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BSI Standards Publication

Consideration of reference impedances and public supply network impedances for use in determining disturbance characteristics of electrical equipment having a rated current ≤ 75 A per phase

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National foreword

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TECHNICAL REPORT

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Consideration of reference impedances and public supply network impedances for use in determining the disturbance characteristics of electrical equipment having a rated current ≤75 A per phase

Étude des impédances de référence et des impédances des réseaux publics d’alimentation aux fins de la détermination des caractéristiques de perturbation des équipements électriques utilisant un courant nominal ≤75 A par phase

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CONSIDERATION OF REFERENCE IMPEDANCES AND PUBLIC SUPPLY NETWORK IMPEDANCES FOR USE IN DETERMINING THE DISTURBANCE CHARACTERISTICS OF ELECTRICAL EQUIPMENT HAVING A RATED CURRENT ≤75 A PER PHASE

FOREWORD

The main task of IEC technical committees is to prepare International Standards. However, a technical committee may propose the publication of a technical report when it has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

IEC 60725, which is a technical report, has been prepared by subcommittee 77A: EMC – Low frequency phenomena, of IEC technical committee 77: Electromagnetic compatibility. This third edition cancels and replaces the second edition, published in 2005, and constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- new survey and other data from countries having public supply networks operating at 60 Hz have been included;
- recommendations that were applicable to 50 Hz systems are now mirrored by new recommendations that are relevant to 60 Hz systems.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
77A/784/DTR	77A/789/RVC

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.

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

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

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

CONSIDERATION OF REFERENCE IMPEDANCES AND PUBLIC SUPPLY NETWORK IMPEDANCES FOR USE IN DETERMINING THE DISTURBANCE CHARACTERISTICS OF ELECTRICAL EQUIPMENT HAVING A RATED CURRENT ≤75 A PER PHASE

1 Scope

This Technical Report records the information that was available and the factors that were taken into account in arriving at the reference impedances that were incorporated in IEC 60555 and which are now incorporated in some parts of IEC 61000-3.

In addition, information is given on the impedances of public supply networks associated with service current capacities ≥100 A per phase.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 61000-3-3, *Electromagnetic compatibility (EMC) – Part 3-3: Limits – Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current ≤16 A per phase and not subject to conditional connection*

IEC 61000-3-11, *Electromagnetic compatibility (EMC) – Part 3-11: Limits – Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems – Equipment with rated current ≤75 A and subject to conditional connection*

IEC 61000-3-12, *Electromagnetic compatibility (EMC) – Part 3-12: Limits – Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current >16 A and ≤75 A per phase*

3 Systems of low-voltage supply

3.1 Three-phase supply systems

Three-phase, four-wire, distribution systems are used worldwide to supply low-voltage consumers with nominal voltages in the region of 230 V/400 V.

To conform with IEC standard voltages, these systems are described as 230 V/400 V throughout this report.

There is considerable variation in the way in which the supplies to individual consumers are connected to three-phase systems.

In some countries, all four wires are taken into the consumer’s premises, allowing the use of three-phase 400 V for large loads, with small appliances and lighting circuits connected between one line and neutral at 230 V.

In other countries, three wires are taken into the consumer's premises, allowing the use of 400 V across two phases for large loads, with small appliances and lighting circuits connected between one line and neutral at 230 V.

In other countries, of which the United Kingdom is an example, it is unusual to take more than one phase into a residential consumer's premises. Therefore, both large loads that are less than 15 kVA and lighting circuits are supplied between line and neutral at 230 V.

3.2 Single-phase two-wire supply systems

In the rural areas of most countries, it is common to connect the winding of distribution transformers across two phases of medium voltage systems and afford supplies to low-voltage consumers via a phase and return conductor. A wide range of voltage is associated with this type of supply system.

In Korea, there are extensive networks supplying single-phase two-wire connections at 220 V.

3.3 Single-phase three-wire supply systems

In some countries, of which the United States of America is an example, a single-phase, three-wire distribution is used. Large loads are connected across the outer wires at 240 V whilst small appliances and lighting circuits are connected between one outer and the centre wire at 120 V, as shown in Figure 1.

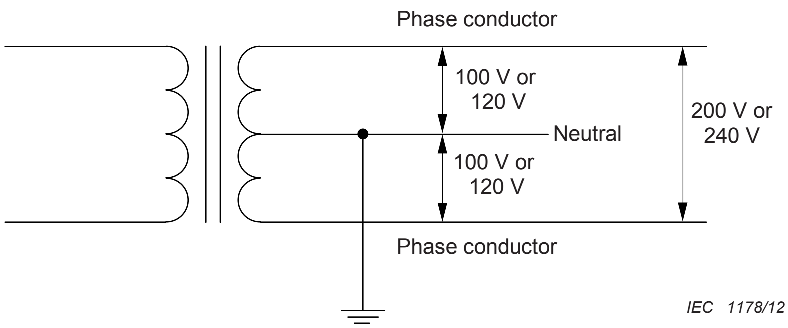


Figure 1 – Representation of a single-phase three-wire supply system

In North America, distribution systems use smaller size transformers, each supplying 4 to 8 customers with shorter secondary (LV) feeder lengths. In Japan the nominal supply voltages are 100 V and 200 V.

These supply systems have quite different supply impedances from those of three-phase distribution systems and might require a different reference impedance for testing equipment having a rated voltage within the range 100 V to 125 V.

4 Supply impedances

4.1 Typical residential premises

The supply system impedance associated with the supply to the premises of a typical residential consumer, is determined by the average value of maximum power demand of all the consumers connected to a typical network and the steady state voltage drop at maximum load used to design the system.

Information on the supply system impedance was collected from as many countries as possible and is presented in Tables 1 to 5. The impedance to be considered was the impedance up to the point of common coupling with other consumers. However, in many systems, particularly where there were several apartments in the same building, the point of common coupling was close to the metering point. Hence, the impedance figures obtained usually include both the supply system impedance and the service connection impedance.

The phase-to-neutral impedance characteristics of three-phase supply systems, in which each consumer is supplied at 230 V, 50 Hz, differ widely between countries. An international survey of residential consumers' complex supply impedances for single-phase connections at 50 Hz is shown in Table 1.

Table 1 – Residential consumers' complex supply impedances at 50 Hz

Country	Year in which data was provided to IEC	Percentage of consumers having supply impedances equal to or less than the listed complex values in Ω			
		98 %	95 %	90 %	85 %
Australia	2011	0,42 + j0,38	0,30 + j0,27	0,25 + j0,23	0,22 + j0,20
Belgium	1980	–	0,63 + j0,33	0,32 + j0,17	0,28 + j0,15
France	1980	–	0,55 + j0,34	0,45 + j0,25	0,34 + j0,21
Germany	1980		0,45 + j0,25	0,36 + j0,21	0,31 + j0,17
Ireland[a]	1980	1,47 + j0,64	1,26 + j0,60	1,03 + j0,55	0,94 + j0,43
Italy	1980	–	0,59 + j0,32	0,48 + j0,26	0,44 + j0,24
Netherlands	1980	–	0,70 + j0,25	0,41 + j0,21	0,32 + j0,17
Switzerland	1980	–	0,60 + j0,36	0,42 + j0,25	0,30 + j0,18
United Kingdom	1980	0,46 + j0,45	–	0,25 + j0,23	–
USSR	1980	–	0,63 + j0,30	0,50 + j0,26	–
NOTE This table shows the phase-to-neutral impedance for single-phase systems.					
[a] System impedances for residential consumers in Poland are similar to those in Ireland.					

Since 1981, when the impedance survey was published as Table 1, there has been natural development and reinforcement of public supply networks and the 1980 values in the 90 % column, on which the reference impedances for residential supplies were based, are now more relevant to the 95 % column because supply impedances have been reduced overall.

Information on the measurement of supply impedances is given in Annex C.

The impedance data for residential supply systems, based on study data from the year 2000 and surveys from countries with systems other than 230 V/400 V, are summarized in Tables 2 to 5.

Table 2 – Single-phase device capacities <100 A per phase

Country	Connections V	Percentage of consumers having supply impedances equal to or less than the listed complex values in Ω					Remarks
		98 %	95 %	90 %	85 %	Others	
Canada	100 to 120		0,20+j0,06			–	Survey/Calculation
	200 to 240		0,20+j0,08			–	
USA	100 to 120			0,09+j0,05			Calculation (10 % of customers have higher impedance)
	200 to 240			0,10+j0,06			
Mexico [a]	100 to 120		0,10+j0,07			–	Calculation
	127		0,16+j0,08			–	
Korea	220	0,40+j0,18	0,34+j0,15	0,31+j0,11	0,28+j0,10	–	Survey
Japan	100		0,35+j0,13			–	Survey/Calculation
	200		0,42+j0,21			–	

NOTE 1 The figures for the USA are 90th percentile.

NOTE 2 All references to data from Korea relate to data from South Korea.

NOTE 3 The data from Korea has been taken from rural and urban networks.

NOTE 4 The wide difference in network topographies in the 60 Hz countries mean that it is not possible to provide a single reference impedance 60 Hz countries.

NOTE 5 TBD (to be derived).

[a] The values for Mexico are listed under the 95 percentile but Mexico is working towards 100 % of the network impedance values to be at or below the specified values.

Table 3 – Three-phase service capacities <100 A per phase

Country	Connections V	Percentage of consumers having supply impedances equal to or less than the listed complex values in Ω				Remarks
		98 %	95 %	90 %	85 %	
Canada	120/208	TBD	0,07+j0,04	TBD	TBD	Survey/CalculationCIRED paper
USA	277/480	No data		0,10+j0,06		Estimate/survey
Mexico [a]	277/480		0,11+j0,09			
Korea	220/380	0,30+j0,20	0,29+j0,18	0,26+j0,16	0,22+j0,15	Survey
Japan	200	No data	0,38+j0,18			Survey/ Calculation estimate based on JIS-C IEC 61000-3-2

NOTE 1 The figures for the USA are 90th percentile.

NOTE 2 All references to data from Korea relate to data from South Korea.

NOTE 3 The data from Korea has been taken from rural and urban networks.

NOTE 4 The wide difference in network topographies in the 60 Hz countries mean that it is not possible to provide a single reference impedance 60 Hz countries.

NOTE 5 TBD (to be derived).

[a] The values for Mexico are listed under the 95 percentile but Mexico is working towards 100 % of the network impedance values to be at or below the specified values.

4.2 Large residential, commercial and light industrial premises

4.2.1 General

The premises considered in this subclause have service current capacities equal to or in excess of 100 A per phase.

It is anticipated that the number of requests from consumers and their agents to distribution network operators for information relating to the system impedance at their supply terminals will increase as a consequence of the publication of IEC 61000-3-11 and the procedure for the conditional connection of equipment that it promulgates.

In order to assist distribution network operating companies worldwide in determining a practical value of actual supply impedance at a particular consumers' premises and to assist manufacturers in assessing the marketability of their products in particular countries worldwide, a basic approach to the determination of maximum supply impedance has been developed and is given in Annex A.

The following values of supply impedance have been obtained by application of the method given in Annex A, on the assumptions that

a) the distribution transformer has a rating of 500 kVA, a 3 % voltage regulation or a 2,68 % reactance,
b) there is 95 % probability of occurrence, i.e. 5 % of consumers, are likely to have a supply system impedance greater than the tabled values.

If necessary, these supply impedances, or the maximum supply impedances listed in Annex A, Tables A.1 and A.2, may be amended to represent national or particular public supply networks in accordance with Clause A.5.

The impedance data for residential supply systems, based on recent studies and surveys from countries with systems other than 230 V/400 V, is summarized in Tables 4 and 5.

Table 4 – Single or two-phase service capacities ≥100 A per phase

Country	Connections V	Percentage of consumers having supply impedances equal to or less than the listed complex values in Ω				Remarks
		98 %	95 %	90 %	85 %	
Canada	347	TBD	0,58+j0,11	TBD	TBD	Survey/Calculation
USA	480	No data	No data	0,10+j0,06		Estimate/survey
Korea	220	0,32+j0,14	0,29+j0,12	0,27+j0,11	0,22+j0,09	Survey
Japan		No data	No data	No data	No data	
TBD = To be derived.						

Table 5 – Three-phase service capacities ≥100 A per phase

Country	Connections V	Percentage of consumers having supply impedances equal to or less than the listed complex values in Ω				Remarks
		98 %	95 %	90 %	85 %	
Canada	600	TBD	0,39+j0,07	TBD	TBD	Survey/Calculation CIRED paper
USA	480	No data	No data	No data	No data	
Korea	380	0,27+j0,21	0,24+j0,19	0,21+j0,17	0,20+j0,17	Survey
Japan	–	–	–	–	–	Not applicable
TBD = To be derived.						

4.2.2 Supply impedance relevant to the connection of three-phase equipment

Table 6 contains, under the assumptions stated in 4.2, the values of the modulus in ohms, of the supply impedance of the line-conductors of 230 V/400 V, 50 Hz public electricity supply networks relevant to three-phase services, the various statutory voltage ranges declared to consumers and service capacities in common use.

Table 6 – Modulus values of supply impedance, in ohms at 50 Hz, relevant to the connection of three-phase equipment and having a 95 % probability of not being exceeded

Declared voltage range %	Service capacity in amperes per phase				
	150 A	**200 A**	**300 A**	**400 A**	**600 A**
8	0,09	0,06	0,04	0,03	0,02
9	0,10	0,07	0,05	0,04	0,03
10	0,11	0,08	0,05	0,04	0,03
11	0,12	0,09	0,06	0,05	0,03
12	0,14	0,10	0,07	0,05	0,03
13	0,15	0,11	0,08	0,06	0,04
14	0,17	0,13	0,08	0,07	0,04
15	0,18	0,14	0,09	0,07	0,05
16	0,20	0,15	0,10	0,08	0,05
17	0,21	0,16	0,10	0,08	0,05
18	0,22	0,17	0,11	0,09	0,06
19	0,24	0,18	0,12	0,09	0,06
20	0,25	0,19	0,13	0,10	0,06

4.2.3 Supply impedances relevant to the connection of single-phase equipment

Table 7 contains, under the assumptions stated in 4.2, the values of the modulus, in ohms, of the supply impedance of the line-to-neutral conductors of 230 V/400 V, 50 Hz public electricity supply networks relevant to the connection of single-phase equipment to three-phase 4-wire services.

Table 7 – Modulus values of supply impedance, in ohms at 50 Hz, relevant to the connection of single-phase equipment and having a 95 % probability of not being exceeded

Declared voltage range %	Service capacity in amperes per phase				
	150 A	200 A	300 A	400 A	600 A
8	0,13	0,10	0,06	0,05	0,03
9	0,15	0,12	0,08	0,06	0,04
10	0,18	0,13	0,09	0,07	0,04
11	0,20	0,15	0,10	0,08	0,05
12	0,23	0,17	0,11	0,08	0,06
13	0,25	0,19	0,12	0,09	0,06
14	0,27	0,20	0,14	0,10	0,07
15	0,30	0,22	0,15	0,11	0,07
16	0,32	0,24	0,16	0,12	0,08
17	0,34	0,26	0,17	0,13	0,09
18	0,37	0,28	0,18	0,14	0,09
19	0,39	0,29	0,20	0,15	0,10
20	0,42	0,31	0,21	0,16	0,10

5 Reference impedances

5.1 General

Values of reference impedances appropriate to low-voltage public supply systems are given in the following subclauses; some are values already established in IEC 61000-3-3 and IEC 61000-3-11, whilst others, pertaining to 60 Hz supply systems, are recommended values.

It should be clearly understood that it is not possible to define a single reference impedance that applies in all regions of the world, because of different supply voltages and different distribution systems.

5.2 Reference impedances for equipment with current ratings ≤16 A

5.2.1 Overview

Equipment having current ratings ≤16 A is mainly connected in premises having service current capacities less than 100 A per phase. Such premises are predominantly in residential supply areas, which were initially surveyed in Europe in 1980, while other surveys have been made at more recent dates. Reference impedances relevant to the connection of equipment having current ratings ≤16 A have therefore been derived from the values given in Table 1.

It was planned that the reference impedances should represent existing system impedances and have values that can be used to assess the emissions of equipment against voltage limits with a view to ensure that connection of equipment to a public supply network would not cause undue voltage disturbance and distortion.

It has not proved possible to find an automatic and logical way of relating the reference impedance to the range of system impedances. It was recognised that to say that 10 % of consumers had supply impedances greater than a given value did not imply that 10 % of consumers would be disturbed. A consumer at the far end of a line causes less disturbance (due to voltage fluctuations or harmonic distortion) to consumers nearer to the source than to his immediate neighbour.

Divergence of views about the use of a single reference impedance may be summarized as follows:

a) some countries with high impedance networks do not consider it economically possible to reinforce their networks;
b) some countries with high impedance networks have no need to reinforce their networks because they have readily available alternative fuels for cooking and heating appliances;
c) some countries are not concerned with the switching of significant loads at 230 V because they connect large appliances to two or three phases at 400 V.

The values in the following subclauses were chosen as reference impedances and take account of experience with the use of existing appliances on existing systems as well as the survey values of system impedance presented in Tables 1, 2, 3, 4 and 5.

5.2.2 50 Hz and 60 Hz low-voltage supply systems

5.2.2.1 Three-phase, four-wire, 230 V/400 V supply systems with service capacities <100 A

Adoption of the following reference impedances, Z_{ref}, for testing purposes is recommended, see Table 8.

Table 8 – Reference impedances for testing purposes

Conductor	Impedances Ω
Phase conductor	0,24 + j0,15
Neutral conductor	0,16 + j0,10
Total	0,40 + j0,25

NOTE In Korea, there are three-phase four-wire 220 V/380 V low-voltage supply networks.

5.2.2.2 Single-phase, two-wire 230 V systems with service capacities <100 A

In this category of supply systems, Ireland has a network in which a high percentage of consumers have supply impedances greater than (0,4 + j0,25) Ω. Italy and Poland also have a large proportion of rural networks with relatively high supply impedances. In the United Kingdom, supplies to only about 2 % of consumers exceed (0,4 + j0,25) Ω.

A single value of reference impedance of (0,4 + j0,25) Ω (phase to neutral) has been adopted with the advantages that

- this value gives the same limit conditions for appliances manufactured for use in all countries;
- it complies with the decision that there should be a single reference impedance used for the assessment of emissions from equipment rated ≤16 A per phase;
- it simplifies the test house procedure;
- experience shows that most appliances already connected to public supply systems comply with limits based on this impedance (but there are exceptions);
- it simplifies the setting of limits.

The choice of a single impedance also has disadvantages, namely:

- although conditions on networks with relatively high impedance are normally acceptable at present, this may not be so if equipment intended for simultaneous use in large numbers were designed to produce the maximum values of voltage change foreseen;

- equipment forming part of a larger appliance, which operates for only short periods and which is known to be acceptable, would be prohibited.

Equipment rated ≤16 A, which does not comply with the voltage limits of IEC 61000-3-3 when tested with the reference impedance may be retested or evaluated to show conformity with IEC 61000-3-11. IEC 61000-3-11 is applicable to equipment with rated input current ≤75 A per phase and enables conditional connection of equipment by a public distribution network operating company.

5.2.2.3 Single-phase, three-wire, 100 V/200 V and 120 V/240 V supply systems with service capacities <100 A

The recommended reference impedances for 50 Hz and 60 Hz single-phase three-wire supply systems, see Figure 1, having nominal voltages within the range of 100 V to 120 V are given in Table 9.

Table 9 – Reference impedances for 100 V/200 V and 120 V/240 V supply systems <100 A

Conductor	Impedances Ω
Phase conductor	0,209 + j0,103
Neutral conductor	0,143 + j0,025
Total	0,35 + j0,13
This impedance is based on data from US, Canada and Japan.	

The recommended reference impedances for 50 Hz and 60 Hz single-phase three-wire supply systems, see Figure 1, having nominal voltages within the range of 200 V to 240 V and service capacities <100 A are given in Table 10.

Table 10 – Reference impedances for 200 V to 240 V supply systems <100 A

Conductor	Impedances Ω
Phase conductor	0,209 + j0,103
Return phase conductor	0,209 + j0,103
Total	0,42 + j0,21
This impedance is based on data from US, Canada and Japan.	

5.2.2.4 Three-phase, four-wire supply systems having service capacities ≥100 A per phase

For 50 Hz and 60 Hz single-phase supply systems having nominal voltages within the range of 200 V to 240 V and with service capacities ≥100 A per phase the recommended reference impedances are given in Table 11.

Table 11 – Reference impedances for 200 V to 240 V supply systems, ≥100 A per phase

Conductor	Impedances Ω
Phase conductor	0,15 + j0,15
Neutral conductor	0,10 + j0,10
Total	0,25 + j0,25

5.3 Reference impedance for 50 Hz and 60 Hz equipment with current ratings >16 A and ≤75 A per phase

Equipment rated ≤75 A per phase is extensively used in commercial and industrial premises, and to a lesser extent in residential premises.

50 Hz supply system impedance values for a range of higher service capacities are given in Tables 6 and 7.

For equipment rated ≤75 A and intended to be used only in premises having a service capacity <100 A per phase (where the single-phase voltage is in the range 200 V to 240 V) it is recommended that test reference impedances, Z_{test}, from 5.2.2.1 are adopted.

For equipment rated ≤75 A and intended to be used only in premises having a service capacity ≥100 A per phase (where the single-phase voltage is in the range 200 V to 240 V) it is recommended that test reference impedances, Z_{test}, shown in Table 12 are adopted.

Table 12 – Reference impedances for testing purposes, for 200 V to 240 V supply systems, ≥100 A

Conductor	Impedances Ω
Phase conductor	0,15 + j0,15
Neutral conductor	0,10 + j0,10
Total	0,25 + j0,25
NOTE The above impedance values are recommended for tests in accordance with IEC 61000-3-11 on equipment having current ratings >20 A r.m.s. Equipment having current ratings above 19 A by definition exceed the d_c limit of 3,3 % and thus require a system impedance that is lower than the Z_{ref} shown in Table 8.	

6 Impedance at frequencies above the supply frequency

Theoretical considerations suggest that resonance between power factor correction capacitors and the system inductance is possible at harmonic frequencies, but this phenomenon has only been observed in a few cases. For this reason, it is recommended that the reference impedance be regarded as purely resistive and inductive for assessing harmonic emissions.

The supply impedance values presented in this report may be used to determine the minimum short-circuit level at the fundamental frequency used in IEC 61000-3-12 to specify the limits of harmonic current emissions from equipment.

Annex A
(informative)

Methods for determining the maximum modulus values of public electricity supply low-voltage network impedances relevant to three-phase services of more than 100 A per phase at 50 Hz

A.1 Relevance of this Technical Report

The main body of this Technical Report was published in 1981 in order to facilitate the connection of residential equipment to public supply low-voltage networks by providing test reference impedances for use with the IEC 60555 emission standards.

However, when the IEC 60555 standards were converted to IEC 61000-3 standards in 1995, the scopes were changed to incorporate most equipment rated less than or equal to 16 A. This change meant that equipment for use in commercial, light industrial and industrial premises, previously considered as professional equipment, had to comply with the emission limits for harmonics and voltage fluctuations.

Manufacturers now design and test equipment to the new standards, as much of modern equipment is used in all environments. Modern equipment includes for example: very large television sets, personal computers, photocopiers, air-conditioning units and high-powered water jet equipment.

The object of this annex is to extend the supply impedance information provided by supply authorities to service capacities in excess of 100 A per phase, thereby facilitating the assessment of equipment for connection to a specific supply and to form a common knowledge base which can be used by equipment manufacturers when discussing the marketing of their products with supply authorities at a national level.

Because there is an enormous variety throughout the world of statutory supply voltages, permitted variations and the specifications used by supply authorities for power system plant and equipment, a statistical survey to determine supply impedances relevant to particular service capacities would be extremely expensive and the results would be too specific.

Consumer demand for enhanced performance equipment has had the effect of driving up the ratings of equipment and manufacturers have had problems in meeting the voltage fluctuation limits in IEC 61000-3-3 in particular. A solution was found to manufacturers' problems by publishing IEC 61000-3-11 with a scope that overlaps that of IEC 61000-3-3.

IEC 61000-3-11 is applicable to equipment rated less than or equal to 75 A and subject to conditional connection, and it permits manufacturers of equipment that does not meet the limits of IEC 61000-3-3, when tested with the reference impedance Z_{ref}, to retest the equipment with a variable test reference impedance. Thus they may

a) either determine the maximum permissible system impedance Z_{max} at the interface point of the user's supply, which gives compliance with the standard's limits, declare it in the equipment instruction manual and instruct the user to determine in consultation with the supply authority, if necessary, that the equipment is connected to a supply of that impedance or less, or
b) test single-phase equipment with a test impedance of (0,25 + j 0,25) Ω and test three-phase equipment with a line test impedance of (0,15 + j 0,15) Ω and a neutral test impedance of (0,1 + j 0,1) Ω. If the equipment meets the limits set in the standard, the manufacturer shall declare in the equipment instruction manual that the equipment is intended for use only in premises having a service current capacity equal to or greater than 100 A per phase, supplied from a distribution network having a nominal voltage of

400 V/230 V, and instruct the user to determine, in consultation with the supply authority if necessary, that the service current capacity at the interface point is sufficient for the equipment.

The equipment shall be clearly marked as being suitable for use only in premises having a service current capacity equal to or greater than 100 A per phase.

For options a) and b), if the supply capacity, service current capacity, and/or the actual system impedance at the service cut-out of the premises where the equipment is to be used have been declared to, or measured by, the user or equipment installer, this information may be used to assess the suitability of equipment without reference to the supply authority.

This annex, therefore, presents impedance data in a form that enables supply authorities worldwide to determine appropriate values specific to the construction of their supply systems and statutory obligations. Values of impedance are derived from consideration of a basic model of a 500 kVA transformer supplying a 400 V/230 V, 50 Hz, three-phase public distribution network, which in turn supplies a service having a declared capacity of 200 A per phase.

A.2 Network model appropriate to low-voltage public electricity supply networks

The basic model used to determine the impedance of a supply from a public electricity network is single-phase and uses a declared voltage U_{dec} with a declared voltage variation range. For the purpose of this example the following descriptions will be used: ΔU_{range}, expressed as a percentage of U_{dec} and comprised of an upper voltage limit, ΔU_{up}, and a lower voltage limit, ΔU_{down}, both expressed as a percentage of U_{dec}.

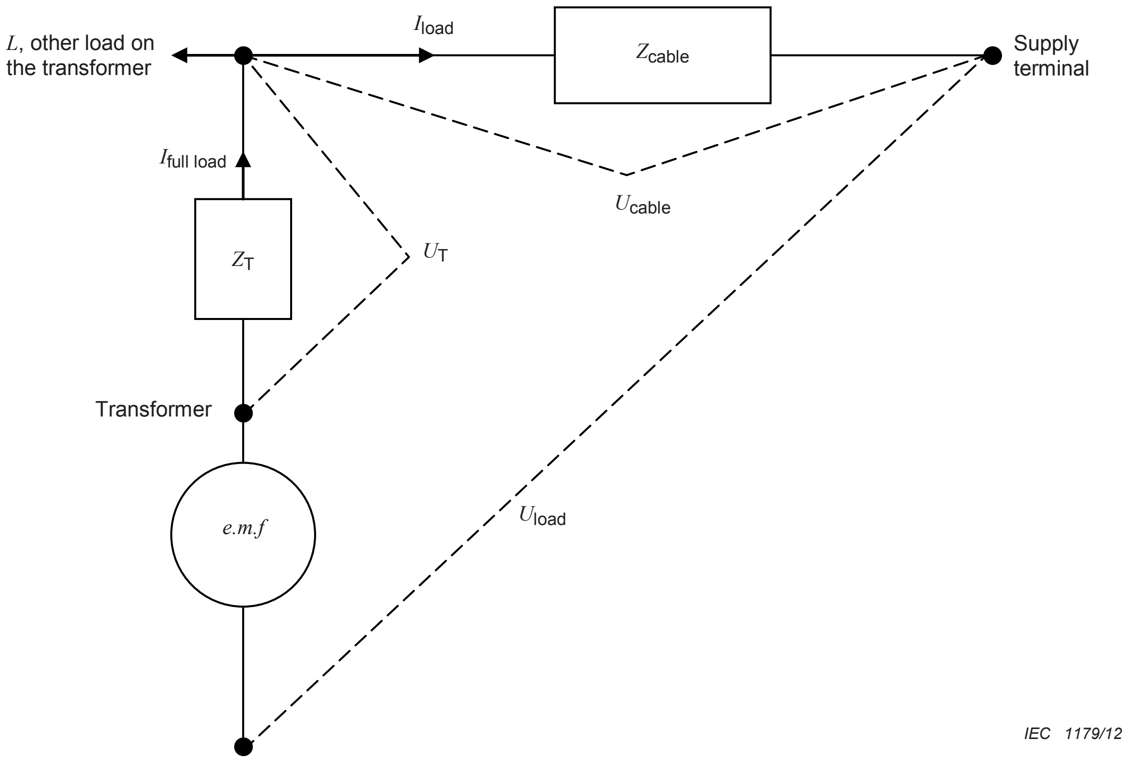
The single-phase model is shown in Figure A.1 and is comprised of

a) transformer, T, having an *e.m.f.* equal to the maximum permissible voltage, i.e. U_{dec} (1 + ΔU_{up}/100), a voltage regulation U_{reg} from no-load to full–load expressed as a percentage of U_{dec} , an impedance Z_T, and a full-load rated current of $I_{\text{full load}}$,

b) network load, L, connected directly to the transformer, which together with the capacity of the service being considered equals the capacity of the transformer,

c) distribution cable and service line having a combined impedance of Z_{cable}, and service load of I_{load} amperes per phase equal to the declared service capacity,

d) U_{load} is the voltage across the load connected at the supply terminal.



Key

e.m.f. electromotive force

Figure A.1 – Model used for determining the impedance of a network line conductor from a transformer to a three-phase service cut-out

The voltage, U_{cable}, across Z_{cable} is given by

$$U_{\text{cable}} = e.m.f. - U_{\text{T}} - U_{\text{load}}$$

NOTE This is a simplified formula that assumes the power factor of the load and the power factor of the network are equal.

$$= U_{\text{dec}} (1 + \Delta U_{\text{up}}/100) - U_{\text{reg}}/100 \cdot U_{\text{dec}} (1 + \Delta U_{\text{up}}/100) - U_{\text{dec}} (1 - \Delta U_{\text{down}}/100)$$

$$= \Delta U_{\text{range}}/100 \;\; U_{\text{dec}} - U_{\text{reg}}/100 \cdot (1+ \Delta U_{\text{up}}/100) \cdot U_{\text{dec}}$$

$$U_{\text{cable}} = \frac{U_{\text{dec}}}{100}\left[\Delta U_{\text{range}} - U_{\text{reg}}\left(1 + \frac{\Delta U_{\text{up}}}{100}\right)\right] \qquad \text{(A.1)}$$

The modulus value of Z_{cable} is given by dividing U_{cable} by the service cut-out phase-current capacity, which is also I_{load}.

A complex value of Z_{cable} may be obtained from the modulus value by application of the impedance ratio of the line impedance components of cables in common use; see Clause A.3 where the R/Z ratio of 0,877 is applied to cables. Vector addition of Z_{T} to Z_{cable} yields the impedance of the network line conductor. Provided that the power-factor of the assumed load is in the region of, and higher than, 0,9, reasonably accurate results are obtained by this method.

To obtain the value of supply impedance relevant to the connection of single-phase equipment to a three-phase service, Z_{cable} is multiplied by 1,667 before the addition of Z_T, in order to reflect the impedance in the cable's neutral return path in accordance with the ratio of line components to neutral components of Z_{ref} given in Table 8 and adopted in IEC 61000-3-3.

A.3 Application of the network model to 230 V/400 V, 50 Hz public supply systems

A.3.1 Method

In the case of 230 V/400 V, 50 Hz supply systems, it is possible to use the known impedance and voltage regulation characteristics of distribution transformers, together with the impedance characteristics of mains cables and an assumed load current power-factor, and apply them directly to the model in order to obtain maximum values of supply impedance.

The modulus value Z_{sys} of the line conductors, which represents the network impedance, is obtained by adding the component of Z_T in-phase with the mains cable impedance, Z_{Teqiv}, to the calculated value of Z_{cable}; the Z_{Tequiv} component is 0,007 6 Ω for U_{reg} = 3; 0,010 2 Ω for U_{reg} = 4; 0,012 7 Ω for U_{reg} = 5 and 0,015 2 Ω for U_{reg} = 6.

These nominal values of Z_{Tequiv} are derived from the impedance characteristic of a typical 500 kVA delta-star transformer (0,005 09 + j0,017 1)Ω, whose R:Z ratio is typical of all three-phase transformers, by considering the components in-phase with the impedances of commonly used main distribution cables, which have an R:Z ratio of 0,877:1; see Figure A.2 below.

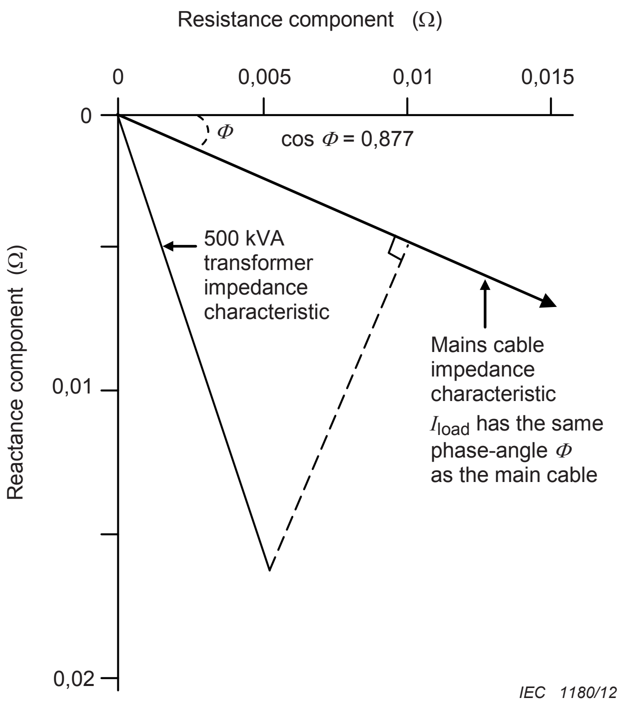


Figure A.2 – Three-phase impedance diagram of a typical 500 kVA transformer and mains cable

The typical mains cable impedance line has a R/Z value of 0,877, which is also typical of the power-factor of consumers' load. As voltages are calculated from the vector multiplication of current and impedance, it is reasonable to reference all impedances to the mains cable and assume that all values are in-phase. Hence the calculations are simplified but sufficiently accurate for the voltage ranges considered.

Figure A.2 above shows that a 500 kVA transformer having a nominal 5,3 % reactance and an impedance of 0,017 8 Ω has a component of 0,012 7 Ω in-phase with the load current and mains cable impedance.

The impedance value obtained by this method is relevant to the connection of three-phase equipment to the service line.

To obtain the value of impedance relevant to the connection of single-phase equipment to a three-phase service, Z_{cable} is multiplied by 1,667 before the addition of Z_T, in order to reflect the impedance in the cable's neutral return path in accordance with the ratio of line components to neutral components of Z_{ref} given in Clause 5.

Table A.1 contains values of system impedance, Z_{sys3}, relevant to the connection of a three-phase load to a service having a capacity, I_{load}, of 200 A per phase. Values of system impedance are obtained by application of equation (A.2), which is equation (A.1) with the addition of Z_T. Calculations are made to four decimal places and then corrected to two decimal places.

$$Z_{sys3} = U_{dec} / (100 \cdot I_{load}) \cdot [\, R_{ange} - U_{reg} (1 + R_{up} / 100) \,] + Z_{Tequiv} \quad \text{(A.2)}$$

Table A.2 contains values of Z_{sys1} relevant to the connection of single-phase load to a service having a capacity, I_{load}, of 200 A per phase, obtained by application of equation (A.3). Calculations are made to four decimal places and then corrected to two decimal places.

$$Z_{sys1} = 1{,}667 \cdot U_{dec} / 100 \cdot I_{load} [\, R_{ange} - U_{reg} (1 + R_{up} / 100) \,] + Z_{Tequiv} \quad \text{(A.3)}$$

The voltage regulation characteristics of transformers are related to the winding impedances and a voltage regulation of 3 % corresponds to a transformer having a reactance, expressed as a percentage of the impedance represented by the terminal voltage at full load divided by the current at full load, within the band of 2,5 % to 3,0 %. 4 % voltage regulation corresponds to reactance within the band of 3,5 % to 4,0 %. 5 % voltage regulation corresponds to reactance within the band of 4,5 % to 5,0 %. 6,0 % voltage regulation corresponds to reactance within the band of 5,5 % to 6,0 %.

Hence, either transformer voltage regulation or percentage reactance may be used to ascertain a maximum value of supply impedance from Tables A.1 and A.2.

If equations (A.2) or (A.3) are used to calculate particular values of Z_{sys} and only percentage reactance values are available, the equivalent voltage regulation values may be used in the calculations.

A.3.2 Example of a calculation

Considering the service to a consumer having a three-phase service capacity, I_{load}, of 200 A per phase, a declared supply voltage, U_{dec}, of 400 V/230 V ± 10 % (i.e. R_{up} = 10 %, R_{down} = 10 % and R_{ange} = 20 %), connected to a network supplied from a 500 kVA transformer having a no-load to full-load voltage regulation of 3 % (i.e. U_{reg} = 3):

The line-conductor impedance

$$= U_{dec} / (I_{load} \cdot 100) \cdot [\, R_{ange} - U_{reg} \cdot (1 + R_{up} / 100) \,] + Z_{Tequiv}$$

$$= 230 / (200 \cdot 100) \cdot [\, 20 - 3 (1 + 10 / 100) \,] + 0{,}007\,6$$

$$= 0{,}192\,0 + 0{,}007\,6$$

$= 0{,}20\ \Omega$ …see last row of Table A.1, column 2.

The impedance value obtained by this method is relevant to the connection of three-phase equipment to the service line.

To obtain the value of impedance relevant to the connection of single–phase equipment to the three-phase service, Z_{cable} is multiplied by 1,667 before the addition of Z_{Teqiv}.

The line and neutral impedance = (0,192 0 · 1,667) + 0,007 6

= 0,33 Ω …See last row of Table A.2, column 2.

A.4 Maximum values of system impedance relevant to three-phase services connected to 400 V/230 V public supply networks

Table A.1 values are relevant to the connection of three-phase equipment to a three-phase service and Table A.2 values are relevant to the connection of single-phase equipment to a three-phase four-wire service.

The values of system impedance presented in Tables A.1 and A.2 have been calculated for three-phase 230 V/400 V electricity services having service capacities of 200 A per phase, using the network model given in Clause A.2, and the equations developed in Clause A.3. See Clause A.5 for system impedances appropriate to conditions other than those assumed in Clause A.3.

In most countries the declared range of voltage variation is symmetrical about the declared nominal network voltage and R_{up} has the same value as R_{down}; the values in the Tables are based on this condition. It has been assumed that the medium voltage network is regulated to maintain the nominal system voltage at the distribution transformer terminals and therefore all the voltage drop, represented by the R_{ange} is attributable to the transformer and low-voltage cable network. For other voltage drop conditions, see Clause A 5.

Table A.1 – Modulus values of the maximum supply impedance, in ohms, of the line-conductors of 230 V/400 V, 50 Hz, public electricity supply networks, relevant to three-phase services having service capacities of 200 A per phase

Declared voltage range %	Characteristics of the network supply transformer			
	Voltage regulation: 3 % Reactance: 2,5 % to <3,5 %	Voltage regulation: 4 % Reactance: 3,5 % to <4,5 %	Voltage regulation: 5 % Reactance: 4,5 % to <5,5 %	Voltage regulation: 6 % Reactance: 5,5 % to <6,5 %
8	0,06	0,05	0,04	0,04
9	0,08	0,07	0,06	0,05
10	0,09	0,08	0,07	0,06
11	0,10	0,09	0,08	0,07
12	0,11	0,10	0,09	0,08
13	0,12	0,11	0,10	0,09
14	0,13	0,12	0,11	0,10
15	0,14	0,13	0,12	0,11
16	0,15	0,14	0,13	0,12
17	0,17	0,16	0,15	0,14
18	0,18	0,17	0,16	0.15
19	0,19	0,18	0,17	0,16
20	0,20	0,19	0,18	0,17

Table A.2 – Modulus values of the maximum supply impedance, in ohms, of the line and neutral conductors of 230 V/400 V, 50 Hz, public electricity supply networks, relevant to three-phase services having service capacities of 200 A per phase

Declared voltage range %	Characteristics of the network supply transformer			
	Voltage regulation: 3 % Reactance: 2,5 % to <3,5 %	Voltage regulation: 4 % Reactance: 3,5 % to <4,5 %	Voltage regulation: 5 % Reactance: 4,5 % to <5,5 %	Voltage regulation: 6 % Reactance: 5,5 % to <6,5 %
8	0,10	0,08	0,06	0,05
9	0,12	0,10	0,09	0,07
10	0,14	0,12	0,10	0,09
11	0,16	0,14	0,12	0,10
12	0,18	0,16	0,14	0,12
13	0,20	0,18	0,16	0,14
14	0,22	0,20	0,18	0,16
15	0,23	0,22	0,20	0,18
16	0,25	0,23	0,22	0,20
17	0,27	0,25	0,23	0,22
18	0,29	0,27	0,25	0,23
19	0,31	0,29	0,27	0.25
20	0,33	0,31	0,29	0,27

A.5 Alternative methods of determining supply impedance

If the column headings of Tables A.1 and A.2 do not match the voltage regulation or reactance parameters of a particular system being considered then linear interpolation between values in adjacent columns is valid. For example, the supply impedance appropriate to the connection of a single-phase load to a 200 A service having a voltage range of 12 % and supplied by a transformer having a voltage regulation of 5,5 % is 0,13 Ω.

Values relevant to a service having a current capacity "Y", greater than 100 A per phase, may be interpolated crudely from the Tables by multiplying the impedance values by the factor: 200/Y. Accurate values can be obtained by subtracting the transformer impedance relevant to the voltage regulation from the value in the relevant table, multiplying the remainder by the factor 200/Y and then adding the relevant transformer impedance to the result.

Values relevant to a supply network having a source transformer, or transformers having an aggregate capacity of "C" kVA, may be interpolated from the Tables by increasing or reducing the impedance values by an amount given by: $(500/C \cdot 0{,}01) - 0{,}01$.

Values relevant to a supply network operating at a nominal phase voltage of "X" may be interpolated with reasonable accuracy from the Tables by multiplying the impedance values by the factor: X/230.

In countries where R_{up} does not have the same value as R_{down}, it will be necessary to calculate appropriate supply impedance values by inserting the actual value of R_{up} into equations (A.2) and (A.3).

If a low-voltage network is supplied from a medium voltage circuit of considerable length, the system design may allow for voltage drop in the medium voltage circuit. In such cases, which are usually associated with rural areas, the statutory low-voltage R_{ange} is reduced by the medium voltage drop allowance. For example, if the statutory voltage declared to a rural low-voltage consumer has a tolerance of ±10 % and there is an allowance of 5 % for voltage drop in the medium voltage supply system, the supply impedance values will be those appropriate to a R_{ange} of 15 %.

A supply authority may declare a voltage variation range to consumers in accordance with its statutory obligation but nevertheless design its networks to a more stringent value. In such cases the supply authority can quote impedance values appropriate to its design criteria.

The maximum supply impedance values in Tables A.1 and A.2 that will not be exceeded, are easily adjusted to represent particular probability values by multiplying the given 100 % probability values by the required probability. For example, if supply impedance values are required that will not be exceeded in 95 % of locations, the values in the Tables are multiplied by 0,95.

A.6 Another method of determining supply impedance

Supply authorities normally terminate the low-voltage service line to a consumer with either a cut-out containing a protective fuse, or a protective device. In both cases the protective device serves to limit the duration of fault current entering a consumer's installation and disconnect the supply authorities' wiring and equipment before the consumer's main switchboard in the event of a fault occurring on that part of the installation.

The minimum fault current at the point of supply, that will enable the supply authorities' protective device to meet the requirements for protection given in IEC 60384, can be used to determine a maximum value of network impedance for a given supply capacity.

The characteristics of protective devices vary considerably and for that reason no alternative general technique for ascertaining supply impedance values can be given in this annex.

Annex B
(informative)

Methods for determining the maximum modulus values of public electricity supply low-voltage network impedances relevant to three-phase services of more than 100 A per phase at 60 Hz

The basic model used to determine the impedance of a supply from a public electricity network is single-phase and uses a declared voltage U_{dec} with a declared voltage variation range, R_{ange}, expressed as a percentage of U_{dec} and comprised of an upper voltage limit, $+R_{up}$, and a lower voltage limit, $-R_{down}$, both expressed as a percentage of U_{dec}.

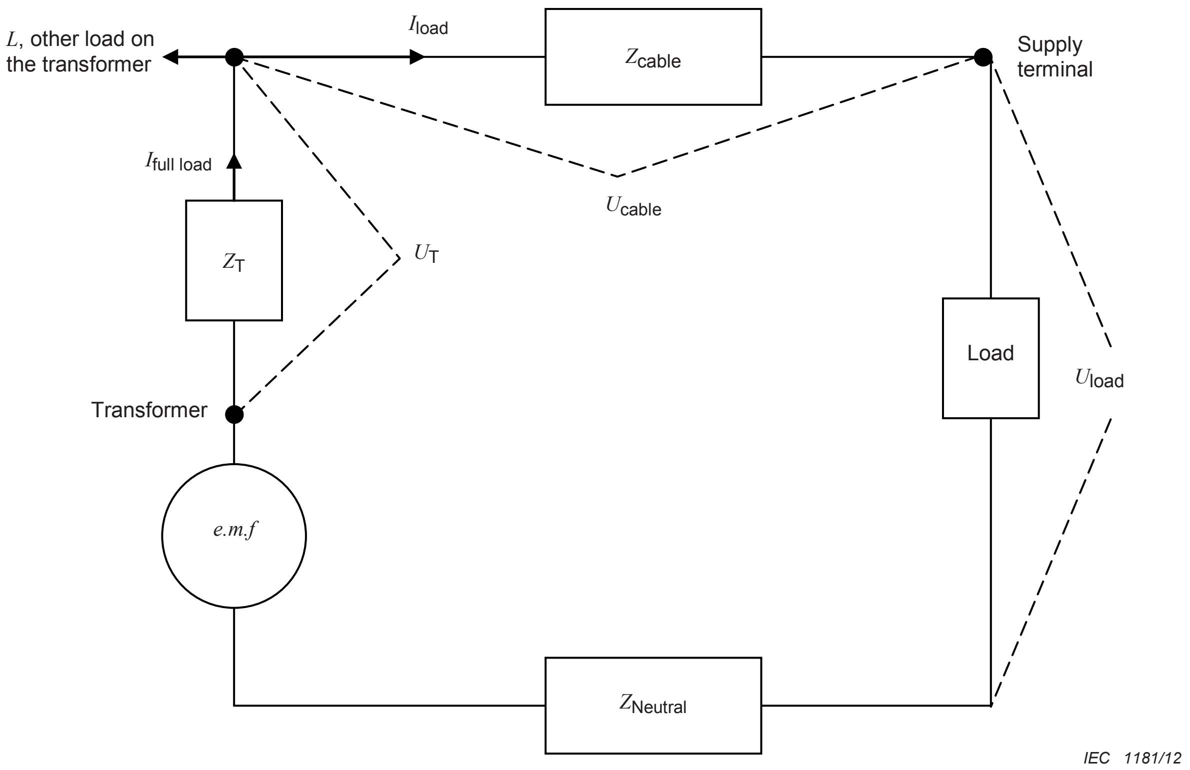
The single-phase model is shown in Figure B.1 and is comprised of

a) transformer, T, having an *e.m.f.* equal to the maximum permissible voltage, i.e. U_{dec} (1 + R_{up}/100), a voltage regulation from no-load to full–load of U_{reg}, expressed as a percentage of U_{dec} , an impedance Z_T, and a full-load rated current of $I_{full\ load}$,

b) network load, L, connected directly to the transformer, which, together with the capacity of the service being considered, equals the capacity of the transformer,

c) distribution cable and service line having a combined impedance of Z_{cable}, and

d) service load of I_{load} amperes per phase equal to the declared service capacity.



Key

e.m.f. electromotive force

Figure B.1 – Model used for determining the impedance of a network line conductor from a transformer to a three-phase service cut-out

The voltage, U_{cable}, across Z_{cable} is given by

$$
\begin{aligned}
U_{\text{cable}} &= e.m.f. - U_{\text{T}} - U_{\text{load}} \\
&= U_{\text{dec}}\,(1 + R_{\text{up}}/100) - U_{\text{reg}}/100 \cdot U_{\text{dec}}\,(1 + R_{\text{up}}/100) - U_{\text{dec}}\,(1 - R_{\text{down}}/100) \\
&= R_{\text{ange}}/100 \cdot U_{\text{dec}} - U_{\text{reg}}/100 \cdot (1 + R_{\text{up}}/100) \cdot U_{\text{dec}}
\end{aligned}
$$

$$U_{\text{cable}} = \frac{U_{\text{dec}}}{100}\left[R_{\text{ange}} - U_{\text{reg}}\left(1 + \frac{R_{\text{up}}}{100}\right)\right] \qquad \text{(B.1)}$$

The modulus value of Z_{cable} is given by dividing U_{cable} by the service cut-out phase-current capacity, which is also I_{load}.

60 Hz single-phase and two-phase supply systems have many configurations and plant parameters, which prevent the development of a representative model. In particular the impedances of supply transformers and the capacities of service cut-outs vary considerably. Consequently, it is recommended that supply system impedances are calculated for particular premises by the application of equation (B.1), to determine the cable impedance component, and then adding the impedance of the supply transformer.

Annex C
(informative)

Measurement of supply impedance and survey method

C.1 Impedance measurement surveys

The object of the Unipede impedance survey was to establish a value of reference impedance for use in the testing of electrical equipment, which could be purchased by a user and plugged into a supply without reference to the local supply authority or a professional installer of equipment. Z_{ref} is used in IEC 61000-3-3, which is applicable to equipment rated ≤16 A. 16 A is the largest rating of ordinary socket outlets in common use worldwide.

Whilst IEC 61000-3-3 is applicable to equipment used in all environments, IEC 61000-3-11, which is primarily applicable to equipment rated >16 A, even though it covers all equipment rated ≤75 A, is mainly applicable to equipment used in commercial and industrial environments. Reference impedances for the connection of large equipment are not established, because most connections of such equipment are made by qualified professional installers who are able to ascertain, by measurements or enquiries, the supply impedance at the point of use, and advise the user as to the suitability of equipment for connection.

C.2 Selection of measurement sites

Assuming that all residential customers are supplied at low-voltage by single-phase and that three-phase supplies are only given to commercial and industrial customers, the survey should be divided in two sections “A” and “B”.

Survey A should identify a representative number of residential customers located towards the far end of distribution circuits. The number required to give a representative sample will depend upon the differences in the type of network and the type of customer (in terms of their use of electrical energy) within the survey area. It is expected that the number will be no more than 200. The reason for choosing customers located towards the end of the distribution circuit is the need to determine highest levels of source impedance for a particular circuit, the results of all measurements will then be used to derive a percentile figure that will be relevant to all similar networks. This approach will minimise the risk of poor equipment performance for customers located at the end of distribution circuits. The survey should consider the distribution of customer numbers across urban and rural networks, supplied by overhead lines and/or underground cables.

Survey B should identify a representative number of commercial customers and industrial customers located towards the far end of distribution circuits. The number required to give a representative sample will depend upon the differences in the type of network and the type of customer (in terms of their use of electrical energy) within the survey area; it is expected that the number will be no more than 50 commercial and 50 industrial customers.

To select measurement sites of low-voltage network customers, the following points should be considered:

- information about the number of customers on the distribution mains;
- determination of typical network arrangements;
- information regarding the supply capacities of the customers;
- identification of typical distribution network configurations;
- the national percentage of customers in each customer category;
- calibration of the measuring instrument.

C.3 Measurement procedure

Measurements at a location should be taken at a point as near as possible to the supply cut-out; see Figure C.1. At each location, three measurements should be taken and the results recorded.

The approximate length and size of the conductors from the supply cut-out to the measurement point should be recorded.

It is preferable, but not essential, to take measurements at times of low load.

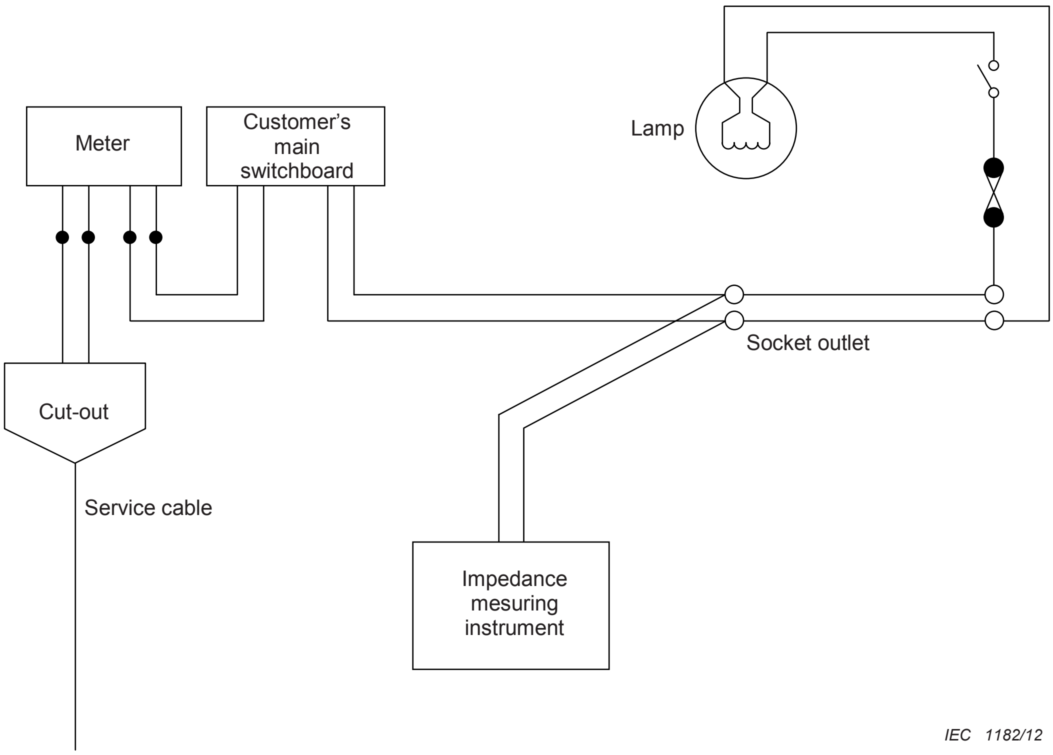


Figure C.1 – Measurement of impedance at a customer's premises

C.4 Processing recorded measurements

The second highest, or second lowest, of the three measurements taken at a location should be taken as the representative reading. This reading should be reduced by the impedance of the installation circuit from the cut-out to the point of measurement, and the impedance of the measuring instrument leads.

If the impedance measurement is complex, only the resistive component is reduced by the circuit and lead impedances, provided that the cross-sectional area of the copper conductors, or equivalent copper conductors, is $\leq$16 mm^2. The inductive component is negligible because, for example, the inductance of a 2,5 mm^2 cable is only 0,75 μH/m.

Table C.1 – Impedance values for copper conductor installation wiring

Conductor cross-sectional area in mm^2	Conductor resistance in ohms per route metre
1,0	0,034 5
1,5	0,023 0
2,5	0,013 8
4,0	0,008 6
6,0	0,005 7
10,0	0,003 5
16,0	0,002 2

Table C.1 gives circuit conductor impedances in ohms at 20 °C/m of route length, i.e. the “go” and “return” conductor impedance.

An impedance having a 95 % probability of occurrence should be deduced for each set of survey results taking into account the number of customers in each type of environment for which there are measurement results.

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