PD IEC TR 61000-1-8:2019

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Electromagnetic compatibility

Part 1-8: General — Phase angles of harmonic current emissions and voltages in the public supply networks — Future expectations

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National foreword

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TECHNICAL REPORT

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Electromagnetic compatibility –
Part 1-8: General – Phase angles of harmonic current emissions and voltages in the public supply networks – Future expectations

INTERNATIONAL
ELECTROTECHNICAL
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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ELECTROMAGNETIC COMPATIBILITY –

Part 1-8: General – Phase angles of harmonic current emissions and voltages in the public supply networks – Future expectations

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IEC TR 61000-1-8, which is a Technical Report, has been prepared by subcommittee 77A: EMC – Low frequency phenomena, of IEC technical committee 77: Electromagnetic compatibility.

The text of this Technical Report is based on the following documents:

Draft TR	Report on voting
77A/1002/DTR	77A/1012/RVDTR

Full information on the voting for the approval of this Technical Report can be found in the report on voting indicated in the above table.

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This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 61000 series, published under the general title *Electromagnetic compability*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

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- withdrawn,
- replaced by a revised edition, or
- amended.

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INTRODUCTION

0.1 Series overview

IEC 61000 is published in separate parts, according to the following structure:

Part 1: General

General considerations (introduction, fundamental principles)

Definitions, terminology

Part 2: Environment

Description of the environment

Classification of the environment

Compatibility levels

Part 3: Limits

Emission limits

Immunity limits (in so far as they do not fall under the responsibility of the product committees)

Part 4: Testing and measurement techniques

Testing techniques

Part 5: Installation and mitigation guidelines

Installation guidelines

Mitigation methods and devices

Part 6: Generic standards

Part 9: Miscellaneous

Each part is further subdivided into several parts, published either as international standards or as technical specifications or technical reports, some of which have already been published as sections. Others will be published with the part number followed by a dash and a second number identifying the subdivision (example: 61000-6-1).

0.2 Purpose of this document

This part of IEC 61000 documents measurements at a number of public supply networks in Germany, and explains the analysis of the obtained data. Data were acquired under certain conditions. These conditions include categories of different network structures, load structures and power generation structures, especially including a review of networks with varying degrees of renewable energy. The loads in various networks include mainly

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consumers, office buildings, and retail/shopping centres, and thus represent several categories of technologies in the input circuit of the electrical devices.

This document provides statistical evaluations aimed at quantifying the level of diversification of the prevailing harmonic current phase angles, and, where possible, to identify methods to reduce the overall emissions of dominant harmonics in the network.

For that purpose, the existing prevailing phase angle in the network at this time is analysed, and the type of prevailing phase angle expected in the future is evaluated. In particular, the potential changes in phase angle that can be expected, because of new technologies and/or network structures, are of interest. This would mean determining what harmonic compensation, if any, can be expected from various products. The goal is to determine or verify the existing phase angle (mainly of the 5th harmonic) and to assess the possible influences of future developments – such as changes in lighting types and other electronic equipment.

This document is exclusively applicable to public low-voltage electricity supply networks.

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ELECTROMAGNETIC COMPATIBILITY –

Part 1-8: General – Phase angles of harmonic current emissions and voltages in the public supply networks – Future expectations

1 Scope

The objective of this part of IEC 61000 is to provide information about the current conditions, and project future developments, of prevailing phase angles, predominantly for the 3rd and 5th harmonic currents, on public supply networks. This objective is accomplished by monitoring a number of networks, and efforts to forecast the effects of changes in technologies.

This document presents information to guide the discussion about the effectiveness of potential mitigation techniques and the generalisation of effects of the prevailing angle positions of selected current harmonics.

This document mainly deals with the phase angles of the 3rd and 5th harmonic currents, but also contains information about other harmonics.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
phase angle of I_5 related to the fundamental phase-to-neutral voltage U_{p1}
phase angle of the 5th harmonic current determined as described in Figure 1

[SOURCE: IEC 61000-3-12:2011, 3.16, modified – the reference to Figure 2 has been removed.]

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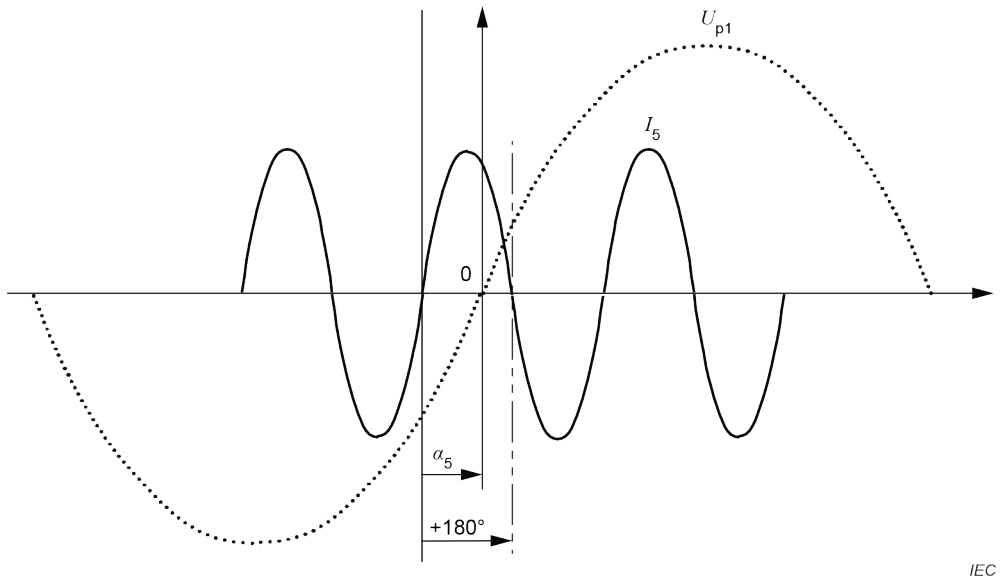

Figure 1 – Definition of the 5th harmonic current phase angle (I_5 leads U_{p1}, $\alpha_5 > 0$)

3.2
prevailing vector

$$\underline{x}_{pv} = x_{qm} \cdot e^{jx_{vs_ph}} \tag{1}$$

where the quadratic mean of magnitudes is

$$x_{qm} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left|\left(\underline{x}_i\right)^2\right|} \tag{2}$$

with $\left|\left(\underline{x}_i\right)^2\right|$ as the magnitude (absolute value) of the complex value $\underline{x}$,

and where the phase of the vectoral sum is the phase of the prevailing vector:

$$x_{vs_ph} = \tan^{-1}\left(\frac{\sum_{i=1}^{n}\mathrm{Im}\left(\underline{x}_i\right)}{\sum_{i=1}^{n}\mathrm{Re}\left(\underline{x}_i\right)}\right) \tag{3}$$

Note 1 to entry: The phase of the vectoral sum is different from the definition of the vectoral mean: this is the arithmetic mean of the real-part and the arithmetic mean of the imaginary-part.

Note 2 to entry: See 6.2.3 for details.

3.3
in-phase factor

$$r_{in_phase} = \frac{x_{vs_mg}}{x_{as_mg}} \tag{4}$$

where the magnitude of the vectoral sum is:

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$$x_{\text{vs_mg}} = \sqrt{\left(\sum_{i=1}^{n} \text{Re}(x_i)\right)^2 + \left(\sum_{i=1}^{n} \text{Im}(x_i) b\right)^2} \tag{5}$$

and the arithmetic sum of magnitudes is:

$$x_{\text{as_mg}} = \sum_{i=1}^{n} \left|\underline{x}_i\right| \tag{6}$$

Note 1 to entry: See 6.2.3 for details.

3.4
dispersion factor
deviation factor
subtraction of the in-phase factor from digit 1:

$$r_{\text{disp_phase}} = 1 - \frac{x_{\text{vs_mg}}}{x_{\text{as_mg}}} \tag{7}$$

Note 1 to entry: See 6.2.3 for details.

3.5
total harmonic current
THC
total RMS value of the harmonic current components of orders 2 to 40:

$$THC = \sqrt{\sum_{h=2}^{40} I_h^2} \tag{8}$$

3.6
total harmonic distortion
THD
ratio of the RMS value of the sum of the harmonic components (in this context harmonic current components I_h of orders 2 to 40) to the RMS value of the fundamental component:

$$THD = \sqrt{\sum_{h=2}^{40} \left(\frac{I_h}{I_1}\right)^2} \tag{9}$$

4 Summary of field measurements and data analysis

4.1 Field measurement methods and concepts

All measurements reported in this document have originated from an initiative by Forum Netztechnik/Netzbetrieb (FNN) and within the scope of a research assignment financed by FNN and assigned to the University of Technology of Dresden. The network operating authority N-ERGIE (today MDN) was involved, along with several other network operating authorities in the realisation of the measuring campaign. Data have been handed over to the research partner, but the network authorities could carry out their own analyses as well. Apart from the task of the research partner, additional test sites have been examined by N-ERGIE and data analyses continue, with emphasis on correlation aspects.

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This document is based primarily on the results of the N-ERGIE investigations which are consistent, nevertheless, with the results of the larger FNN studies. The data pool of FNN offers the big advantage of a large number of random tests (within Germany). The enormous amount of data necessitates substantial compression for a meaningful presentation, and admittedly leads to a less-detailed consideration of the results. More detailed analysis has also been carried out, however, particularly concerning correlation, and that analysis is presented as well.

Test sites were chosen according to criteria from [1][1] with regard to network structure, load structure and generator structure. These diverse test sites, representing various topologies and load types in the network area of the N-ERGIE are listed in Table 1.

Thus, eight residential area networks (e.g. “A1” and “A2” in the column “Category” of Table 1, see Table 9 for definitions) and four networks that include commercial offices, trade, and retail stores, were examined. Additionally, one of the last four networks was a repetition of M9 concerning the phase angle of the harmonic voltage instead of the phase angle of the harmonic current, listed as M17. At the test sites M1 to M8, measurements were made from the middle of December 2012 to the middle of January, 2013, with a duration of 35 days to 40 days. The measurements at the test sites M9 to M12 followed in May 2013. These were repeated at the same test sites in July 2013, listed as M13 to M16, with a modified interval time of measurement (60 s instead of 1 s) at M10 to M12, respectively M14 to M16. These test sites (M9 to M12) are listed as M13 to M16, mainly as a means of differentiation. With a choice of the measuring period, the opportunity was consciously taken to measure, on the one hand, during the winter months and summer months and to measure, on the other hand, in a time window with varying users' behaviour (work times and holidays about the turn of the year). The background is to identify network parameter dependencies, specifically the prevailing phase angle of harmonics, resulting from the users' behaviour and load structure.

As follows from Table 1, the 16 measurement sites are representative of a good cross section of the public supply, and as follows from the more detailed data review, the analysis includes a statistically meaningful sample set that can be extrapolated to the 220/230 V 50 Hz public supply networks in general. No attempt is made to extrapolate the findings to other network topologies, but given that the load structures are similar in 120 V 60 Hz networks, the findings of this document can apply to some extent to those other networks as well.

The field measurements included exclusively the public low-voltage network at the terminals of the local network transformers. Current and voltage were measured in each of the three phases, and included magnitude and phase. The measurement window was 200 ms with a sampling rate of 100 kS/s. The measurement repetition rate amounted to 1 min, except with M10 to M12 where data were acquired with 1 s intervals. The measuring instruments used by N-ERGIE recorded the harmonics up to the 50th order and the basic electrical parameters, including phase angle information for current and voltage. The harmonic currents phase angles are measured with reference to the zero crossing of the fundamental of the voltage according to 61000-3-12 [3] (positive zero crossing).

In 4.2, a brief summary of the measurement results is presented, along with a summary review of the potential future impact of technologies and societal developments. The data are then analysed in detail, and technology and economic factors are analysed in more detail, to further explain the summary findings.

[1] Numbers in square brackets refer to the Bibliography.

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Table 1 – Structure of test (measurement) sites

Test site	Network	Load	Generation	Category[a]	Number of days
M1	Mid-sized network	SFH, small residential area	No renewables	N2 A1S E1	40
M2	Large-sized network	SFH, small residential area	Sporadic renewables	N3 A1S E2	40
M3	Large-sized network	SFH, Mid residential area	Sporadic renewables	N3 A1M E2	43
M4	Large-sized network	SFH, Mid residential area	A few renewables	N3 A1M E3	36
M5	Large-sized network	SFH, Large residential area	A few renewables	N3 A1L E3	36
M6	Large-sized network	MFH, Mid residential area	No renewables	N3 A2M E1	41
M7	Large-sized network	MFH, Large residential area	No renewables	N3 A2L E1	43
M8	Large-sized network	MFH, Large residential area	A few renewables	N3 A2L E3	41
M9	Mid-sized network	Office	No renewables	N2 A4 E1	10
M10	Small-sized network	Stores	No renewables	N1 A3 E1	1[b]
M11	Small-sized network	Stores	A lot of renewables	N1 A3 E4	1[b]
M12	Mid-sized network	Office	A lot of renewables	N2 A4 E4	1[b]
M13	Mid-sized network	Office	No renewables	N2 A4 E1	27
M14	Small-sized network	Stores	No renewables	N1 A3 E1	26
M15	Small-sized network	Stores	A lot of renewables	N1 A3 E4	27
M16	Mid-sized network	Office	A lot of renewables	N2 A4 E4	26
M17	Mid-sized network	Office	No renewables	N2 A4 E1	12

[a] The description of 'Category' is given in Table 8, Table 9 and Table 10.

[b] For these measurements, an aggregation time of 1 s was used instead of 60 s.

4.2 Summary of measurement results, analysis, and conclusions

Harmonic emission standards, such as [2] and [3], are based on past analysis by various experts and institutions. It was found, through a number of measurements and long-time monitoring on the networks, that the lower order harmonics H3 and H5 are dominant and represent the highest impact on voltage distortion. Consequently, network operators and authorities are mainly concerned with emission levels at H3 and H5, and to some extent H7.

During the last 10 years, several IEC working groups considered that it might be possible to “guide” developments in technology or network topology and structure, to achieve compensation of emissions, in the sense that the emissions of one product group or specific technology might compensate for the prevailing harmonics on the network. If, therefore, the prevailing phase angle on the network can reliably be established, and is sufficiently consistent, it might be possible to devise products or product technologies with power input topologies that – if any – generate harmonic emissions that oppose, i.e. compensate for, the distortion on the networks.

The results of the measurement campaign explained in 4.1 appear to dispel the possibility of “guided compensation” of prevailing distortion in the network. Figure 2, Figure 3 and Figure 4 with the measurement results from 3 of the 16 measurement sites, M1 – M7 – M16, are used to illustrate this initial observation.

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Prior to the measurement campaign, it was assumed that harmonic emissions were such that the lower order harmonics (H3 and H5) had a relatively narrow distribution, such as shown for the test site M16 below (Figure 4). The measurements at other test sites, however, show a broad dispersion of emission phase angles and amplitudes. High dispersion for H3 and a moderate level of dispersion for H5 are observed at test site M1. A very wide distribution of emissions, both in amplitude and phase for the 5th (and 7th) harmonic is observed for test site M7. In addition, the prevailing phase angle for H5, with moderate dispersion at test site M1, opposes the prevailing phase angle with narrow dispersion at M7. Likewise, the main amplitudes of the highly dispersed H5 emissions at test site M7 oppose the narrow distribution of H5 at test site M16.

Similar conclusions can be drawn when comparing other test sites, such as M15 and M16 (see Annex A).

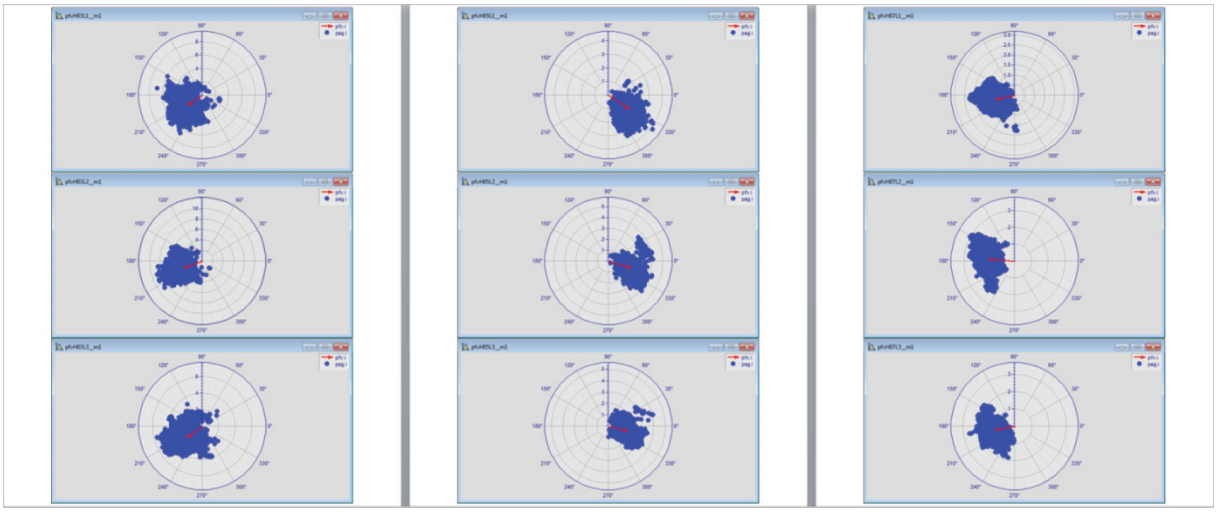

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Figure 2 – Polar diagrams with prevailing vector for each of the three phases of the 3rd, 5th and 7th harmonic currents at test site M1

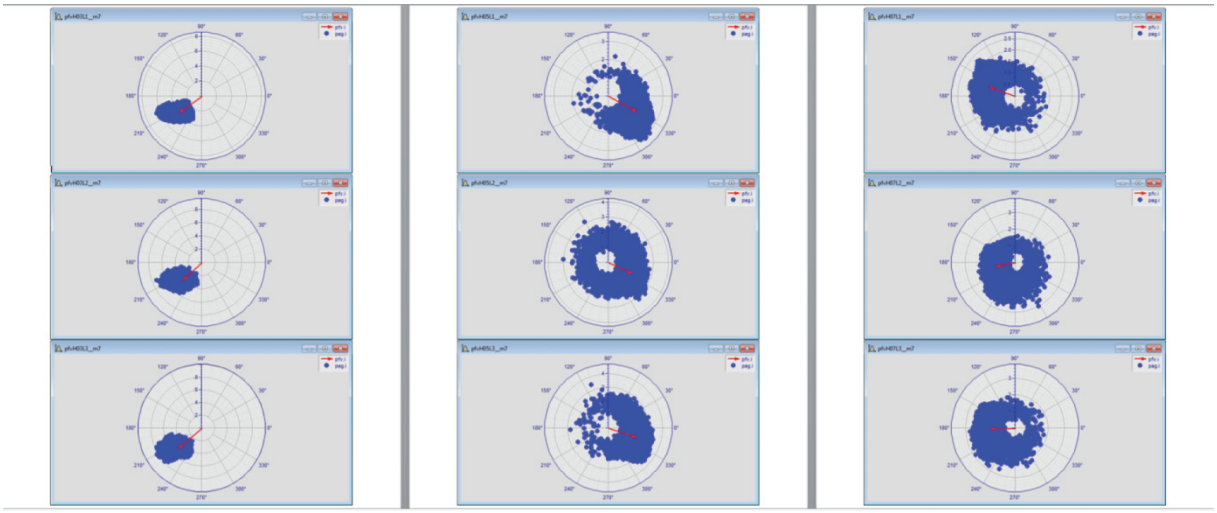

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Figure 3 – Polar diagrams with prevailing vector for each of the three phases of the 3rd, 5th and 7th harmonic currents at test site M7

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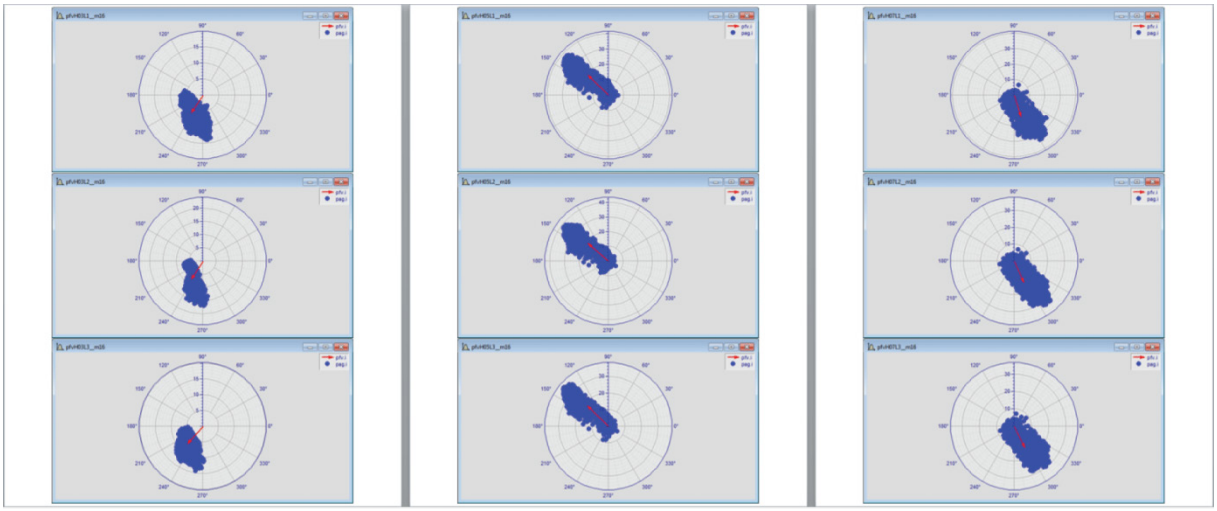

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Figure 4 – Polar diagrams with prevailing vector for each of the three phases of the 3rd, 5th and 7th harmonic currents at test site M16

Whereas the harmonic current phase angles show a wide variety, the 3rd, 5th, and 7th harmonic voltage phase angles vary by measurement site as well. This is depicted in several forms in Figure 5 to Figure 9.

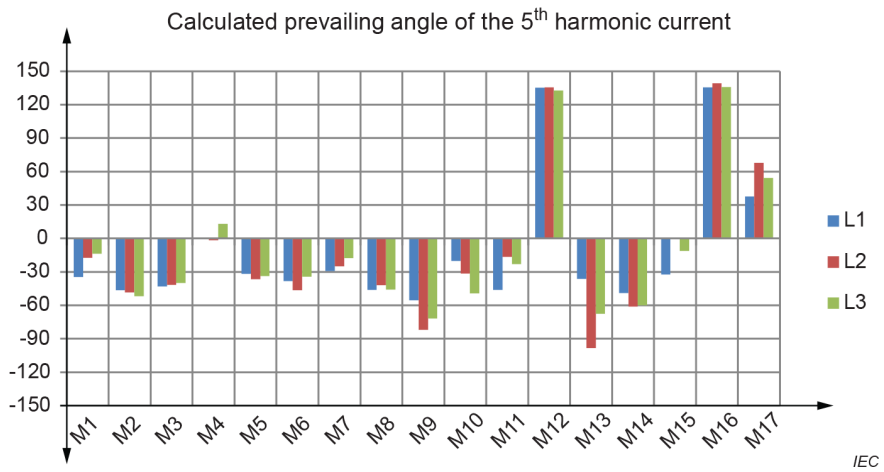

Figure 5 – Computed prevailing phase angle of the 5th harmonic current

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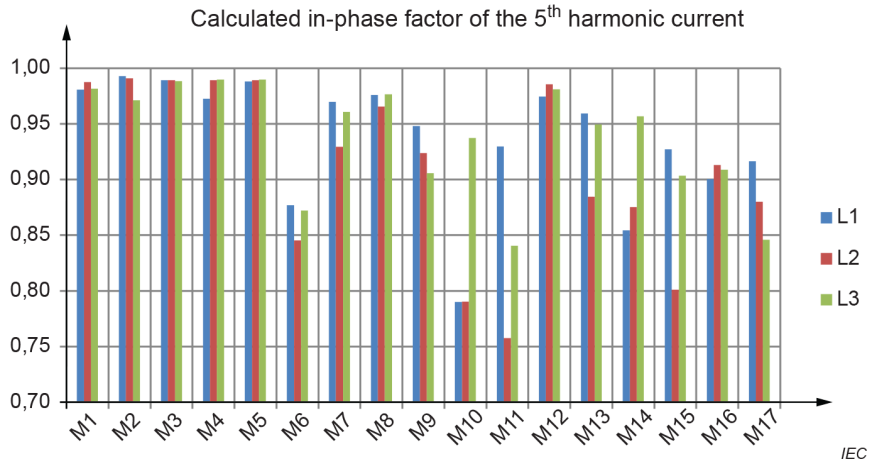

Note 1 to entry: The term in-phase factor is defined in 3.3. The term prevailing ratio is not used in this document.

Figure 6 – Computed in-phase factor of the 5th harmonic current

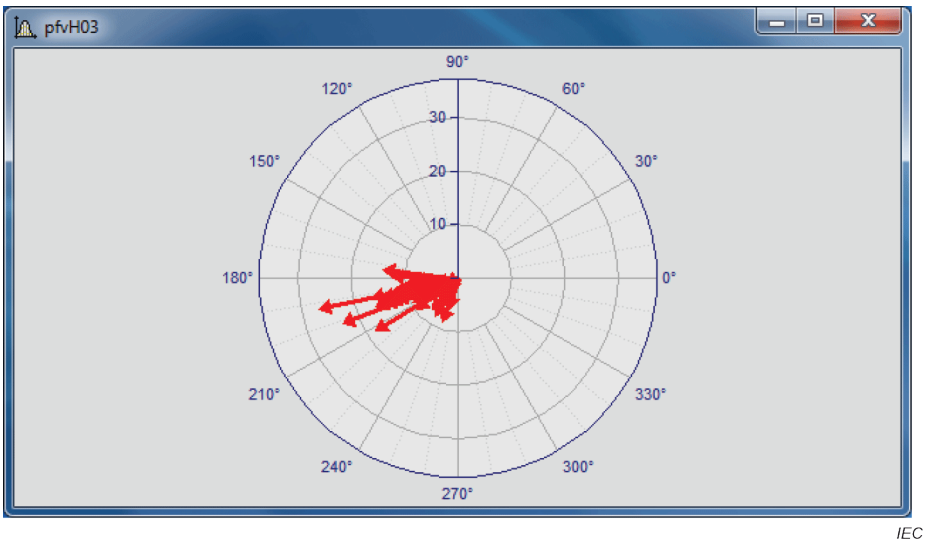

Figure 7 – Prevailing vectors of the 3rd harmonic current (three phases, all test sites)

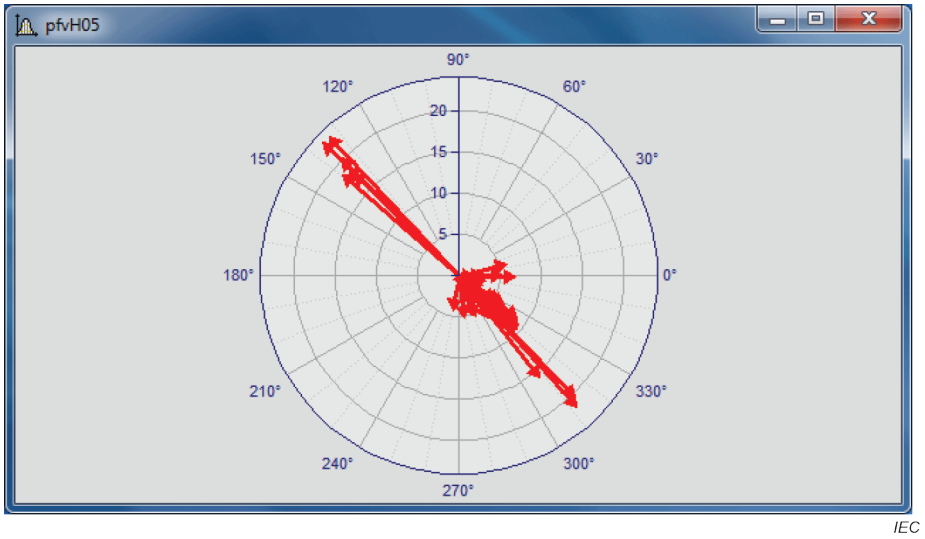

Figure 8 – Prevailing vectors of the 5th harmonic current (three phases, all test sites)

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Figure 9 – Prevailing vectors of the 7th harmonic current (three phases, all test sites)

As is already evident from the foregoing figures, “guided compensation” in the form of recommending specific technologies, or network topologies, appears to be a very difficult –if not impossible – task. The voltage (and current) distortion at various measurement sites vary(ies) so much, that what “compensates’ for one site, can exacerbate distortion at another site.

In other words, to achieve compensation of certain products for the emissions of others or compensation for global distortion levels in the network does not seem to be a possibility, except perhaps for very much localized situations.

To numerically quantify the measured data, that data are analysed in substantial detail, and evaluation of various calculated parameters is performed. The methodology and analysis techniques are explained in Clauses 6 and 7. Subsequently, somewhat more detailed conclusions are presented.

Before going into great detail on the technical and data analysis aspects of the survey, it is appropriate to evaluate economic and societal conditions and assess whether or not a major shift in electricity demand and/or type of loads is to be expected because of economic reasons, such as disrupting new technologies and/or widespread adoption of products that significantly alter power demand.

5 Critical appraisal of potential economic impact

5.1 General

Electricity consumption and demand is relatively stable in the developed nations. Even though new technologies, such as solid state lighting, can have some impact, lighting represents less than 10 % of the electricity consumption, and solid state lighting is just a part of that percentage. Similar considerations apply to renewable energy and the effect of energy efficient motor drives. Because each sector represents only a fraction of the total demand, and changes in each sector represent only a small part of the applicable sector, no significant shift in either consumption of electricity or emission patterns in developed countries is to be expected. A possible exception could be the widespread adoption of electrical vehicles, and associated battery chargers, but any such development will take at least 5 years to 10 years to even emerge. Even if such developments take place, industry plus household electricity consumption will still dominate, and thus no significant change in harmonic current emission patterns is anticipated.

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While electricity consumption in the BRICS countries has increased rapidly in the last 20 years or so (see Figure 10), electrical products consumption patterns mimic those of the developed nations, and thus few differences in harmonic emissions are to be expected in those countries.

Economic impact factors will be reviewed in more detail later in this document.

5.2 Dependencies on electrical parameters

Thus far, economic factors have not been considered with respect to their potential impact on the phase angles of the harmonic current. For example, if economic factors lead to a major shift in power consumption, this could affect the phase angle of harmonic emissions also.

5.3 Dependencies on non-electrical influence quantities

5.3.1 General

It can be concluded that at the present time, there is no direct connection between the initial network structure and the electricity producer's structure regarding harmonic compensation effects for selected harmonics. Thus far, network topology and structure are mainly aimed at ensuring reliable power delivery to the consumer. There are power quality requirements in most developed nations, but “harmonic compensation” has not been a design criterion for network structure.

Changes in consumer behaviour, i.e. economic aspects, can have feedback effects on technologies and thus on diversity – or the lack thereof – in the vectoral overlapping of harmonic current of various products. These effects are considered in the detailed analysis, but any impact appears to be limited.

Finally, climate developments can also have an effect on technology developments, and in turn feed back into the power system.

Nevertheless, the main influence quantities, and the status quo, are economic drivers as is briefly indicated in 5.3.2 to 5.3.4.

5.3.2 Development of economic sectors and demand of energy

The worldwide electricity demand amounted in 1980 to 7 328 TWh and had increased in 2008 to 17 455 TWh. This corresponds to an annual growth rate of 3,15 %. The demand[2] split for electric energy between the regions[3],[4] of the world is shown in Figure 10.

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2 Source of data: U.S. IEA.

3 BRICS: Brazil, Russia, India, China, South Africa.

4 EU-27: BE, DE, FR, IT, LU, NL, DK, IE, UK, GR, PT, ES, FI, AT, SE, EE, LV, LT, MT, PL, SK, SI, CZ, HU, CY, BG, RO.

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