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TECHNICAL SPECIFICATION

colour inside

Sensing devices for non-intrusive load monitoring (NILM) systems

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Sensing devices for non-intrusive load monitoring (NILM) systems

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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SENSING DEVICES FOR NON-INTRUSIVE LOAD MONITORING (NILM) SYSTEMS

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IEC TS 63297 has been prepared by IEC technical committee 85: Measuring equipment for electrical and electromagnetic quantities. It is a Technical Specification.

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

Draft	Report on voting
85/727/DTS	85/750/RVDTS

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 Specification 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/standardsdev/publications.

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

- transformed into an International standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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INTRODUCTION

Non-intrusive load monitoring (NILM), or non-intrusive appliance and load monitoring (NIALM), is a process for providing estimated energy usage, e.g. by type of use (heating, cooling, etc.) or type of appliance (microwave, etc.) based on load signatures at a single point in the installation.

NILM systems can be used to survey the specific uses of electrical power in homes, buildings or industrial areas (see Figure 1).

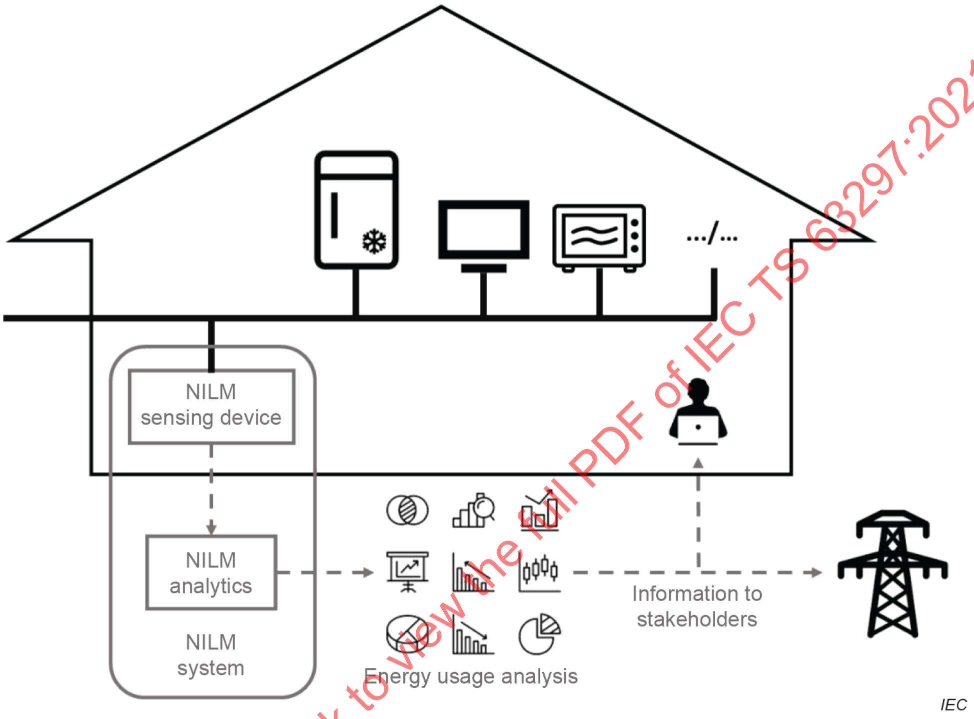

Figure 1 – Principle of non-intrusive load monitoring (NILM)

At the moment, NILM systems are essentially used in AC distribution networks, but DC networks are not excluded.

SENSING DEVICES FOR NON-INTRUSIVE LOAD MONITORING (NILM) SYSTEMS

1 Scope

This Technical Specification is an attempt to provide classification of NILM sensing devices for use in NILM systems, according to the state of the art of NILM technologies.

The classification of NILM analytics and NILM systems, as well as performance indicators for NILM systems, can be considered in the future.

NILM systems produce estimated disaggregation into energy usages. When accurate measurement and analysis of energy consumption and/or other electrical parameters is needed (e.g. for monitoring the electrical installation), systems based on standardized measuring devices (e.g. PMD, PQI or meters) are used.

NOTE Standardized measuring devices have guaranteed accuracy over a specified range and have limited deviations in presence of influence quantities (temperature, frequency deviations, etc.) in addition to safety and constructional requirements. See Annex C for more information.

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
electrical parameter
electrical quantity to be measured or estimated

EXAMPLE RMS value of current, RMS value of voltage, active power, reactive power, harmonics, power quality related parameters, etc.

3.2
estimated value
value of an electrical parameter (e.g. current, power, energy related to a specific usage) produced by a NILM sensing device or a NILM system

Note 1 to entry: Estimated values are typically less accurate than values measured with standardized measuring devices (e.g. PMD, PQI, meters).

3.3
measured value
value of an electrical parameter (e.g. current, power, energy related to a specific usage) produced by a measuring device complying with an electrical measurement standard

Note 1 to entry: Examples of measuring devices complying with an electrical measurement standard include PMD, PQI and meters.

3.4
load signature
pattern in the data produced by a NILM sensing device that can be attributed to a specific type of load or energy usage

3.5
non-intrusive load monitoring
NILM
process for providing estimated categorization of energy usage based on load signatures obtained at a single point in the installation

3.6
NILM analytics
process for analysing data produced by a NILM sensing device and providing information about energy usage

Note 1 to entry: NILM analytics can be performed within the NILM sensing device and/or in the cloud.

3.7
NILM sensing device
NSD
device connected to the electrical installation and producing data to be used by NILM analytics

3.8
NILM system
combination of a NILM sensing device and NILM analytics

3.9
power metering and monitoring device
PMD
combination in one or more devices of several functional modules dedicated to metering and monitoring electrical parameters in energy distribution systems or electrical installations, used for applications such as energy efficiency, power monitoring and network performance

Note 1 to entry: Under the generic term "monitoring" are also included functions of recording, alarm management, etc.

Note 2 to entry: PMDs have a known measurement uncertainty over a specified measurement range and are robust to influence quantities and industrial environments

[SOURCE: IEC 61557-12:2018, 3.1.1, modified – Note 2 to entry has been modified and Note 3 to entry has been deleted]

3.10
power quality instrument
PQI
instrument complying with IEC 62586-1 whose main function is to measure, record and possibly monitor power quality parameters in power supply systems, and whose measuring methods (class A or class S) are defined in IEC 61000-4-30

Note 1 to entry: PQIs have a known measurement uncertainty over a specified measurement range and are robust to influence quantities and industrial environments. They often also have transient event detection and waveform capture capabilities.

[SOURCE: IEC 62586-1:2017, 3.1.1, modified – A reference to IEC 62586-1 and Note 1 to entry have been added]

3.11
gapless measurement
measurement technique where the measurement is performed continuously without gap, that is, using contiguous measurement windows

Note 1 to entry: For digital techniques and for a given sampling rate, no sample shall be missing in the measurement processing.

Note 2 to entry: When gapless measurement techniques are used, no assumption is made regarding the stability of the signal, as opposed to non-gapless measurement techniques, where the signal is considered to be stable during the time where no measurement is done.

4 Elements of a NILM system

4.1 General

A NILM system comprises (see Figure 2):

– a NILM sensing device (NSD) connected to the electrical installation and producing data relevant for load signature identification;

– NILM analytics using the data output from the NSD and producing information to the users about their energy usage.

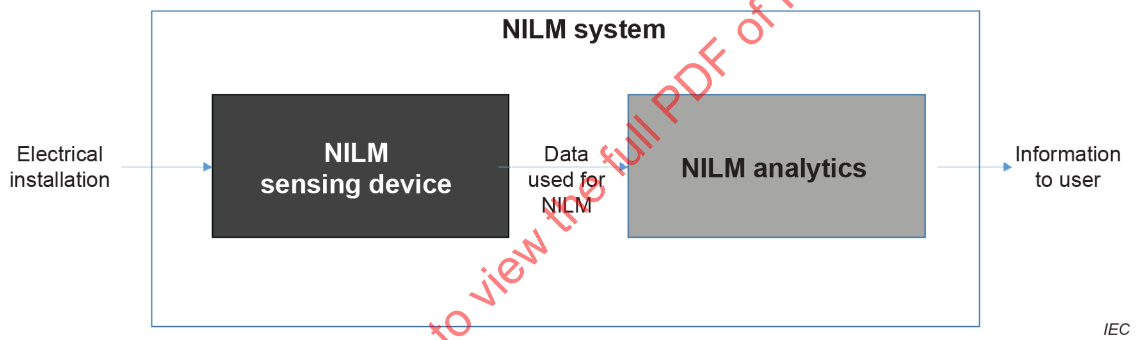

Figure 2 – Elements of a NILM system

The performance of the NILM system depends on the characteristics of the NILM sensing device (NSD) and on the characteristics of the NILM analytics. There are a lot of differences between the NILM systems available today. For example:

- NILM systems may use several types of NSD, e.g.
  a) meter;
  b) power metering and monitoring devices (PMD);
  c) power quality instrument (PQI);
  d) dedicated proprietary hardware;
- Some NILM systems may produce energy usage information over one day, while others may show results on a much shorter time scale;
- Some NILM systems may disaggregate into types of usage, others may disaggregate into types of current using equipment (e.g. appliances), while others may focus on providing behavioural analysis.

NILM analytics may also use data produced by smart devices. Smart devices are devices producing information not related to electrical quantities, e.g. position sensors, motion sensors, temperature control equipment, etc.

4.2 NILM sensing device

A NILM sensing device (NSD) is a device connected to the electrical installation. It produces data that can be used by NILM analytics. Examples of data that may be produced by an NSD include:

– samples of current and/or voltage waveforms;
– features characterizing the current and/or voltage waveforms;
– features related to the high-frequency patterns in the electrical signals;
– estimated values of electrical parameters;
– measured values of electrical parameters.

4.3 NILM analytics

The value of NILM systems is essentially in the analytics and how well they are able to make use of the data produced by the NSD.

NILM analytics are algorithms that analyse the data output by an NSD and produce estimated disaggregated information that can help stakeholders make decisions.

Examples of information that may be produced by NILM analytics are:

– estimated disaggregation of energy consumption into specific usages (heating, refrigeration, entertainment…);
– estimated disaggregation of energy consumption into specific types of appliances (ovens, fridges, pumps…).

NOTE NILM systems produce estimated disaggregation into energy usages. When accurate measurement and analysis of energy consumption and/or other electrical parameters is needed (e.g. for monitoring the electrical installation), systems based on standardized measuring devices (e.g. PMDs or meters) are used.

5 Classification of NILM sensing devices (NSD)

5.1 General

A NILM sensing device (NSD) is a gateway between the physical electrical installation and the world of analytics. In order to operate efficiently, NILM algorithms need to know the type of data they are to process. The behaviour of the NSD depends on several characteristics (see Figure 3).

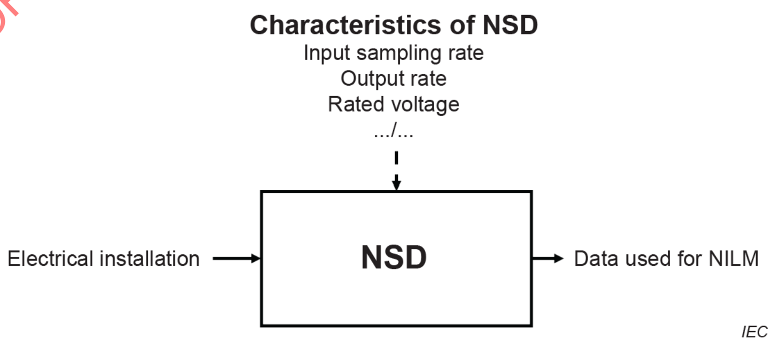

Figure 3 – Component view of a NILM sensing device (NSD)

To facilitate the development of NILM analytics, it is useful to specify the characteristics of NILM sensing devices, for easier selection and comparison.

5.2 Definition of NSD classes

NILM sensing devices should be classified according to a limited number of essential parameters, for example:

– Input sampling frequency: the frequency at which the electrical signals are sampled by the NSD. This frequency typically varies from a couple of kHz to the MHz range. The sampling process may be gapless or not.

  This parameter is essential to characterize NSDs that produce samples of the electrical waveforms. It is less relevant for NSDs producing estimated or measured values; therefore a separate class is specified (class P as "parameters only").

– Output rate: the rate at which the NSD produces data that can be used by NILM analytics. This rate typically varies from one set of data per second to one set of data per 30 minutes.

– Data bit rate: the average bit-per-second (bps) over an hour at which the electrical signals are quantified by the NSD. This data bit rate typically varies from a few bps to the Mbps range.

Table 1, Table 2 and Table 3 provide a classification of NILM sensing devices according to these three parameters.

Table 1 – Classification of NSDs according to the input sampling frequency

Input sampling frequency f	Parameters only	< 5 kHz	5 kHz ≤ f < 8 kHz	8 kHz ≤ f < 100 kHz	100 kHz ≤ f < 1 MHz	≥ 1 MHz
Class	P	1	2	3	4	5

Table 2 – Classification of NSDs according to output data rate

Output data rate d	> 30 min	30 min ≧ d > 1 min	1 min ≧ d > 1 s	1 s ≧ d > 0,1 s	≤ 0,1 s
Class	E	D	C	B	A

Table 3 – Classification of NSDs according to the data bit rate

Data bit rate b	< 100 bps	100 bps ≤ b < 1 kbps	1 kbps ≤ b < 10 kbps	10 kbps ≤ b < 100 kbps	≥ 100 kbps
Class	L	M	H	S	X

Class P in Table 1 is for NSDs that do not produce samples of the electrical waveforms. Instead, they produce measurements or estimates of electrical parameters (e.g. active power, reactive power, power factor, harmonic distortion, etc.).

– Classical measuring instruments like power metering and monitoring devices (PMD) can be considered class-P NSDs as they produce measurements of electrical parameters.

– Power quality instruments (PQI) also produce measurements of electrical parameters, but also often have waveform capture capabilities. They can therefore be considered as class-P NSDs and, typically, class 3 or 4 NSDs depending on their sampling properties.

The classes from Table 1, Table 2 and Table 3 should be combined. For example,

– a NILM sensing device sampling the electrical signals at 7 kHz and producing data for NILM analytics every second with an average data bit rate of 500 bps can be referred to as a class 2BM NSD;

– a NILM sensing device sampling the electrical signals at 1 MHz and producing data for NILM analytics every 0,02 s (50 Hz) with a data bit rate of 1 Mbps can be referred to as a class 5AX NSD;
– a PMD producing active power measurements every second can be referred to as a class PBL NSD.

In case an NSD is able to have several sampling frequencies, manufacturers should provide a class for each sampling frequency.

In case an NSD is able to have several output data rates, manufacturers should provide a class for each output data rate.

In case an NSD is able to have several data bit rates, manufacturers should provide a class for each data bit rate.

For NSDs using information related to transient events, the data bit rate depends on the occurrence of the transient events, and the rate of occurrence used for classification shall be indicated.

Annex A provides examples of NILM systems and examples of classification of NILM sensing devices. Annex B provides information about the calculation of the data bit rate.

5.3 Other NSD parameters

In addition to the class or classes, the manufacturer should provide the following important information:

– list of produced estimated values, e.g. active power values, RMS current values, etc. with corresponding accuracy class, if any, for NSDs classified as P according to Table 1;
– rated voltage;
– rated current;
– rated frequency;
– performance (resolution, range, operating conditions, etc.) of the estimated data produced, as claimed by the NSD manufacturer;
– number of phases (typically one or three);
– number of acquisition channels;
– starting current or power (threshold for operation);
– network communication type, protocol and range (Wifi, 3G/4G/5G, PLC, Ethernet, etc.);
– memory storage capabilities in case of network failure;
– data compression (lossless or lossy);
– environmental conditions;
– safety data;
– EMC data;
– behaviour with generating devices (PV, batteries, etc.).

For safety and EMC aspects of NSDs, relevant references of EMC and safety standards should be provided, e.g. safety according to IEC 61010-1. See also Annex C for more information.

NOTE For devices with radio features, local regulations can also apply.

6 Operation of NILM systems

The operation of a NILM system may involve the following elements (see Figure 4):

– NILM sensing device (NSD);

– Network transmission: means of transmitting the data produced by the NSD to the NILM analytics, commonly to the cloud;

– NILM analytics: processing the data through a set of algorithm calculations to estimate the breakdown of power consumption usage;

– CRM: customer relations management to determine to which installation the data belongs;

– NILM reporting: the results from the NILM analytics are typically reported via mobile phones, websites or paper reports.

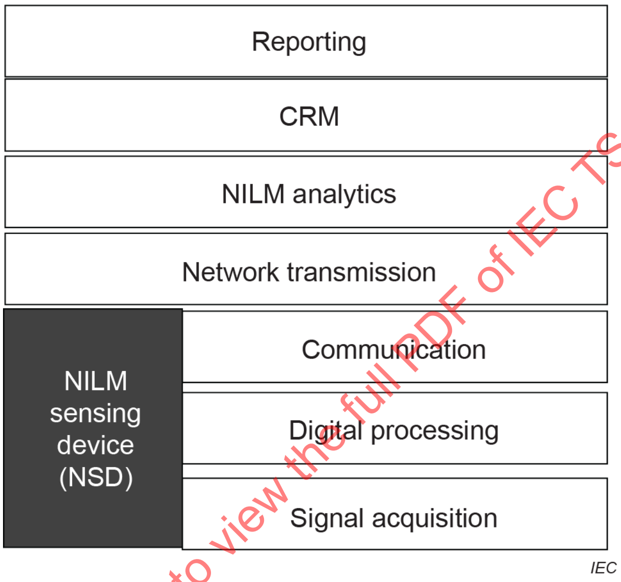

Figure 4 – Framework for NILM systems operation

Annex A
(informative)

Introduction of NILM process

A.1 Example of NILM process

An example of implementation of a NILM system is shown in Figure A.1.

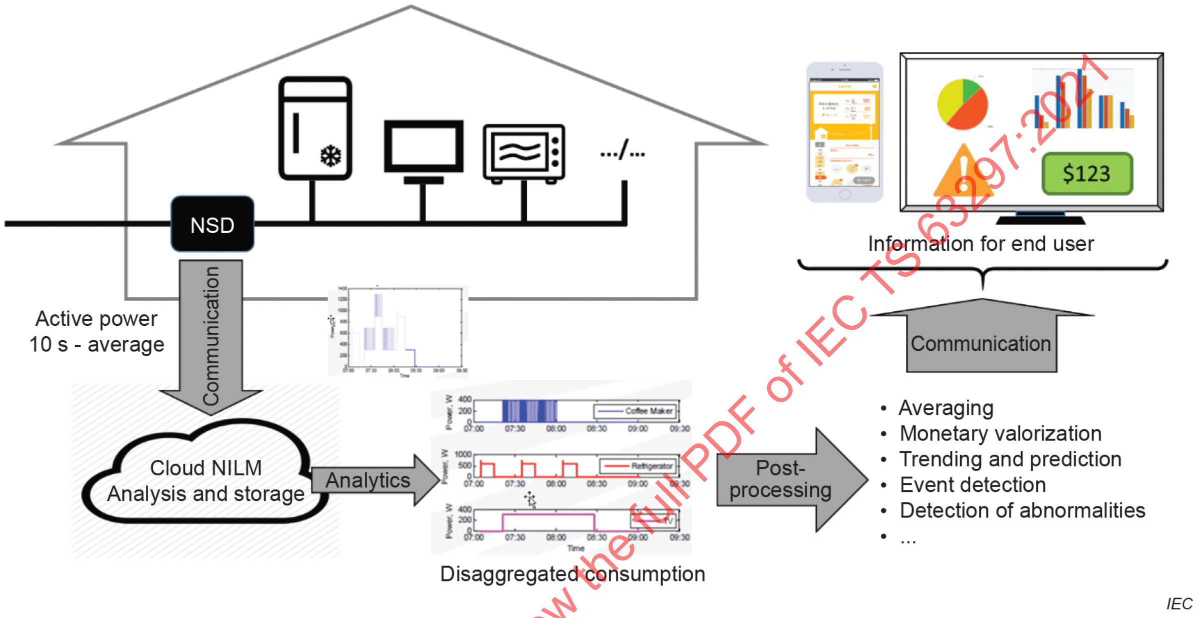

Figure A.1 – Example of NILM System implementation

A.2 Data and techniques for NILM

Table A.1 shows examples of data and techniques that may be used in NILM systems.

Table A.1 – Example of data and techniques used in NILM systems

Operation step	Purpose of operation step	Typical implementation
Analog measurement	Sense electrical signals	Sense current and voltage signals
Digital processing	Compute features for NILM analytics	Compute basic electrical parameters: active power, other powers (reactive, apparent, fundamental), harmonic distortion, etc. Sample waveforms and/or compute specific waveform parameters or advanced parameters (e.g. high-frequency content)
Data transmission to analytics	Transmit features to analytics	Use GSM or HTTP network
Disaggregation analytics	Disaggregate power consumption	Machine learning algorithms, supervised or unsupervised neutral networks, nearest neighbours, decision trees, etc.
Post-processing of results	Transform disaggregated consumption into valuable information for end user	Compute averages, detect events, detect trends and abnormalities, derive advice for end user…
Presentation to end user	Present valuable information to end user for information and actions for energy savings, ambient assisted living, etc.	Web pages, phone applications, specific alarms and notifications, etc.

A.3 Examples of NILM sensing devices (NSD)

Figure A.2 shows an example of a NSD installed in a home panel board.

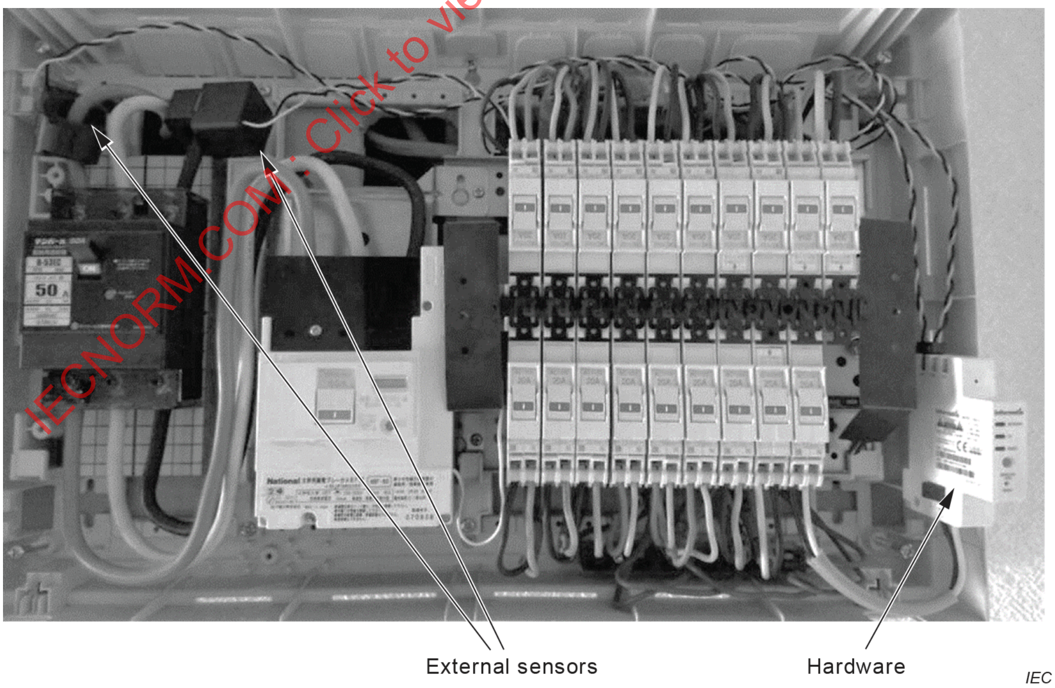

Figure A.2 – Example of NILM sensing device installed in a home panelboard

Several types of devices can be considered as NILM sensing devices. Table A.2 shows several such devices with typical characteristics.

Table A.2 – Examples of NILM sensing devices and typical specification

Type of NILM sensing device	Input sampling frequency class	Output date rate class	Data bit rate class
Smart meter	1/2	C/D/E	L
Smart meter with customized firmware	2/3	B/C	M/H
Power metering and monitoring device (PMD)	1/2/3	A/B/C	L/M
Power quality instrument (PQI)	3/4/5	A/B/C	M/X
Proprietary	2/3/4/5	A/B/C	M/S/H/X

Annex B
(informative)

Data bit rate

The data bit rate is the average number of bits per second at which the electrical signals are quantified by the NILM sensing device. It depends on

– the size of the dataset produced by the NSD and used by NILM analytics;
– the number of channels considered by the device;
– the rate at which data are produced to be used by NILM analytics;
– the compression ratio, if a data compression algorithm is used

as:

$$DBR = DS \times DPH \times CR \,/\, 3\,600$$

where

DBR is the data bit rate in bits per second;
DS is the size of the dataset used for NILM in bits;
DPH is the number of datasets produced per hour;
CR is the maximum compression ratio (CR = 1 for no compression).

Table B.1 gives examples of data bit rate calculation and class according to Table 3 for a variety of NILM sensing devices.

Table B.1 – Examples of data bit rate calculation

NSD example	*DS*	*DPH*	*CR*	*DBR*	*DBR* class
Proprietary	2 688 14 bit × 64 sample × 3 factors (voltage + current ×2)	3 600	0,18	483	M
Smart meter (single-phase application) [a]	96 Current, voltage, active power over 32 bits	6	1	0,16	L
PMD-II (single-phase application) [a]	96 Current, voltage, active power over 32 bits	3 600	1	96	L
PQI (single-phase application) [a]	160 Current, voltage, active and reactive power, harmonic distortion over 32 bits	18 000	1	800	M
PQI with waveform capture every 200 ms, 3-phase application	12 288 1 cycle × 128 samples × 6 channels × 16 bits	18 000	1	6 1440	X

[a] For three-phase applications, *DPH*, *CR* and *DBR* need to be multiplied by 3 (the DBR class may change).

Annex C
(informative)

Measuring equipment compared to NILM sensing devices

C.1 General

This annex provides information on the characteristics of measuring equipment for electrical quantities, and how they compare to NILM sensing devices.

C.2 Types of measuring equipment

There are different types of devices designed for measuring electrical quantities. An overview is presented in Table C.1.

Table C.1 – Overview of measuring equipment

Main reference product standard(s)	Name of equipment	Typical usage
IEC 62053-21 IEC 62053-22 IEC 62053-23 IEC 62053-24 IEC 62054-21	Static meter for active energy also called electricity meter Static meter for reactive energy Time switch	Measure active (or reactive) power for the purpose of billing
IEC 61557-12	Power metering and monitoring device (PMD) also called multifunction meters	Measure powers and other electrical quantities (voltage and RMS, frequency, unbalance, harmonic distortion, etc.) for the purpose of energy management or cost allocation
IEC 62586-1	Power quality instrument (PQI)	Quantify the quality of the voltage waveform. Assess compliance of power supply to regional quality standards

IEC TR 63213:2019 provides information on the various electricity measurement applications made in the grid (supply side) or in electrical installation (demand side), and on the related standards covering these applications.

C.3 Overview of requirements for measuring equipment

Although the exact requirements may differ from one type of device to the other, any measuring equipment listed in Table C.1 shall comply to a full set of requirements to ensure proper and safe operation in real-world conditions.

Those requirements include, as applicable:

– accuracy (limited uncertainty);
– safety: protection against electric shock, mechanical stresses, spread of fire, resistance to heat, etc.;
– environmental conditions (temperature, humidity, vibration, etc.);
– mechanical construction;
– electro-magnetic compatibility;