



BSI Standards Publication

Electromagnetic compatibility (EMC)

Part 3-18: Limits — Assessment of network characteristics for the application of harmonic emission limits — Equipment connected to LV distribution systems not covered by IEC 61000-3-2 and IEC 61000-3-12

National foreword

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TECHNICAL REPORT



**Electromagnetic compatibility (EMC) –
Part 3-18: Limits – Assessment of network characteristics for the application of
harmonic emission limits – Equipment connected to LV distribution systems
not covered by IEC 61000-3-2 and IEC 61000-3-12**

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

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CONTENTS

FOREWORD.....	4
INTRODUCTION.....	6
1 Scope.....	7
2 Normative references	7
3 Terms, definitions and abbreviated terms	7
3.1 Terms and definitions.....	8
3.2 Abbreviated terms.....	10
4 General	10
5 State of existing IEC standards.....	12
5.1 Overview of existing standards	12
5.2 Voltage gaps.....	12
5.3 Frequency gaps	13
5.4 System impedance considerations	13
6 General approach.....	14
7 Detailed implementation of the methodology.....	15
7.1 Overview.....	15
7.2 European reference network model (RNM).....	15
7.2.1 History.....	15
7.2.2 Adjusted RNM for assessing harmonic sensitivity	16
7.3 Harmonic current model.....	18
7.4 Methodology for adapting IEC equipment harmonic emission limits.....	20
7.4.1 General	20
7.4.2 Conversion factor (C_{fh}).....	21
7.5 Sensitivity ratio S_R	22
8 Simulation considerations.....	22
8.1 Overview.....	22
8.2 Simulation model adjustment	23
8.3 Studies with only the maximum harmonic distortion of each feeder	23
8.4 Sampling the feeders of the entire power system	24
9 Statistical analysis.....	24
10 Conclusions.....	25
Annex A (informative) Other methods studied for comparing feeder harmonic sensitivity.....	27
A.1 General.....	27
A.2 Voltage droop	27
A.2.1 Explanation	27
A.2.2 Voltage droop simulation	27
A.2.3 Concept of the voltage droop approach	28
A.2.4 Validation of the voltage droop method.....	29
A.2.5 Clustering.....	30
A.2.6 Feeder parameters	33
Annex B (informative) Power distribution systems in Canada	36
B.1 Overview.....	36
B.2 Conversion factor.....	37
Annex C (informative) Power distribution systems in Japan	40

C.1	Background for harmonics limits	40
C.2	Outlook on a typical distribution system in Japan	40
C.3	Power supply to customers in Japan	42
C.4	Distribution system impedance in Japan	42
C.5	Case study of 95 th percentile and conversion factor in Japan	43
C.6	Comparing the 95 th percentile distortion level of Japan vs. EU RNM	43
Annex D (informative) Example of a Python script used with CYMDIST software		46
Bibliography.....		57
Figure 1 – Reference network medium-voltage power system		17
Figure 2 – LV network of 153 customers supplied by a 400 kVA transformer.....		17
Figure A.1 – Scatter plot of voltage harmonic levels (3 rd and 5 th) as function of the voltage droop.....		28
Figure A.2 – Comparison of the 95 th percentile harmonic levels obtained from simulation and calculated from the voltage droop.....		30
Figure A.3 – $q = 1$, Manhattan distance.....		31
Figure A.4 – $q = 2$, Euclidian distance		31
Figure A.5 – Two-parameter k-means clustering example		32
Figure A.6 – Illustration of SSE		33
Figure A.7 – Harmonic distortion levels at cluster centroids		35
Figure B.1 – Low-voltage system in Canada		36
Figure B.2 – Multi-unit building of 32 customers.....		37
Figure B.3 – Buildings with > 1 000 residential customers.....		37
Figure C.1 – Overview of the power system in Japan [11]		41
Figure C.2 – Standard neutral grounding systems for HV and MV distribution system in Japan		41
Figure C.3 – Distribution transformer for HV/MV in Japan		41
Figure C.4 – Popular LV distribution systems in Japan.....		42
Table 1 – Modelled RNM voltage distortion compared with compatibility levels		18
Table 2 – 5 th harmonic current (h5) per household proposed by [4]		19
Table 3 – 7 th harmonic current (h7) per household proposed by [4]		19
Table 4 – Harmonic load injection at each customer POI in the modelled network.....		20
Table 5 – Creating the cumulative data function.....		25
Table A.1 – Coefficients of linear regression obtained from the harmonic and droop data		29
Table B.1 – LV feeder impedance in Canada		36
Table B.2 – Data for assessing the Canada 240 V limits		38
Table B.3 – Limits for Class A Equipment		39
Table C.1 – Impedance survey results for MV distribution lines (Ω).....		42
Table C.2 – Results of long-range survey of MV distribution lines (km)		43
Table C.3 – Impedance survey results for LV distribution lines (m Ω).....		43
Table C.4 – Data and calculated limits at 100 V in Japan.....		44

INTERNATIONAL ELECTROTECHNICAL COMMISSION

ELECTROMAGNETIC COMPATIBILITY (EMC) –**Part 3-18: Limits – Assessment of network characteristics
for the application of harmonic emission limits – Equipment
connected to LV distribution systems not covered
by IEC 61000-3-2 and IEC 61000-3-12**

FOREWORD

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IEC TR 61000-3-18 has been prepared by subcommittee 77A: EMC – Low frequency phenomena, of IEC technical committee 77: Electromagnetic compatibility. It is a Technical Report.

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

Draft	Report on voting
77A/1197/DTR	77A/1202/RVDTR

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Report is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 61000 series, published under the general title *Electromagnetic compatibility (EMC)*, 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 webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

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INTRODUCTION

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 levels

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

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: IEC 61000-6-1).

ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 3-18: Limits – Assessment of network characteristics for the application of harmonic emission limits – Equipment connected to LV distribution systems not covered by IEC 61000-3-2 and IEC 61000-3-12

1 Scope

This part of IEC 61000, which is a technical report, reports on the development of a methodology for adapting IEC equipment emission limits from IEC 61000-3-2 and IEC 61000-3-12 for use in regions not covered by these documents. It identifies gaps in the existing equipment emission limit standards concerning their international applicability and identifies public power system characteristics important for the evaluation of harmonic voltage performance.

The purpose of adapting the above-mentioned IEC equipment harmonic emission standards in a particular region is to maintain similar electromagnetic compatibility (EMC) of equipment up to 75 A per phase in the public power systems in those regions.

NOTE The boundaries between the various voltage levels differ amongst different countries (see IEC 60050-601:1985, 601-01-28). This document uses the following terms when referring to 50 Hz and 60 Hz system voltages:

- low voltage (LV) refers to $U_n \leq 1 \text{ kV}$;
- medium voltage (MV) refers to $1 \text{ kV} < U_n \leq 35 \text{ kV}$;
- high voltage (HV) refers to $35 \text{ kV} < U_n \leq 230 \text{ kV}$.

EMC requirements can have economic and societal impacts; these have not been considered in the development of this document. The consideration of these factors generally occurs in the technical committees working on development and maintenance of emission limit standards.

2 Normative references

There are no normative references in this document.

3 Terms, definitions and abbreviated terms

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 Terms and definitions

3.1.1

distribution system operator

DSO

party operating an electric power distribution system

[SOURCE: IEC 60050-617:2009, 617-02-10, modified – electric power has been added to the definition.]

3.1.2

distributed energy resource

DER

generator (with its auxiliaries, protection and connection equipment), including loads having a generating mode (such as electrical energy storage systems), connected to a low-voltage or a medium-voltage network

[SOURCE: IEC 60050-617:2017, 617-04-20, modified – changed to singular]

3.1.3

electromagnetic compatibility

EMC

ability of equipment or a system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment

[SOURCE: IEC 60050-161:2018, 161-01-07]

3.1.4

(electromagnetic) compatibility level

the specified electromagnetic disturbance level used as a reference level for co-ordination in the setting of emission and immunity limits

Note 1 to entry: By convention, the compatibility level is chosen so that there is only a small probability that it will be exceeded by the actual disturbance level. However electromagnetic compatibility is achieved only if emission and immunity levels are controlled such that, at each location, the disturbance level resulting from the cumulative emissions is lower than the immunity level for each device, equipment and system situated at this same location.

Note 2 to entry: The compatibility level can be phenomenon, time or location dependent.

[SOURCE: IEC 60050-161:1990, 161-03-10]

3.1.5

emission limit (of a disturbing source)

specified maximum permitted emission of a source of electromagnetic disturbance

3.1.6

electric power network

network

particular installations, substations, lines or cables for the transmission and distribution of electricity

Note 1 to entry: Electric power network can also be referred to as electric power system (system).

[SOURCE: IEC 60050-601:1985, 601-01-02]

3.1.7

harmonic (component)

component of order greater than 1 of the Fourier series of a periodic quantity

[SOURCE: IEC 60050-161:1990, 161-02-18]

3.1.8**point of connection****point of interconnection****POC****POI**

reference point on the electric power system where the user's electrical facility is connected

[SOURCE: IEC 60050-617:2009, 617-04-01, modified – in the term “point of connection” and “POI” have been added.]

3.1.9**point of common coupling****PCC**

point of a power supply network, electrically nearest to a particular load, at which other loads are, or can be, connected

Note 1 to entry: These loads can be either devices, equipment or systems, or distinct customer installations.

Note 2 to entry: In some applications, the term “point of common coupling” is restricted to public networks.

[SOURCE: IEC 60050-161:1990, 161-07-15]

3.1.10**reference network model****RNM**

95th percentile representation of a power system by means of one circuit designed with lines, cables, equipment, and loads having specified configurations for an intended study

Note 1 to entry: A reference network model for obtaining the 95th percentile of steady-state voltage performance might be different from a reference network model for obtaining the 95th percentile of voltage harmonic distortion.

3.1.11**network sensitivity**

ratio of change produced in a network variable by injection of a known disturbance

Note 1 to entry: The change in harmonic distortion level in a network by injection of harmonic current is one example of sensitivity that can be used for comparative purposes.

3.1.12**system impedance**

impedance of the supply system as viewed from the point of common coupling

[SOURCE: IEC 60060-161:1990, 161-07-16, modified – “supply” has been removed from the term.]

3.1.13**topology**

<network or power system> relative position of the ideal elements representing an electric network.

[SOURCE: IEC 60050-603:1986, 603-02-04]

3.2 Abbreviated terms

C_{fh}	Conversion factor
CP95	95 th percentile
DER	Distributed energy resource
DSO	Distribution system operator
EMC	Electromagnetic compatibility
h	Harmonic of order
LV	Low voltage
MV	Medium voltage
HV	High voltage
NA	North America
PCC	Point of common coupling
POC	Point of connection
POI	Point of interconnection
RNM	Reference network model
S_{hRNM}	95 th percentile of the harmonic voltage at the POIs of the RNM
$S_{hTarget}$	95 th percentile of the harmonic voltage at the POIs of the targeted network
S_R	Sensitivity ratio
SSE	Sum-squared error
SWER	Single-wire earth-return
THD	Total harmonic distortion
U_{NEW}	Supply voltage for the new limits
U_R	Voltage ratio
U_{RNM}	Phase-to-neutral European voltage, which is 230,94 V computed from the phase-phase nominal voltage, which is 400 V
xPyW	x-phase y-wire where x and y are numeric

4 General

IEC documents defining equipment harmonic current emission limits are largely based on European power systems having three-phase three-wire (3P3W) MV feeder topologies supplying three-phase four-wire (3P4W) LV distribution networks through delta-wye transformation. Typically, such LV systems serve hundreds of customers via many kilometres of cables, usually in a grounded configuration. This feeder topology results in a significant portion of the voltage total harmonic distortion (THD) at any given LV point of interconnection (POI) being caused by aggregation of harmonic currents flowing through the LV network impedance.

According to available historical information, existing emission limit studies were based on this European feeder topology with the knowledge that approximately 25 % of the contribution to voltage distortion comes from the LV system. Even though the use of delta-wye transformation effectively blocks zero-sequence harmonics from returning to the MV network, there was no special consideration given for modelling different sequence harmonics, only h5 (negative sequence) and h7 (positive sequence) orders were simulated. Historical documents explaining the method used to establish the emission limits that led to the IEC documents are no longer available, thus the exact method used at that time is difficult to recover. However, recent field measurements carried out in European countries have shown that the actual limits are effective in keeping the harmonic voltage below compatibility levels at most locations. This document does not redefine the approach used to establish emission limits. The objective is to report an appropriate methodology to adapt the existing limits in order to reproduce, for other countries, the same performance as observed in European countries.

Numerous power system topologies exist around the world that have characteristics differing from the 3P3W MV distribution systems used in Europe, which supply a small number of large MV/LV transformer stations. The following are examples of regions having power systems sufficiently different from those of Europe; adaptation of IEC emission limits can be beneficial for them in pursuit of EMC:

- North America: While there are regional differences within North America, generally the MV networks are 3P4W systems with multi-grounded neutrals. They supply hundreds of small MV/LV transformers (mixed single-phase and three-phase), and each serves only a few customers compared to those of Europe which serve hundreds of customers. MV feeders tend to be significantly longer than in Europe, so shunt capacitors and regulating transformers installed at various locations along the feeders are used to control the voltage. Of special note are the 1P3W LV networks supplying 120/240 V service to residential and other small single-phase customers. The three-phase LV networks used for larger multi-unit residential buildings, larger commercial, or industrial customers are 3P4W grounded systems having very short service cables, often less than 100 m in length.
- Japan: The population density in Japan is comparable to that of Europe. The MV system is significantly shorter than that in North America; its 3P3W MV distribution system operates at 6,6 kV to supply residential, commercial, and small industrial sectors. Since this MV system distributes the phase voltage without a neutral conductor, the single-phase LV systems are powered by transformers connected phase-to-phase. An open-delta transformer is used when three-phase voltage is required. Unlike in Europe, the connection of MV/LV transformers allows for triplen harmonics to circulate on the MV network (though not as zero-sequence components). Since the MV network voltage is about three times lower than that found in Europe, the number of customers supplied from it is also lower. On the other hand, an extension of the MV network at 22 kV, like that of Europe, is used to supply the 6,6 kV power system as well as larger MV customers. As in North America, the MV/LV transformers supply residential and small commercial customers with two voltages, however the supply is 100/200 V instead of 120/240 V.
- Australia: The Australian power system might be described as a hybrid topology having characteristics similar to both European and North American networks. They are similar in urban environments to Europe where short MV systems supply a few larger MV/LV transformers which in turn supply many customers in densely populated areas at 230/400 V. However, Australian systems also cover vast open territories using 1P1W MV networks using earth for return currents, called a single-wire earth-return (SWER) system. These are like North America in the sense that they serve rural areas using long single-phase networks, specifically like Canada where some distribution feeders exceed 200 km in length. However, the SWER system serves very few customers and has a lot of capacitance to ground due to its long length, thus the Ferranti effect – normally seen on lightly loaded transmission systems – is a concern here. For this reason, voltage regulation is implemented using shunt reactors instead of shunt capacitors.

Given the physical differences in systems such as impedance, customer density, service voltage, wiring, and grounding configurations it is reasonable to conclude that such topologies are impacted differently by harmonic emissions. As such, emission limits might be adjusted according to the power system capability to maintain the harmonic voltages below the applicable targets. Consider the following important characteristics that impact harmonic distortion performance differently:

- North American lower-impedance LV systems served by higher-impedance MV systems perform differently than European distribution systems in the sense that most of the harmonic aggregation occurs at the MV level. The harmonic voltage drops at the LV level due to having shorter cables and fewer customers, and therefore contribution to voltage THD in each LV network is very small ($< 5\%$ of voltage THD); when aggregated at the MV level it becomes apparent that most of the voltage distortion occurs by aggregation of load currents flowing through the impedance of the MV system ($> 95\%$ of voltage THD).
- The very long single-wire earth-return (SWER) distribution systems in Australia are characterized by light loading and high capacitance to ground; thus, shunt inductors are used to lower the voltage level along the MV lines. The high capacitance of the system in parallel with these inductors leaves it vulnerable to resonances.

The two examples noted above are causes for uncertainty as regions having different power system characteristics than Europe adopt the IEC harmonic emission limits without any local adaptations.

This document reports on the development of design characteristics for a benchmark European distribution power system that can be used for the purpose of modelling harmonic performance. The harmonic distortion level of the reference network model (RNM), when used with the recommended harmonic load, aligns well with present-day IEC compatibility levels. Subclause 7.2 describes in detail the origins of the data used to develop the RNM. A methodology is described for comparing other distribution systems to the European benchmark system for the purpose of adapting IEC harmonic current emission limits (IEC 61000-3-2 and IEC 61000-3-12) for effective use with those networks. The methodology was developed and tested using power system models from both Canada and Japan. Annex B and Annex C include power system details and the resulting limits from applying the methodology for both Canada and Japan respectively.

5 State of existing IEC standards

5.1 Overview of existing standards

IEC 61000-3-2 and IEC 61000-3-12 establish harmonic emission limits for equipment with input currents ≤ 16 A per phase and ≤ 75 A per phase, respectively. The limits are intended for equipment that is connected to the public LV distribution system in attempt to control the voltage THD in the electromagnetic environment. These standards form one part of the harmonic EMC framework intended to control harmonic distortion in the environment. When these standards are adopted in a region, then a baseline distortion level can be expected if these standards function as intended. DSOs can then enforce further harmonic controls on large customers through application of IEC TR 61000-3-6, which accounts for the baseline distortion level controlled by IEC 61000-3-2 and IEC 61000-3-12. The proper application of these standards is therefore of utmost importance to maintain EMC in the network.

The existing standards were created for European public distribution systems, and as such are based on characteristics of those systems. This leaves potential gaps with respect to their applicability in other regions of the world where the characteristics of the public supply systems differ. The obvious gaps which exist in the standards relate to applicable voltage levels and frequencies. The less obvious gaps with respect to differing system and sequence impedances exist because only one network model was used to determine the limits.

5.2 Voltage gaps

IEC 61000-3-2:2018 states the following in 6.1:

“The requirements and limits specified in this document are applicable to the power input terminals of equipment intended to be connected to 220/380 V, 230/400 V and 240/415 V systems operating at 50 Hz or 60 Hz. Requirements and limits for other cases are not yet specified.”

IEC 61000-3-12:2011 states the following in Clause 1, second paragraph:

“The limits given in this edition apply to equipment when connected to 230/400 V, 50 Hz systems.”

It then goes on to state the following in NOTE 1:

“The limits for the other systems will be added in a future edition of this standard.”

The following voltages, known to be used elsewhere in the world, are presently not mentioned in the equipment harmonic emission limit standards. This might not represent the whole list of voltages not previously considered:

Single-phase voltages:

100 V, 110 V, 115 V, 120 V, 127 V, 200 V

Three-phase voltages:

3P4W systems: 100/200 V, 120/208 V, 127/220 V, 277/480 V, 347/600 V

3P3W systems: 190 V, 200 V, 240 V, 440 V, 480 V

5.3 Frequency gaps

The IEC standards are sometimes restricted to 50 Hz supply systems; the 60 Hz power system frequency is used in many parts of the world:

- 60 Hz supply limits are presently specified in IEC 61000-3-2
- 60 Hz supply limits are not presently specified in IEC 61000-3-12

5.4 System impedance considerations

IEC TR 61000-1-4 provides the historic rationale for the harmonic limits defined in IEC 61000-3-2 and IEC 61000-3-12. IEC TR 61000-1-4:2022 states the following with respect to network characteristics and rationale for equipment harmonic limits in Clause 1:

“Some concepts in this document apply to all low voltage AC systems, but the numerical values apply specifically to the European 230 V/400 V 50 Hz system.”

IEC TR 61000-1-4:2022, Annex A, Clause A.1 goes on to state the following:

“The typical percentage impedances in European networks are given in Figure A.1. The partition of the total compatibility level into the parts assigned to each voltage level reflects roughly the relation of these percentage impedances. In order to account for the geometric summation of the voltage drops, the value of 25 % for the LV-network is increased with respect to the value which can be derived from the ratio of the impedance values. 25 % of the total compatibility level is therefore used in IEC 61000-3-2 and IEC 61000-3-12 for the assessment of the maximum harmonic currents from non-linear loads in the LV-network for 230 V 50 Hz systems.”

It follows, therefore, that public distribution supply systems in other regions of the world which are known to have different network characteristics require special consideration when introducing IEC equipment harmonic current emission limits.

6 General approach

The general approach of this study is to compare the harmonic sensitivity of different power systems and use the resulting voltage distortion differences to adapt the existing harmonic current emission limits for application to the target network. Numerous different ways to characterize networks and model harmonic sensitivity were studied in attempt to find a simplified approach, one that would provide accurate results and account for all the local variations that can exist in a power system. Regrettably, studies using voltage droop and clustering of feeder characteristics did not reveal any promising simplifications that are accurate enough to be useful; thus detailed harmonic modelling of the target power system in comparison with the benchmark European system is identified as the most accurate and reliable means of determining the network's sensitivity to harmonic current injection.

The methodology presented in this document is based on studies using real power system models obtained from various DSOs in Europe, North America, and Asia. Modern scripting techniques included with some modelling software allow for harmonic simulation at every customer connection point of the whole power system, thereby providing the detailed results that will be used for finding the 95th percentile levels to use for comparative analysis. It is noted that the methodology aims to evaluate the sensitivity of each electrical network to harmonic currents rather than to evaluate the real harmonic level that is expected. The harmonic sensitivity level is the 95th percentile of the harmonic voltage distortion at all customer POIs in the target region, given a specific harmonic load injection at each POI.

The tasks undertaken to implement the developed methodology are described in this document; they are as follows:

- a) the European RNM is developed for easy implementation in any power system modelling software;
- b) the harmonic load profile is defined;
- c) a scripting interface with power system modelling software is used to assess the harmonic power flow at every POI in the power system. A detailed PythonTM ¹ script for use with CYMDIST² models is provided in Annex D for users of that software;
- d) the statistical methods for analysing the results are defined;
- e) the resulting procedure is the technical basis for translating the IEC equipment harmonic current emission limits for use in the target network, based on the resulting power system harmonic sensitivity.

1 Python is the trade name of a product supplied by PythonTM. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC of the product named. Equivalent products may be used if they can be shown to lead to the same results.

2 CYMDIST is the trade name of a product supplied by Eaton. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC of the product named. Equivalent products may be used if they can be shown to lead to the same results.

The methodology in this document provides only a technical basis for applying limits in regions not covered by IEC 61000-3-2 and IEC 61000-3-12, with the primary goal of maintaining EMC equivalent to that which has been achieved in Europe. To complete the process of setting limits by consensus, in a second step, the impact of suppression measures on physical, operational, manufacturing and the overall economic aspects will also be considered, and the limits will be negotiated with all essential parties.

7 Detailed implementation of the methodology

7.1 Overview

According to IEC TR 61000-2-1:1990, Clause 4, the compatibility level covers at least 95 % of cases of an entire population. Since compatibility levels and harmonic emission limits have been designed for European countries, this entire population refers to the POIs of all customers in Europe. In other words, the 95th percentile of all harmonic levels at POIs in Europe should not exceed the level of compatibility established in IEC 61000-2-2. If the same harmonic current flows in a network whose design is different from that of the European reference network, the 95th percentile of the harmonic level could be either lower or higher than the compatibility level, depending on whether the network is less or more sensitive to harmonic loads. To maintain the level of the harmonic voltage in accordance with electromagnetic compatibility requirements, this methodology works on the principle that emission limits are adjusted according to the sensitivity of the electrical network to harmonic currents flowing in its components.

Clause 7 reports on a methodology to use for finding the conversion factor C_{fh} for each harmonic order h to adjust the harmonic emission limits that allow a non-European network to keep the 95th percentile of the harmonic voltage below the compatibility level. Finding the appropriate conversion factors will allow other regions outside of Europe to adopt IEC 61000-3-2 and IEC 61000-3-12 equipment harmonic current emission standards with deviations to account for local network designs.

NOTE This document only provides the methodology, it does not provide the conversion factors for different regions around the world. It is the responsibility of EMC representatives in each region outside of Europe to assess whether or not their power system might give just cause for adaptation of the IEC limits, and if so to conduct their own studies to determine the appropriate conversion factors.

7.2 European reference network model (RNM)

7.2.1 History

The DSO Observatory project launched at the end of 2014 created a database of the largest energy distribution systems operated in European countries. As a result of this project, the European Commission published a report in 2016, Distribution System Operators Observatory [2]³. The data available in this report represents a comprehensive collection of the European power distribution system architecture and characteristics and the data is updated approximately every two years.

In total, 79 of the 190 European DSOs contributed to the collection of data from the Joint Research Centre of the European Commission (JRC). The collaborators manage more than 70 % of the electricity supplied by all European DSOs representing more than 2 000 TWh of electricity supplied to over 200 million customers per year, covering a total area of more than 3 million km². The collected information and data have been used by other researchers and groups to develop detailed RNMs to analyse the impacts of various LV network interactions such as distributed energy resources (DERs).

The RNM proposed by the European Commission for the MV semi-rural system [2] was tested for assessing the harmonic sensitivity. This RNM supplies 34 LV networks which each supply 108 customers [2]. The simulation of this RNM, carried out with each customer injecting the

³ Numbers in square brackets refer to the Bibliography.

harmonic current of Table 4, gives a result for the 95th percentile of the voltage harmonic at the POIs equal to a level of 46 % to 584 % of the compatibility levels depending on the harmonic order considered. The results demonstrate why that RNM, which is mainly intended for economic studies of DER implementation on the electrical system, cannot be used to assess the harmonic sensitivity without being adjusted.

7.2.2 Adjusted RNM for assessing harmonic sensitivity

The RNM for assessing harmonic sensitivity is a simplified equivalent model of a European distribution system. It is expected to meet the following requirements:

- a) the architecture of MV and LV electrical systems are similar to that documented by the European Commission (see [2]);
- b) the implementation in simulation software is simple, allowing for repeated cut and paste of various network components;
- c) the nominal voltage is 230 V and the load flow voltages at each customer POI should be $230\text{ V} \pm 10\%$ per phase;
- d) the currents in cables and transformers do not exceed their specifications;
- e) each customer is supplied by three-phase service;
- f) the load of each three-phase customer is 1,5 kVA (0,5 kVA/phase) [4] with a lagging power factor of 0,98; and
- g) the harmonic current per phase generated by each three-phase customer is that from the 230 V column of Table 4 divided by 3.

NOTE 1 The RNM is a fictional EU feeder meant to supply the 95th percentile distortion levels for simulation purposes. It is not a real network, albeit it has similarities to EU networks.

NOTE 2 Some European DSOs supply residential customers with three-phase service, while some supply one-phase service. The service type that one uses for the RNM is an arbitrary selection and does not impact the final results (i.e. a 1,5 kW one-phase service can also be modelled as three-phase service with 0,5 kW per phase).

NOTE 3 Each feeder connected to the substation contributes to the harmonic level of the main bus. To obtain the same level of voltage harmonic distortion at the main bus, the short-circuit power is increased according to the number of feeders it supplies. In reality many feeders are often supplied from the same bus, in which case the short circuit power would increase accordingly; it is often 200 MVA or more. The 90 MVA fault level was selected for the RNM to give a simple equivalent source impedance for modelling one feeder.

For a simplified implementation, the type and length of the MV lines between each node are the same. In addition, all LV networks are identical. The network model is thereby quickly realized in software by cutting and pasting very few elements that simply repeat over and over again and are equidistant apart.

The adopted MV power system connects 29 identical LV networks, each separated by 2,11 km of overhead line (see Figure 1). The repeating LV network uses two sizes of cables, larger trunk cables near the transformer station and smaller service cable as the load decreases farther away from the station (see Figure 2). Each block in Figure 1 represents one LV network supplying 153 customers. This LV network is detailed in Figure 2 where the number of long cable sections between each customer (11 m apart) is indicated in red and the number of customers in blue.

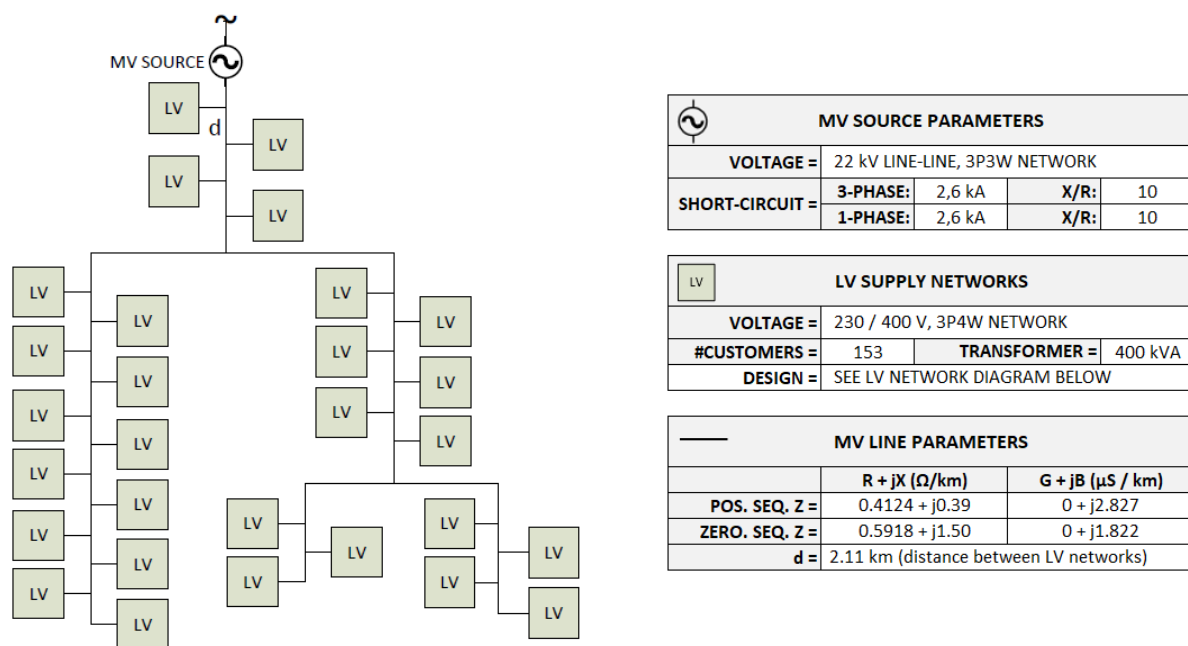
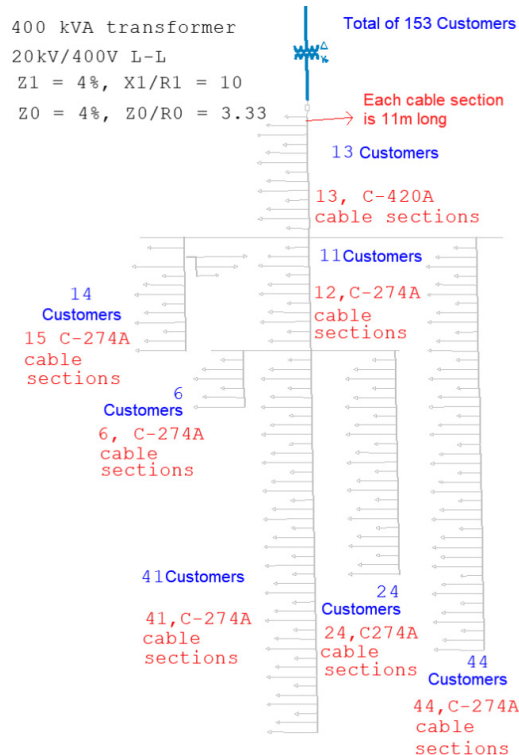


Figure 1 – Reference network medium-voltage power system



		cable impedances	
		R=jX Ω/km	G+jB μS/km
C-274A	Positive sequence	0,207+j0,0913	0,6+j109,7
	Zero sequence	0,824+j0,3652	0.0+j37.7
C-420A	Positive sequence	0.14+j0,08	0,6+j109,7
	Zero Sequence	0,5573+j0,32	0,0+j37,7

Figure 2 – LV network of 153 customers supplied by a 400 kVA transformer

The LV network of Figure 2 has the following important characteristics:

- 1) it supplies 153 three-phase customers at 230/400 V;