can be left out of the sum in equation (C4). The frequency f_K should be well beyond the operating frequency range of the instrument.

C.2 Characteristics of digital realisation

Digital instrumentation is considered in this standard. In order to fulfil the Shannon theorem, the time signal should be sampled with a sampling frequency $f_s > 2 \times f_K$ so that – in principle – all coefficients up to C_K can be calculated. The number of samples within a time window is $N = f_s \times T_w$.

Under the above-mentioned ideal conditions, i.e. the digitized signal is real, periodic and band-limited, and the time window is synchronised to the signal period, equation (C4) can be written:

$$\sqrt{\frac{1}{N}\sum_{i=1}^{N}[g(t_i)]^2} = \sqrt{\sum_{k=0}^{N/2}|C_k|^2} \qquad \text{(C5)}$$

where

$g(t_i)$ are the values of the time function at the sampling points; and

$t_i = i \times T_w/N$.

Equation (C5) states that the r.m.s. content of the frequency domain components equals the r.m.s. content of the time domain representation of the signal, in this case a sampled and digitised form of the signal. Parseval's relation may be usefully employed to ascertain whether the power spectrum accurately represents the time domain signal under certain specific circumstances.

Under the ideal conditions defined above, the power spectrum calculated by the methods defined in this standard, returns the average power of spectral components present in the measured signal during a defined time window. The power spectrum exactly represents the total power of the signal, the power of the individual frequency components, and the frequencies of these components. For practical situations, ideal conditions exist when all components of the measured signal are exact harmonics of the "basic" frequency $f_w = 1/T_w$. Because of the strict requirements defined in this standard for synchronisation, these nearly ideal conditions occur by definition for the fundamental component of the power system and for any components with frequencies which are integer multiples of the "basic" frequency; this includes, of course, the harmonics of the fundamental frequency.

NOTE The "basic" frequency is the reciprocal of the window width. The "fundamental" frequency is the reciprocal of the system cycle.

The width of the time window, $T_w \approx$ 200 ms, is defined as 10 or 12 fundamental cycles for 50 Hz or 60 Hz systems respectively for future designs, and 16 cycles (≈320 ms or ≈267 ms) for instruments designed to comply with requirements given in the first edition of IEC 61000-4-7. The frequency distance of the spectral lines ("basic" frequency f_w) is therefore ≈5 Hz or ≈3,125 Hz or ≈3,75 Hz, respectively. The grouping method according to equation (8) of this standard ensures that the total power is accurately evaluated. It takes account of all spectral lines and not only the lines ("harmonics") at integer multiples of the fundamental frequency. Equation (8) relates only to lines with a distance of ≈5 Hz and has therefore to be modified if other "basic" frequencies are used. By proper application of equation (8) – modified if necessary – under ideal conditions, the power spectrum exactly represents the average power of the measured signal as defined by Parseval's relation.

Under less than ideal conditions, for example, where non-harmonic signal content with frequencies $f \neq k \times f_w$ (k: integer number) is present, the phenomenon of spectral leakage acts to cause a loss of information about frequency content, but signal power generally remains accurately represented. Considering the case of a time window equal to 200 ms, non-harmonic signal content is present whenever there are inter-harmonic signals at frequencies which are not integer multiples of 5 Hz, for example 287 Hz, or when amplitude fluctuation occurs within the analysed time window. The grouping methods defined in this standard assist in ensuring that the total power is for the most part accurately evaluated. Allocation of power to a specific signal group depends upon the nature of the signals involved.

A few examples will help to illustrate the point. The examples in C.3 show the effect of voltage and current amplitude fluctuation. The interharmonic effects are illustrated in C.4. The fundamental component which predominates in practice by far in voltage and current signals is left away in the examples in order to use the full scale of the figures for a more clear presentation of the interesting spectral lines and the grouping effect.

C.3 Fluctuating harmonics

EXAMPLE 1

Figure C.1 illustrates the case of the r.m.s. 5th harmonic current fluctuating from 3,536 A to 0,7071 A. The step in the current occurs after 21,25 periods of the 5th harmonic. The expected calculated r.m.s. current for this case is 2,367 A. The measured 5th harmonic (single line) results in only 1,909 A, i.e. neglecting the other lines produces an error of 19,3 %. The measured harmonic subgroup value in this case results in 2,276 A and would already reduce the error to 3,84%, but the harmonic group of the measured lines yields a value of 2,332 A which corresponds to the small remaining error of only 1,47%.

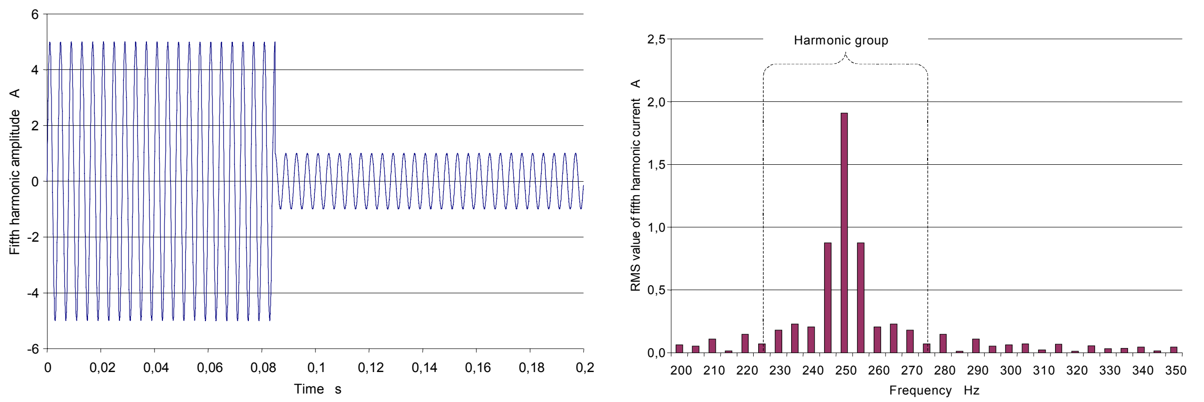


Figure C.1 – Large 5th harmonic current fluctuation

EXAMPLE 2

Power-system harmonic voltages normally result from the combination of emitted harmonic currents produced by several non-linear loads. These loads are generally not fluctuating with significant correlation. Furthermore, quasi-stationary loads are also connected to the power system. Therefore, fast fluctuating harmonic voltage levels with a high fluctuation magnitude are an exception and seldom occur on the power system. For example, figure C.2 shows a fifth harmonic r.m.s. voltage that reduces from 13,225 V to 9,775 V. In this case, the expected total r.m.s. value is 11,37 V, but the single harmonic line is only 11,24 V. The proposed algorithms in this standard yield 11,33 V for the subgroup and 11,34 V for the group which results in errors of only 0,35 % or 0,24 % respectively. These errors are well below the uncertainty of the instrument itself.

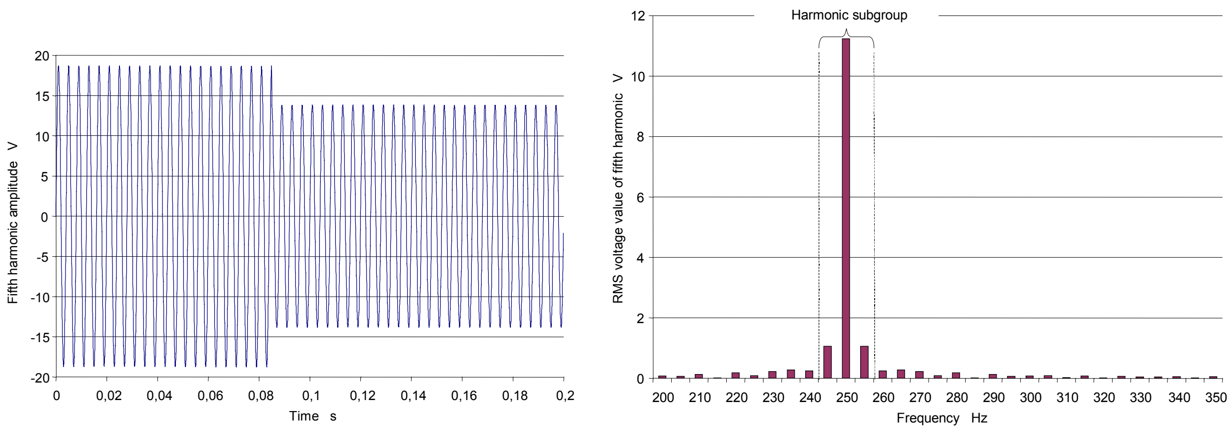
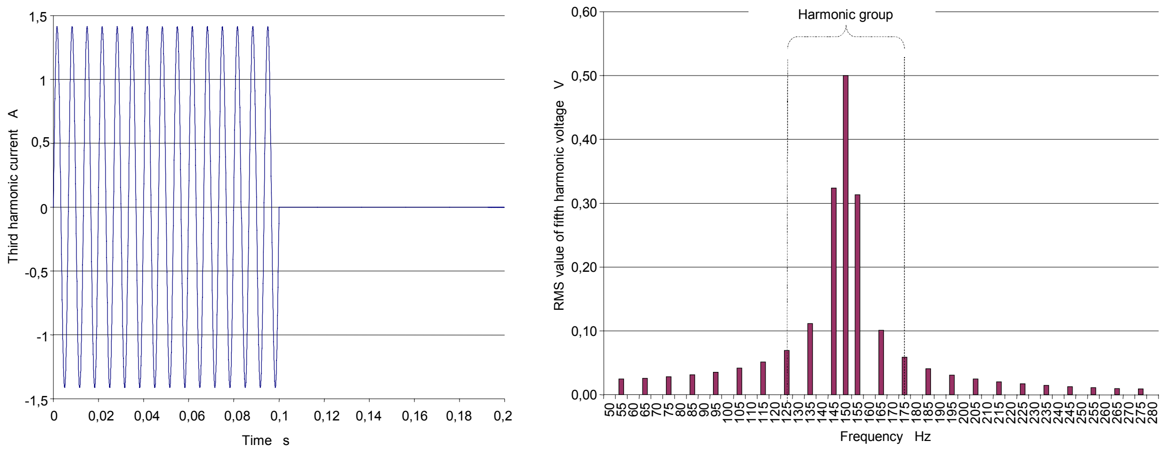


Figure C.2 – Large 5th harmonic voltage fluctuation

EXAMPLE 3

A microwave appliance produces (amongst others) a 3rd harmonic current, for example, 1 A during continuous operation. Its average power is controlled by the zero-crossing multi-cycle method with, for example, a repetition rate of 5 Hz and a duty-cycle of 50%. Figure C.3 illustrates the time function of the 3rd harmonic current and the corresponding spectrum. The total r.m.s current is 0,707 A. The r.m.s. value of the 3rd harmonic spectral line is 0,5 A which results in an error of 29,3 %. The harmonic subgroup yields, however, 0,673 A, and the error is only 4,8 %. The harmonic group value is 0,692 A, reducing the error down to 2,0 %.



IEC 1959/02

Figure C.3 – Fluctuating 3rd harmonic current of a micro-wave appliance

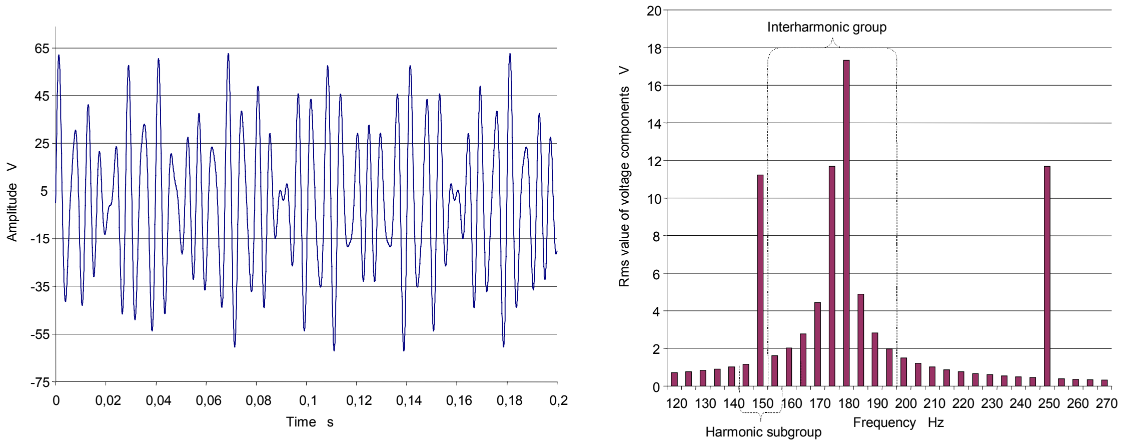
It is evident from these examples that the grouping procedure is well suited to give results which are in good conformity with Parseval´s equation.

C.4 Interharmonics

EXAMPLE 1

Communication (signalling) systems may also be connected to the power system. To prevent them being disturbed by harmonics, the frequencies used are generally between two harmonic frequencies, i.e. interharmonic frequencies. If they are integer multiples of the “basic” frequency f_w and have a constant magnitude within the time window, then the spectrum shows one additional line just at this frequency, and an additional grouping may not be necessary. But in order to transmit information the signal is modulated. The effect on the spectrum is similar to the previous examples, the only difference being that the lines due to the modulation are now centred on the signalling frequency. The “interharmonic grouping” according to annex A reduces the error in the same manner as the harmonic grouping shown in C.3.

In many cases, signalling frequencies which are not integer multiples of f_w are used. For example, figure C.4 shows a communication signal at 178 Hz with constant magnitude of 23 V r.m.s. superposed on a third and fifth harmonic of 11,5 V each, which might already exist on the system. The discrete Fourier transform, which cannot resolve the line at 178 Hz, spreads the energy to the neighbouring lines (“leakage”). In this case, the interharmonic group of order 3,5 (see annex A) collects the major part of the spread “energy” of the communication signal, with a resulting value of 22,51 V, and the error is only 2,15 %.



IEC 1960/02

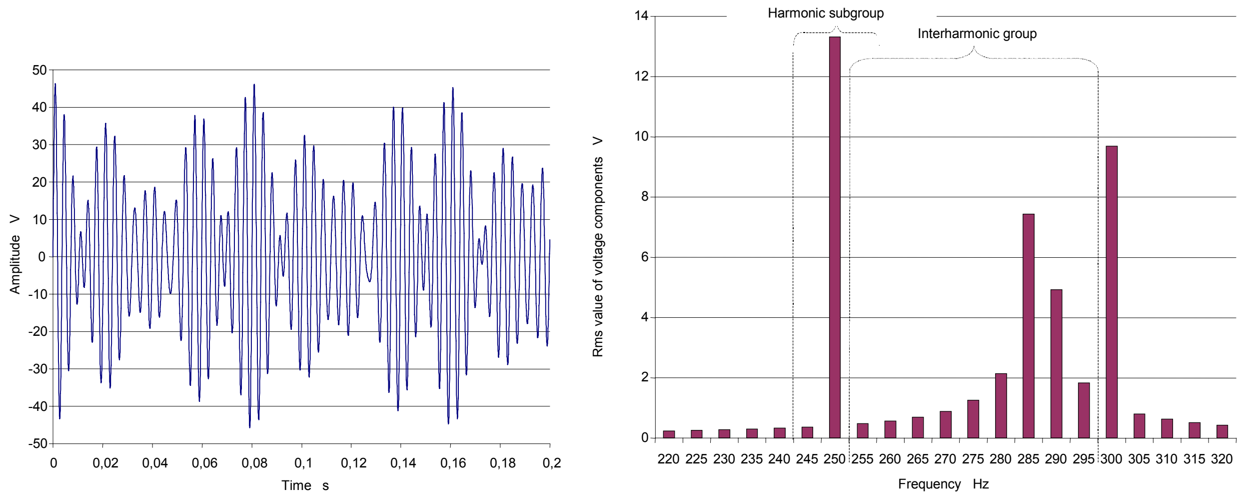
Figure C.4 – Communication signal of 178 Hz together with 3rd and 5th harmonics

NOTE 1 The “leakage” effect of the signal with non-integer multiple of the “basic” frequency superimposes additional vectors on the vectors of the original harmonics (see figure C.7). The phase angle between the additional and the original vector of the same frequency increases (or decreases) by approximately the same amount from window to window. Depending on the actual phase angle, the resulting vector may vary between the difference and the sum of the vector magnitudes. In the given example, the magnitudes are 11,5 V for the original vectors and ≈1,2 V at 150 Hz or ≈0,4 V at 250 Hz (see figure C.4). The resulting vectors may vary between ≈10,3 V and ≈12,7 V at 150 Hz and between ≈11,1 V and ≈11,9 V at 250 Hz. The r.m.s value of the resulting vector evaluated over many contiguous windows equals the “common” r.m.s. value of the original and the additional vector, in the example 11,56 V at 150 Hz and 11,51 V at 250 Hz. The smoothing procedure, which is applied after the grouping, reduces considerably the variation and provides an average output close to this common r.m.s. value.

NOTE 2 The magnitude of the communication signal will in practice be smaller than in the example, so the leakage effect is reduced correspondingly.

EXAMPLE 2:

Interharmonics can also appear in the emission r.m.s. current and consequently in the r.m.s. voltage of the supply. They may occur randomly between two contiguous harmonics. For example, 9,8 V at 287 Hz, 13,2 V of the 5th harmonic and 10 V of the 6th are shown in figure C.5. The “leakage” effect can be seen from the spectrum. The interharmonic group of order 5 (see 3.4) yields 9,534 V, and the remaining error is 2,7 %.



IEC 1961/02

Figure C.5 – Interharmonic at 287 Hz, 5th and 6th harmonic

EXAMPLE 3

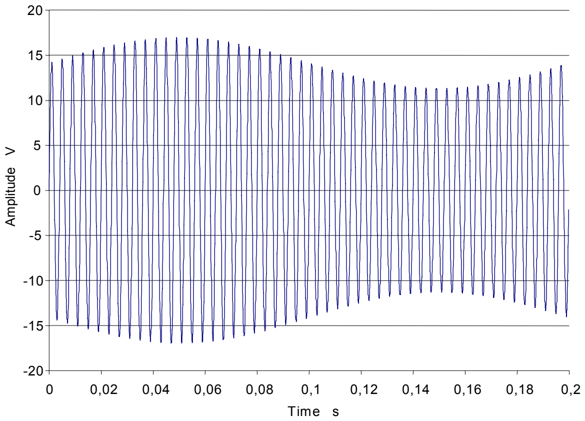
An electronic motor drive with a varying torque, for example a piston pump, produces a 5th harmonic voltage on the supply system which fluctuates around the average r.m.s. value of 10 V with a sinusoidal modulation of 20 % and 5 Hz, figure C.6 a). The total r.m.s. value of the time function, evaluated over 0,2 s, is 10,10 V. The spectrum contains the 250 Hz “carrier” line with an r.m.s. value of 10 V and the two side-lines at 245 Hz and 255 Hz with 1 V each, figure C.6 c). The error of the single line at 250 Hz is 0,99 %, and no error results from the harmonic subgroup.

A communication signal of 9,8 V and 287 Hz may be used on the same system (figure C.6 b)). The “leakage” effect in the spectrum (figure C.6 d), follows from the non-integer number of 57,4 periods of this signal in the time window of 200 ms. The r.m.s. value of the interharmonic group is 9,538 V and the resulting error 2,7 %.

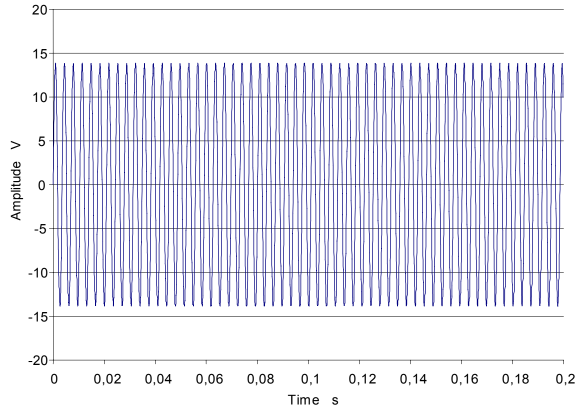
Both the fluctuating harmonic and the communication signal are superimposed on the voltage (figure C.6 e). The total r.m.s. value is 14,07 V. For the grouping of the resulting spectral lines different options exist (figure C.6 f). Since the presence of a harmonic at 250 Hz and a signal close to 285 Hz is obvious from the envelope of the spectrum, two grouping arrangements are reasonable (no line must be counted more than once):

– interharmonic group with 9,36 V (4,5 % error related to 9,8 V) and harmonic single line with 10,16 V (1,6 % error related to 10,0 V) resulting into a total r.m.s. value of 13,81 V (1,8 % error related to 14,07 V) or
– interharmonic sub-group with 9,34 V (4,7 % error related to 9,8 V) and harmonic subgroup with 10,23 V (1,29 % error related to 10,1 V) resulting in a total r.m.s. value of 13,85 V (1,5 % error related to 14,07 V).

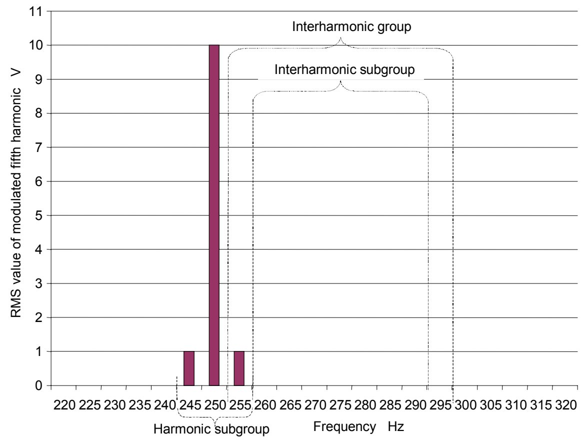
The 2nd grouping corresponds better to the “physics” since the lines at 245 Hz and 255 Hz do not fit to the “leakage” envelope. This is clarified if several spectra from contiguous windows are observed.



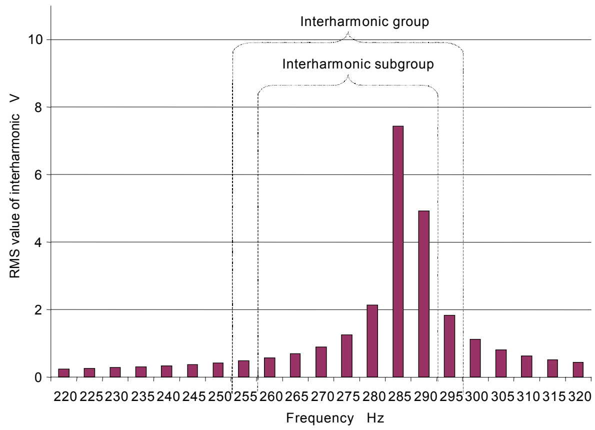
a) 5th harmonic with 20 % amplitude fluctuation



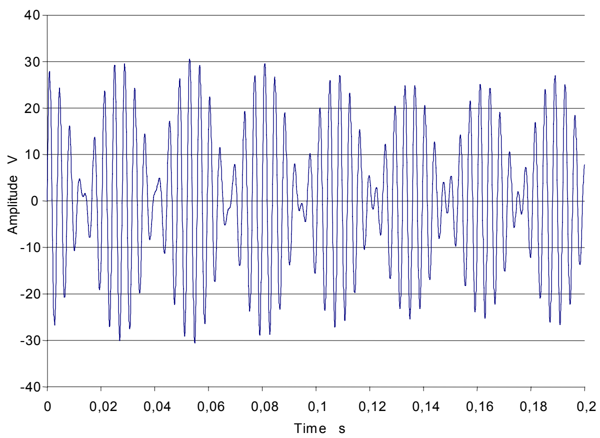
b) Interharmonic at 287 Hz



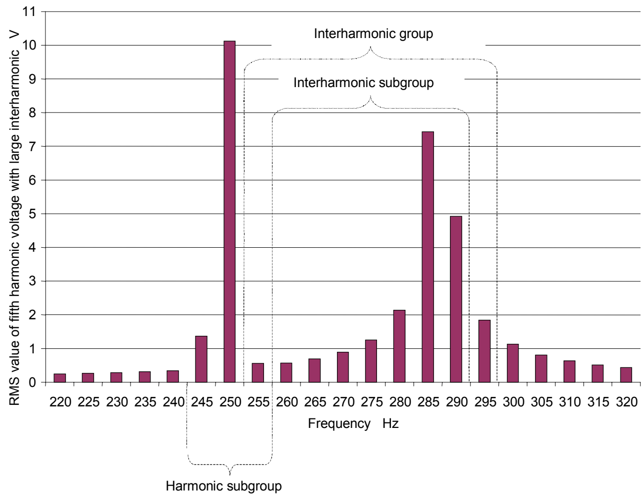
c) Spectrum: 5th harmonic, 20 % amplitude fluctuation



d) Spectrum: Interharmonic at 287 Hz



e) Sum of the harmonic and interharmonic



f) Spectrum: result of the summed signal

IEC 1962/02

Figure C.6 – Modulated 5th harmonic and interharmonic at 287 Hz

The spectral lines due to the sidebands around the fifth harmonic are those which are mainly affected by the leakage effect. For a fluctuating harmonic, the vectors of the components at the same distance from the harmonic frequency, i.e. 245 Hz and 255 Hz, have identical magnitudes but opposite directions. The magnitudes of the vectors remain constant for constant modulation depth but their angles rotate step by step from window to window if the modulation frequency is not an integer multiple of the basic frequency. The magnitudes of the vectors resulting from the interharmonic at 287 Hz remain also nearly constant but their angles change from window to window since the position of the interharmonic within the windows changes. The vectors resulting from the combination of the modulation and the leakage vary from window to window, of course, in angle and magnitude. Figure C.7 illustrates the two components at 5 Hz above and below the 5th harmonic for the time window of figure C.6. In this case, the magnitude of the "combined" 245 Hz is increased, and that of the 255 Hz vector is decreased, compared to the "modulation" vector. Other time windows would yield other angles of the vectors resulting from the 287 Hz signal and, consequently, the magnitudes of the "combination" vectors change: The time presentation of the spectrum shows fluctuating lines at 245 Hz and 255 Hz, and the average over the time would approximate the common r.m.s value of the "modulation" and the "leakage" vector.

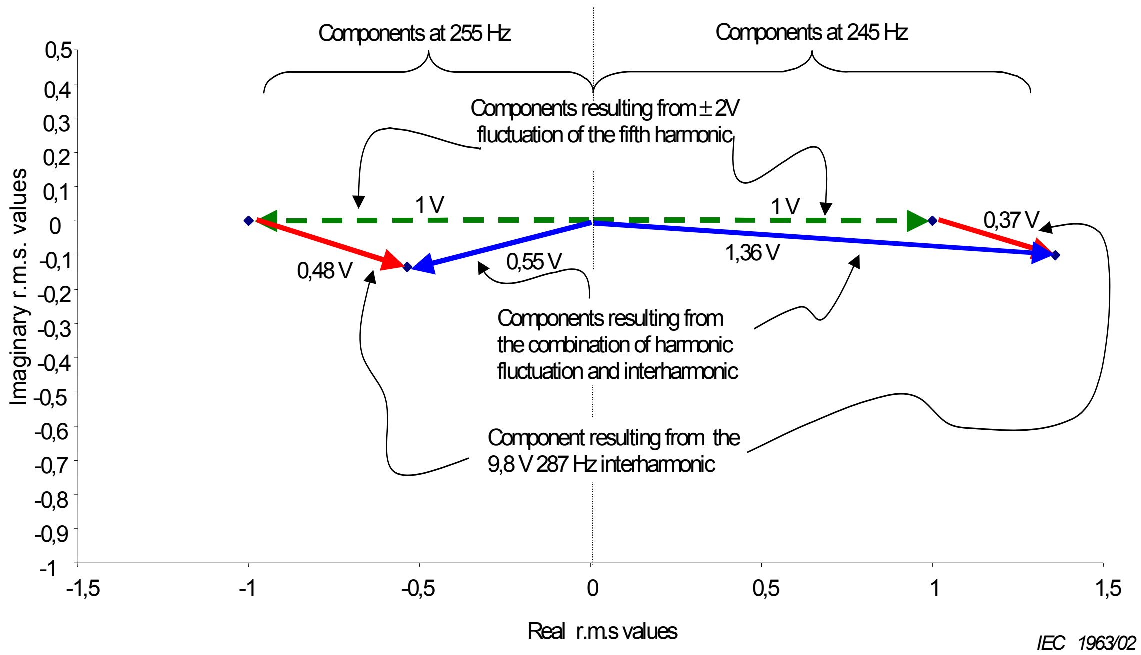


Figure C.7 – Component vectors at frequencies of 245 Hz and 255Hz