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Study Report on Electromagnetic Interference between Electrical Equipment/Systems in the Frequency Range Below 150 kHz

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Study Report on Electromagnetic Interference between Electrical Equipment/Systems in the Frequency Range Below 150 kHz

Rapport d'étude sur les perturbations électromagnétiques entre les équipements / systèmes électriques entre eux dans la plage des fréquences inférieure à 150 kHZ

Studienbericht über elektromagnetische Interferenz zwischen elektrische Betriebsmittel/Systeme im Frequenzbereich unter 150 kHz

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European Committee for Electrotechnical Standardization
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European foreword

This document (CLC/TR 50627:2015) has been prepared by CLC/SC 205A "Mains communicating systems".

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CENELEC [and/or CEN] shall not be held responsible for identifying any or all such patent rights.

This document has been prepared under a mandate given to CENELEC by the European Commission and the European Free Trade Association.

This Technical Report provides useful information for standards related to the following European Mandate(s): M/441, M/490.

This Technical Report is based on the Study Report “Electromagnetic Interference between Electrical Equipment / Systems in the Frequency Range below 150 kHz” of SC 205A (SC 205A/Sec0339/R:April 2013) (second edition) [1b], with some update according to the developments that have taken place since.

Introduction

In April 2010, CLC/SC 205A[1)] published their first Study Report on "Electromagnetic Interference between Electrical Equipment in the Frequency Range below 150 kHz" [1a]. Related studies had been made and information gathered due to first cases of EM interference, with Touch-dimmer lamps (TDLs) as an EMI victim, an inverter as an EMI source, and automated meter reading systems using powerline communication (AMR-PLC) figuring as EMI victims as well as sources.

Following this first CLC/SC 205A Study Report, its second edition [1b] and, based on it, this Technical Report aims at:

a) highlighting the broad relevance of recognized electromagnetic interference for safeguarding EMC also in the frequency range 2 kHz – 150 kHz;

b) extending knowledge about:

    1) EMI cases having been observed between electrical equipment in the frequency range 2 kHz to 150 kHz, with an emphasis on interference between:

        i) electrical equipment and its non-intentional emissions (NIE);

        ii) mains communicating systems (MCS) using (powerline communication) PLC technology with intentional signal injection for the transmission of information over the electricity supply network;

    2) different mechanisms causing interference to electrical equipment due to non-intentional or intentional voltage/current components in the considered frequency range;

as a basis for evaluating the need for closing the recognized gap in standardization as highlighted in the first edition, and considering the recent developments; that:

c) without evaluating certain types of electrical equipment concerning applied technology or priority;

d) and with regard to:

    1) problems having occurred with operational equipment of distribution network operators (DNOs), in particular related to smart metering and smart grids control and monitoring equipment;

    2) complaints by network users to deliverers and subsequently by deliverers to DNOs or by network users directly to their DNO, about degradation or loss of function of certain electrical equipment;

    3) in both cases network users as well as deliverers are primarily annoyed by the troubles they are experiencing with electrical equipment they have traded or bought, trusting in its interference-free operability, which they expect due to the CE mark.

This TR is based on:

e) reports on EMI cases and, following related complaints, investigations performed by an accredited test house, universities, DNOs, manufacturers and consultants;

f) measurements performed by an accredited test house, universities, DNOs, manufacturers and consultants. In both cases to extend knowledge of emissions from different equipment in the considered frequency range, in case of the occurrence of EMI:

    1) to identify the actual interference source;

    2) to clarify the interference mechanism;

    3) to evaluate mitigation measures;

g) the present standardization situation and its actual development.

1) CLC/SC 205A Mains communicating systems.

1 Scope

This Technical Report is based on two Study Reports of CLC/SC 205A, having been worked out by their Task Force EMI [1a][1b] and provides the results and findings of these documents. It was created with the help and input from a broad range of involved stakeholders: network operators, equipment manufacturers, universities, accredited test houses and consultants.

Beside the actual standardization situation it reflects the current emission situation found in supply networks and installations and describes electromagnetic interference (EMI) cases from twelve countries; investigation and analysis of the latter show a wide range of different types of electrical devices to be considered as a source or a victim of related EMI.

This Technical Report highlights the occurrence of high levels of non-intentional emissions (NIE) in the considered frequency range, including values up to and exceeding the standardized limits for intentional signals from mains communicating systems (MCS), which also implies a high potential to cause EMI to other electrical equipment. On the other hand, several types of equipment show susceptibility to related emissions, being insufficiently immune.

The Technical Report addresses the following issues:

– a number of different types of electrical equipment are generating such emissions and/or are susceptible, to such, thus representing EMI potential, as a source or a victim of such EMI;

– the interaction of electrical equipment in a certain supply area respectively installation, with its complex and volatile impedance character, as having an additional EMI potential; that besides NIE from general electrical equipment and signals from MCS and technically being quite different from emissions;

– the fact that besides the conducted interference also radiated interference from NIE or signals from MCS, through the magnetic H-field following to related currents on the mains, is to be considered, what is of some importance also for the interference-free operation of broadcast time-signal systems or electronic circuits controlled by such;

– the ageing of electronic components in electric equipment, which causes increased emissions and EMI to other electrical equipment as a result of not showing the same EMC characteristics as before being placed on the market, therefore no longer being able to conform with EMC requirements;

– the additional aspect of differential mode operation, which should be considered for related immunity and testing specifications.

These findings confirm that EMI in this frequency range is not limited to single types of equipment like inverters or MCS; instead a more general electromagnetic compatibility (EMC) problem concerning a larger spectrum of electrical equipment is identified.

Although a case-by-case mitigation of related EMI cases might be seen as appropriate, the increasing application of technologies and systems with related EMI potential requires a more general solution, through standardization, taking a balanced viewpoint of EMC and economics into account. With regard to the actual standardization situation, a review of the actual EMC and Product standards based on the reported results seems to be advisable.

After initiating the work in CLC/SC 205A, the now ongoing work in IEC SC 77A, as well as the publication of a related Technical Report on testing electricity meters [2] by CLC/TC 13 and of the new Immunity testing standard EN 61000-4-19 [99], appear as right steps into the right direction but needing further, extended efforts.

As stated on European as well as on international EMC standardization level, the availability of compatibility levels for the considered frequency range appears as a key-requirement for future considerations on setting related emission limits and immunity requirements in various standards. A fundamental basis for the co-existence of intentional signals from MCS and NIE needs to be found.

2 General

When talking about EMI in the frequency range 2 kHz to 150 kHz it is appropriate to highlight the development of electricity application respectively the use of the electricity supply network during the past decades, which is characteristic for the today's given situation; this development has led to:

a) a thorough increase of comfort in the application of electrical energy, including the realization of some energy saving effects, in particular through the application of power electronics, and with that, a somehow changed use of the electricity supply network;

b) the deployment of smart metering, in Europe using in the large majority of cases PLC for data transmission, with at present:

   1) more than 50 m PLC endpoints in Europe, from some ten thousand AMR-PLC in Austria to 36 m in Italy;

   2) an expected amount of such smart meters of around 85 m by 2013, 155 m smart meters by the end of 2016 and 250 m smart meters by the end of 2020 [3], [4];

   3) an intermediate status of related projects from beginning of rollout (Spain) to 99 % (Italy);

c) a further extended use of the supply network for operational electricity suppliers' information transmission purposes, in particular with regard to the intended deployment of smart metering and smart grid solutions [5], [6], comprising the installation of about 200 m smart meters in the next 5 years – 7 years with a cumulative investment of up to 40 bn € for smart meters and about 280 bn € for other measures to realize smart grids [7];

that technically accompanied by the superposition of additional voltage components on the practically pure sine wave of the mains voltage.

As a consequence, dependant on the different types of connected equipment/systems at a certain time,

– apparatus/systems using electric energy;
– distributed generation units (DGU) with its ancillary systems;
– MCS;

the original sine wave of the supply develops towards a somehow different shape, which shall be considered for its possibly disturbing effect on the operation of electrical equipment; with regard to the different types of such emissions, figuring as disturbances causing EMI, i.e.

– intentional emissions, i.e. signals;
– non-intentional emissions or
– a combination of both ones;

and following to the cumulative effect of the additional voltage components, for ensuring EMC, the need for appropriate setting of compatibility levels as well as of emission limits and immunity requirements (see also [64]) is given.

Apart from the technical aspects, but connected with it to a certain extent, several EU Directives and Standardization Mandates (see e.g. [5] – [12]) figure as a background for these changes in the use of electricity supply networks. This has also been expressed by the Communication of the Commission on Smart Cities and Communities – European Innovation Partnership [13], which aims at catalyzing progress in areas where energy production, distribution and use, mobility and transport and information and communication technologies (ICT) are intimately interlinked and offer new interdisciplinary opportunities to improve services; that mainly with regard to the global energy situation which, exceeding the primary and basic goal of supplying electrical energy by far, requires measures for ensuring a future-proof energy supply including:

– the efficient use of electrical energy in general;
– increased use of renewable energies, with its ancillary systems for coupling to the supply network, for decentralized generation;
– improved information to the network user about energy consumption together with actual tariffs as well as extended information for the energy supplier about the actual operational and quality status of his network, by extensive information exchange from and to smart meters;
– considerations for the realization of smart grids;
– the realization of appropriate IT infrastructure, as the basis for the aforementioned projects.

3 The frequency range from 2 kHz to 150 kHz

3.1 Challenges in terms of EMI

Regarding EMC (see definition in the EMCD[2)] [14] and the IEV[3)] [15]), on principle:

– unintentional emissions from non-mains-communicating equipment / systems (NCE) or communication equipment, or
– communication signals, both figuring as "emissions" and having some potential for causing EMI, or
– a combination of both ones

shall be considered, according to the classical viewpoint in terms of voltage/current levels, that together with:

– the cumulative effect of voltage components from all emitting equipment connected to a supply network;
– different proliferation of different types of electric equipment and its different times and durations of operation;
– utilization of the frequency range below 150 kHz (see also 3.2).

To ensure EMC and to meet the Essential Requirements (ERs) of the EMCD, a balanced co-existence of appropriately set emission limits, appropriately realized equipment immunity to emissions (non-intentional and signals) and to the supply network characteristics is necessary (see also [16]).

Besides the numerical values of voltage/current levels, at least for the frequency range 2 kHz – 150 kHz, the voltage/current shape is a character which has some impact on the sensitivity of electrical equipment to EM disturbances and should therefore be considered when dealing with EMC requirements for this frequency range in general and with related immunity in particular (see 3.3).

Depending on the levels of such emissions as well as on the voltage shapes of these emissions, the resulting modification of the supply voltage's sine wave through NCE or communication equipment can be followed by:

– degradation of function, maloperation or damage of network users' or energy suppliers' equipment;
– degradation of performance of MCS, e.g. AMR-PLC;
– display of wrong meter register values.

Table 1 gives an overview of a somehow more detailed grouping of EMI effects (see also [17] – [19]).

Table 1 — Main groups of EMI effects

(Non-intentional) Emissions from network users' equipment at or close to frequencies used for MCS interfere with intentional MCS signals, leading to disturbance or loss of MCS communication
Multiples of (non-intentional) emissions from network users' equipment, being close to frequencies applied for MCS may cause interference with the MCS resulting in failed communication
Distortion of the supply voltage due to discontinuous (non-intentional) currents/ voltages from network users' equipment or signal voltages from MCS may lead to degraded performance or maloperation of network users' equipment
Network users' equipment representing a low-impedance path at frequencies used for MCS lead to an attenuation of the intentional MCS signal which might disturb or interrupt communication ("shunting effect")
(Non-intentional) emissions from network users' equipment or (intentional) MCS signal voltages may result in somehow higher currents, leading to overheating and accelerated ageing of components in network users' equipment

2) Electromagnetic Compatibility Directive.
3) International Electrotechnical Vocabulary.

For the frequency range 2 kHz – 150 kHz, at first sight, it appeared that mainly touch-dimmer-lamps (TDLs), inverters and AMR-PLC were involved in related interference [1a]. Anyhow, already in Study Report I,

- EMI cases have been mentioned with other types of equipment having been involved as a source or victim;
- the assumption has been expressed, that somehow more types of equipment could be needed to be considered as EMI sources or victims.

Summarizing information having been gathered from 12 countries (AT, BE, DE, FI, FR, GB, HU, IT, JP, NL, NO, SE)4) about related measurements and investigations on EMI cases and measurement results being described in Clauses 4 and 5, Tables 2 and 3 give an overview of types of equipment showing high level emissions in the related frequency band or having already been recognized as a source or victim of such EMI (see also [1a], [20 – 23]).

Table 2 — Equipment figuring as a source of EMI, Examples

Inverters (e.g. in PV installations) and variable speed drives (VSD), (e.g. in elevator drives, ski lift drives, heating system circulation pumps, ventilation systems, household equipment)
Switch-mode power supplies (e.g. in lighting equipment, PCs, consumer electronic/home entertainment equipment (e.g. TV, DVD), ICT equipment, uninterruptible power supplies (UPS), charging devices)
Lighting equipment (e.g. fluorescent lamps, compact lamps, LEDs)
Household equipment (e.g. induction cookers, washing machines, electric shavers)
Portable mains operated tools
AMR-PLC

Table 3 — Equipment figuring as an EMI victim, Examples

AMR-PLC
Solid state meters
Electronic control (e.g. touch-controlled equipment like Touch Dimmer lamps (TDL), alarm systems, traffic control systems, traffic lights, in heating systems, street lighting, in urinals, for doors, in kitchen appliances (e.g. steam irons, coffee machines, ceramic hobs)
Communication systems (e. g. Ethernet-system, ISDN-, ADSL-modems, IP network branch exchange, routers, LAN)
Telephone systems including inductive train radio systems
Earth leakage circuit breakers (ELB)
Contactless magnetic card readers, credit card terminals
Notebooks (cursor position)
Broadcast standard time-signal systems (e.g. DCF77, Japanese system)
Road vehicle smart keys
TV and radio receivers
Mobile radio
Amateur radio

Tables 2 and 3 may need further amendments in future, following further investigations.

Table 4 provides information about different effects of EMI to certain equipment in the considered frequency range.

4) Austria, Belgium, Finland, France, Germany, Great Britain, Hungary, Italy, Japan, The Netherlands, Norway, Sweden.

Table 4 — Effects of EMI to equipment in the frequency range 2 kHz– 150 kHz, Examples

TDLs	Unintentional switching (between light steps, OFF, also ON)
Street lighting	Unintentional switch-on and –off
Traffic lights	Malfunction
Traffic control system for public transportation buses	Malfunction
Solid state meter	Displaying wrong meter register values
MCS	Temporary or quasi-permanent loss of data transmission function
Heat control with time basis through DCF77 signal	Malfunction
Heating systems	Incorrect alarms due to sensor faults
Contactless magnetic card reader	Malfunction of reading function
ADSL modem	Loss of link, CRC error
Routers	Loss of synchronization (40, 50 and 70 kHz) to the network
Notebooks	Disturbed cursor position (37 kHz)
Inductive Train Radio System	Audible noise
Ceramic hobs	Incorrect relay switching
Coffee cooker	Incorrect control lamp function
Steam irons	Insufficient heat, water loss, incorrect control lamp blinking
Washing machines	Self-restart (some hours) after end of operation phase
Automatic urinal water control	switching to permanent operation
Broadcast standard time-signal systems	Electronic clocks: being fast (gaining up to 15 mins per day), Malfunction of control circuits fed by the time-signal
TV and radio receiver	Audible noise (up to 20 kHz)
Amateur radio	Disturbed reception of distant transmitters

With this overview of potential EMI sources/victims as well as EMI effects together with the measurement and investigation results in Clauses 4 and 5 of this Technical Report it may be taken as a fact, that the EMI potential in the frequency range below 150 kHz, already mentioned in Recommendation Com-1 of the Report “Standards for Smart Grids” published by the CEN/CENELEC/ETSI SG-CG in 2011 [24] (see also [25]), is not restricted to PLC devices and domestic appliances but shall be seen as having a quite larger dimension. This will need to be resolved by creative approaches taking into account the installed base, i.e. products on the market, and future technology development.

3.2 Frequency utilization

When considering the utilization of the frequency range below 150 kHz for different purposes, there is to be distinguished between:

a) conducted voltage/current components representing:

  1) non-intentional emissions (NIE), stemming from:

    i) NCE as a consequence of the applied technology and being a more or less unavoidable waste product of its application of electrical energy;

    ii) from MCS as spurious emissions from such, i.e. unwanted signals, both types of emissions to be considered as disturbances in the sense of the IEV [15] definition of “electromagnetic disturbances” (see also Recommendation 13. in Clause 9);

  2) voltage/current components

    i) stemming from NIE (see above) or MCS signals (see below),

    ii) being induced from wires in an installation via the magnetic H-field to another installation or an electronic circuit

  3) communication signals from MCS, being intentionally impressed on the 50-Hz-supply voltage for the purpose of transmitting information, e.g. for smart metering/smart grid systems in the

public supply area or for network users' purposes within their installation, e.g. for data transmission within their premises or for home automation.

Figure 1 shows the frequency ranges designated to applications using (narrow-band) MCS:

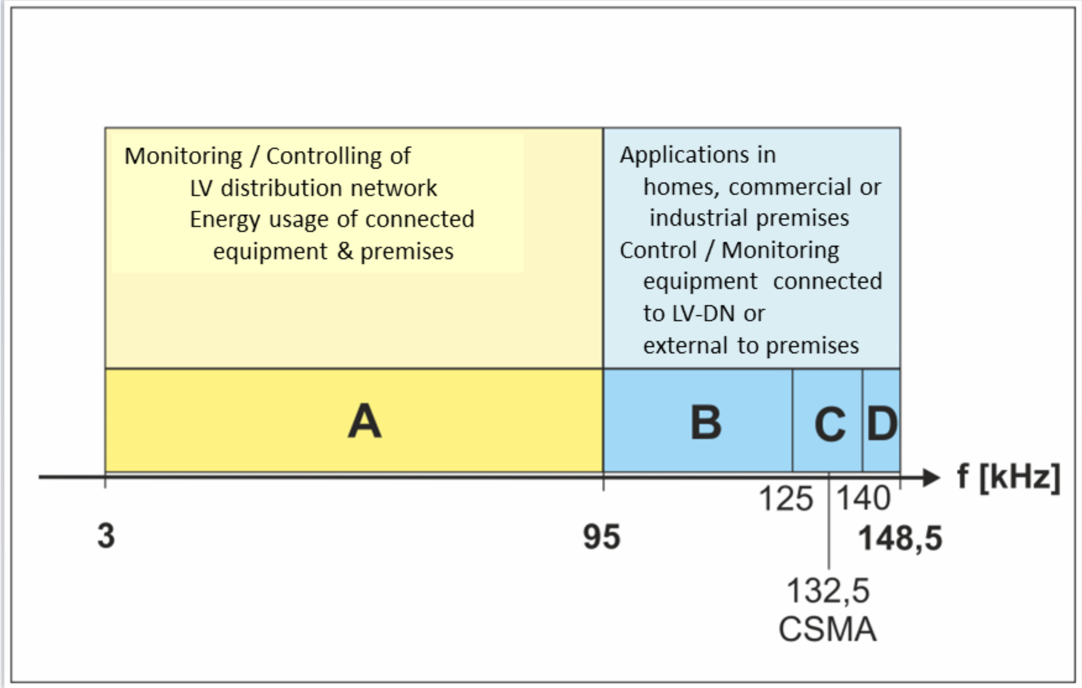


Figure 1 — Frequency band designations according to EN 50065-1 [26]

All the aforementioned voltage/current components have some potential for causing EMI, for which also a combination of the different types shall be considered; that together with:

– the cumulative effect of voltage components from all emitting equipment connected to a supply network;
– different proliferation of different sorts of electric equipment and its different durations of operation.

The aforementioned cumulative effect represents some criterion for dealing with both types of emissions, as:

– NIE are generated from a lot of different equipment operated in a certain supply area and there-fore contributing to a certain cumulative load of such emissions at a certain instant, which varies over time;
– MCS signals, in any case in CENELEC-band A (Figure 1), are normally present in a certain supply area only from *one* MCS, therefore not experiencing any accumulation.

That leads also to the recognition, that – e.g. concerning setting immunity requirements – signals need to be treated different from NIE.

b) radiated magnetic fields stemming from

1) non-intentional currents due to the operation of electronic circuits, as explained above;
2) signal currents from MCS, intentionally impressed on the supply voltage as explained above.

Also these magnetic fields, resulting from non-intentional or signal currents, have some EMI potential, by causing conducted voltages getting induced to installations or electronic circuits (see 5.3.1, List Entry a)).

c) radio applications for services, like broadcast time-signal services.

Concerning the first-mentioned group a):

- contrary to the frequency range up to 2 kHz, where normative specifications exist for harmonics [27] and voltage fluctuations [28] in a LV supply network and up to 3 kHz, where emission levels for intentional signalling from ripple control are standardized (Meister curve) by EN 61000-2-2 [29];
- besides the subject areas of:
  i) lighting equipment and induction cookers [30], [31];
  ii) the Basic standard EN 61000-4-16 [32] specifying test conditions for electric and electronic equipment concerning immunity to conducted asymmetrical disturbances in the frequency range 0 kHz – 150 kHz;
  iii) narrow-band MCS technology, where emission limits and immunity requirements have been standardized for the frequency range 3 kHz – 148,5 kHz, by the EN 50065 series [26], [33] – [35] on from 2001 (see also IEC 61000-3-8 [36] and IEC 61334-3-1 [37] concerning frequency bands and output levels and [38] – [45] for additional normative specifications (filters, couplers, equipment impedance).

this frequency range 2 kHz – 150 kHz, up until now, has not been considered for setting limits for NIE (see 6.1). Recently, some developing situation is given in the field of power electronics, where first proposals for recommending emission values for Active Infeed Converters (AICs) have been approved in IEC/TS 62578 ([46] (see 6.1)).

Concerning radiated magnetic fields no standardized limits exist for this frequency range; that likewise as recently no technical specifications are available for evaluating an EMI situation with EMI to broadcast time-signal systems, although to be seen as protected, in any case in terms of radio interference (see 5.3.1).

With regard to the recognized co-existence problems between equipment generating NIE and MCS in the frequency range 2 kHz – 150 kHz, it is of some interest whether:

- concerning EMC, standards need to consider existing products/technologies on the market
- the intended operation of MCS were to be seen as being protected by the EMCD.

(See also Clause 6.)

The primary status of a standard shall be considered as voluntary, which could be changed if a standard becomes part of a contract

Concerning the EMCD, related discussions resulted in the recognition, that with the inclusion of telecommunication systems/networks in its scope, the EMCD and its ERs are protecting the intended operation also of MCS.

3.3 The impact of voltage / current shapes

From Study Report I [1a] it is known, that besides the numerical values of voltage/current levels, at least for the frequency range 2 kHz – 150 kHz, also the voltage/current shape is a character which has some impact on the sensitivity of electrical equipment to EM disturbances -- what should therefore be considered when dealing with EMC requirements for this frequency range in general and with related immunity in particular.

When having reported about the first investigation results, having been achieved during measurements concerning EMI from AMR-PLC to TDLs, it was shown, that, for the considered frequency range, interference is also a matter of rise (or fall) time of the amplitude/envelope of voltage/current components.

For example, Figure 2 shows the rise of sine wave signal components in the supply voltage with a frequency of 55 kHz respectively 90 kHz, by which a TDL has been switched on. The instant of time of switch-on of the TDL can be recognized through the start of network disturbances from the TDL's triac-controller (see sequences of narrow spikes outside the envelope of the test signal).

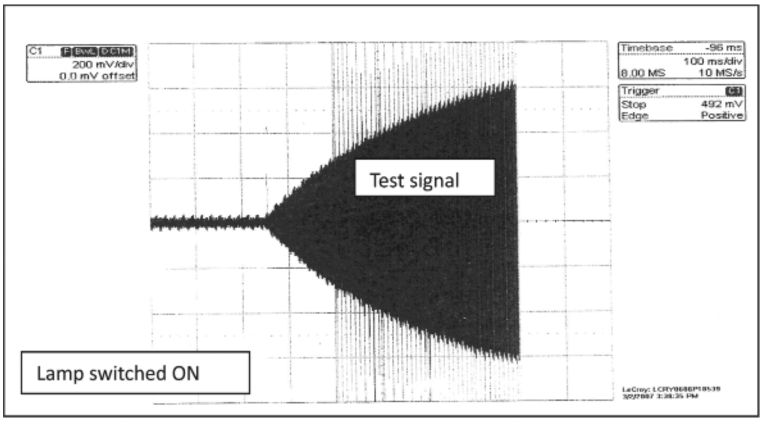


Figure 2 — Sine wave components in the supply voltage, ((test signal) frequency: 90 kHz), leading to a switch-on of a TDL

Additional investigations have been made by an accredited test house [47], with a (modulated) test voltage according to Figure 3 applied to a TDL.

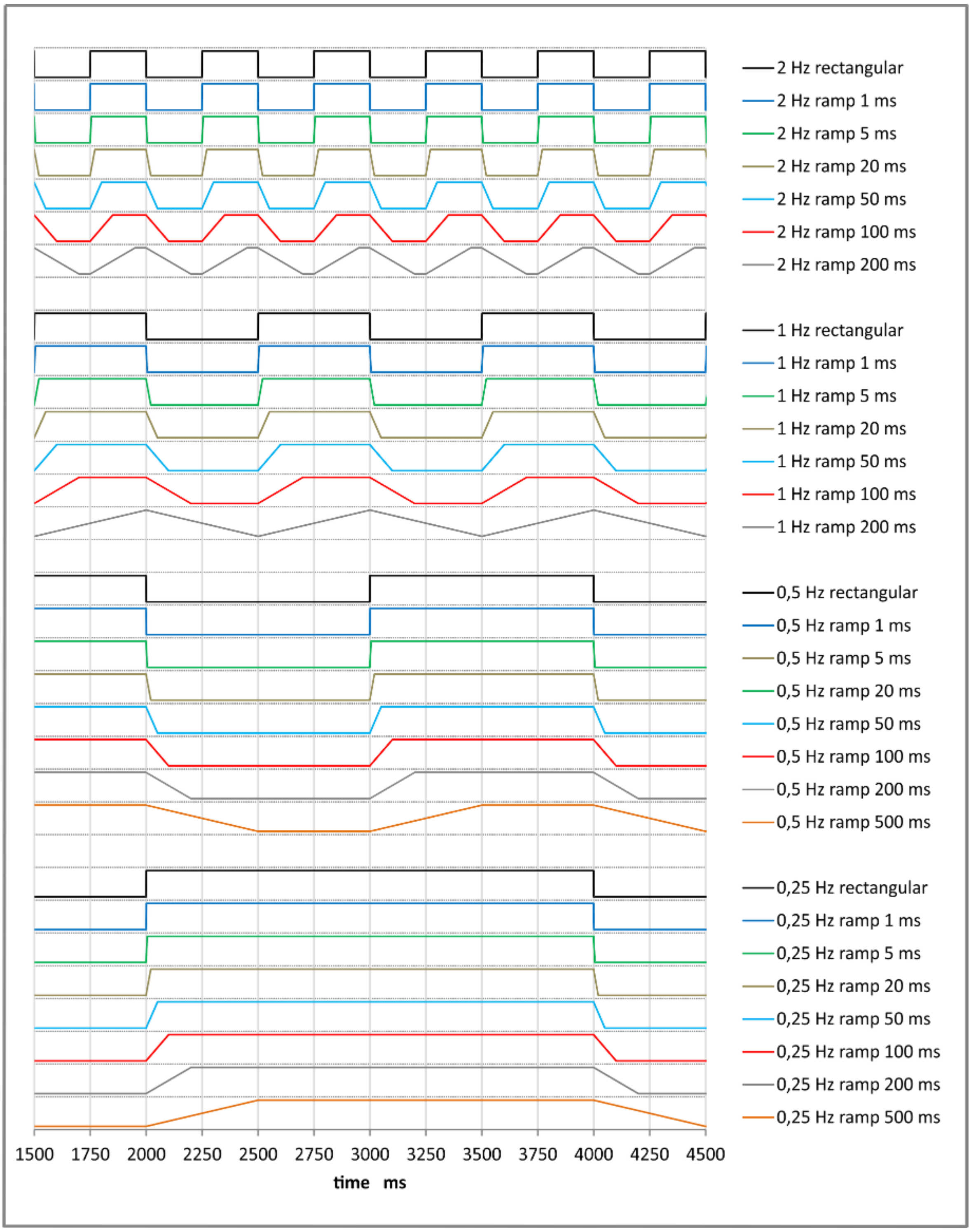


Figure 3 — Test voltage for rise time investigation

The time and the voltage value of the envelope of the modulated test voltage until the EUT appeared as being disturbed (TDL: switched on) were measured with all waveshapes shown in Figure 3 (ramp characteristic, repeating interval times).

It can be recognized as being typical, that the resulting EMI is somehow dependent on the level of the applied test voltage. For testing the impact of rise time for each rise time (1 ms, 5 ms, 20 ms, 50 ms 200 ms, 500 ms), the disturbance voltage was adjusted to that level causing switch-on of the TDL with a probability of 95 %, due to a simulated interference.

To evaluate this probability, a sequence of 100 rises and falls of a test voltage with a frequency of 50 kHz was applied.

In case of simulating an MCS signal, a rise time of about 0,5 s is not applicable because of the resulting loss of bandwith.

As results from these tests, Figures 4 and 5 show the achieved dependence of the test voltage level on the rise time and the rise speed.

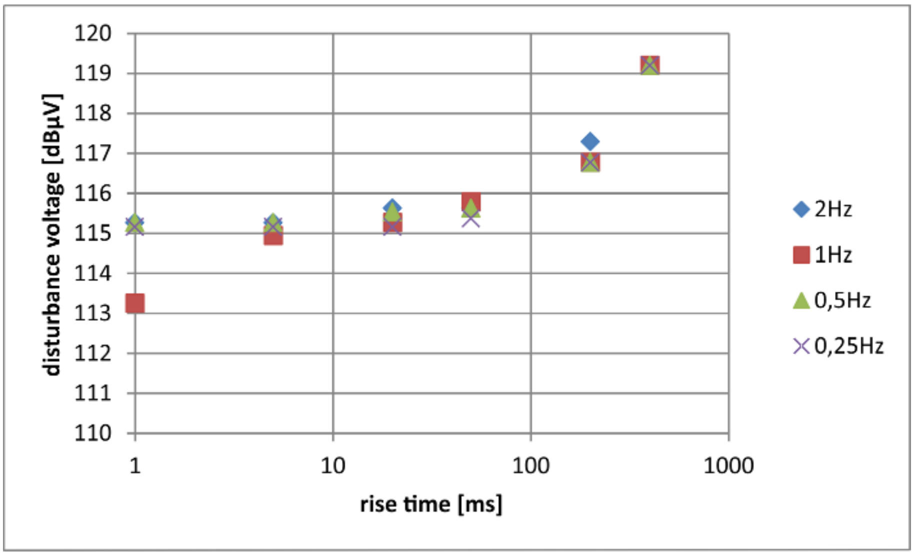


Figure 4 — Rise time tests with a TDL 95%-dependence of threshold on the rise time of an emission / a test level

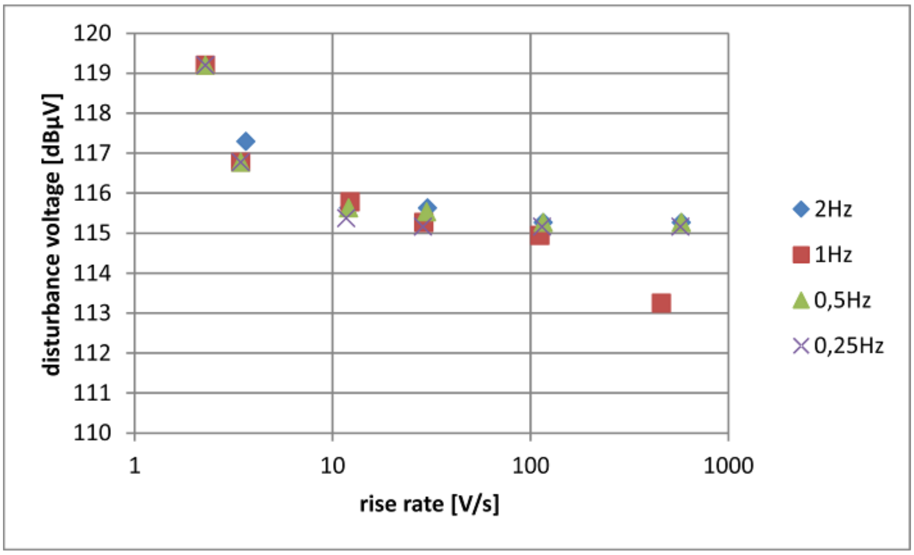


Figure 5 — Rise time tests with a TDL 95%-dependence of threshold on the rise speed of an emission / a test level

The frequency of the periodic rise or fall did not show any impact on the threshold values.

These test results:

- proved the relevance of the rise/fall time of the envelope of an emission/signal respectively a test voltage for the threshold of a control circuit and therefore the relevance of the envelope of a discontinuous voltage for the sensitivity of electronic circuits to such and following to that to related immunity requirements;
- showed, that for a slower rise/fall of the envelope of a modulated emission / signal, the threshold moves to higher values what allows higher emission levels respectively less stringent immunity requirements.

As already mentioned in Study Report I [1a] (5.2), dependent on the coupling method (CM, DM), different EMI effects and thresholds have been observed. Therefore, for comprehensive immunity testing, both coupling methods were to be considered in related tests.

Based on that, it might be deductible, that:

- a solely numerical setting of compatibility levels, emission limits and immunity requirements might not be sufficient in that frequency range;
- leaving consideration of quasi-stationary conditions as the sole basis for setting EMC requirements would offer additional room for ensuring EMC for the considered frequency range.

Combined specification of levels and other characteristics of emissions like (maximum) rise or fall edge of the envelope of a disturbance/signal appears to may offer a technically more appropriate basis for setting related compatibility levels as well as requirements (emissions, immunity) in EMC and Product standards.

3.4 Interaction of equipment

Interactions between different types of NCE connected to the grid, e.g. heat pumps, induction cookers and fluorescent lamps, as well as between such equipment and MCS have been analyzed e.g. in [48], [49], [118].

The effect of such interactions and resulting interference appears as not being predictable due to the permanently changing situation of connected equipment, i.e. sites, power different technologies and duration of connection of loads.

From the related analyses follows, that:

- interaction between connected equipment in the frequency range 2 kHz – 150 kHz differs from the interaction taking place in the frequency range below 2 kHz. That with regard to high frequency emissions flowing between devices and not upstream to the transformer;
- due to technological development of electrical devices, resonances in this frequency range between connected equipment which is simultaneously in operation, e.g. an induction cooker and a heat pump, may increase in future;
- the impact of connected NCE on MCS is much stronger than the impact from the grid itself, such as damping in wires;
- the signal limits for MCS are the highest ones compared with emissions from other equipment; therefore, immunity standards for this frequency range should be based on the standardized signal limits for MCS.

4 Emissions, measurement and test results

4.1 General

This clause provides results of measurements on different types of electrical devices without having been involved in EMI cases before. Related information and measurement results have been provided from Austria, Belgium, Great Britain, Japan, Sweden and IEC SC 77A/WG 8 (see also related contributions to CIRED 2013 [50], [117]) .

With regard to the assumption already made in Study Report I [1a], that some additional types of equipment might need to be considered as potential sources of EMI in the frequency range 2 kHz to 150 kHz, the goal of these measurements was to get more knowledge of the given EMI potential and to better clarify assumed EMI potential between certain types of equipment.

As concerns also the investigation results on EMI cases described in chapter 4, related measurements have been made on site as well as under laboratory conditions, using a wide variety of test methods; therefore, the results cannot be taken as exactly comparable but may fulfil the task of providing an overview of the existing situation.

4.2 Noise measured in a block of flats

Austrian measurements of the noise potential in distribution racks in the frequency range 10 kHz – 100 kHz showed without presence of a PC signal quasi-stationary broadband noise with levels from ~40 dBµV to 66 dBµV, additionally partly with peaks up to 80 dBµV, with a dynamic up to 23 dB. The source of this noise is unknown.

Here, at the lines from the transformer station, currents on single frequencies up to 4 mA peak and with broadband measurement up to ~1 mA have been measured. Also here, time-signal systems like DCF77 could get disturbed (see also 5.3.1).

Source of disturbance unknown.

4.3 Lighting equipment

4.3.1 General

When starting investigations on EMI in the frequency range 2 kHz – 150 kHz, TDLs appeared as one of the initiating elements being involved as an interference victim. As already reported in Study Report I [1a], during laboratory tests in Hungary, disturbances to narrow-band PLC communication have been experienced with different equipment, besides UPS's and inverter drives also with compact fluorescent lamps – this time as a source of interference

In the following, results of measurements on related emissions from lighting equipment are described.

4.3.2 Compact lamps

Measurements of the emissions from two compact lamps (2 x 26 W) in the frequency range 9 kHz to 500 kHz, conducted by an accredited test-house [51], show

- emissions of up to 82 dBµV (around 60 kHz), and with that
- an excess of the limits of EN 50065-1 [26] for spurious signal emissions by nearly 10 dB (Figure 6).

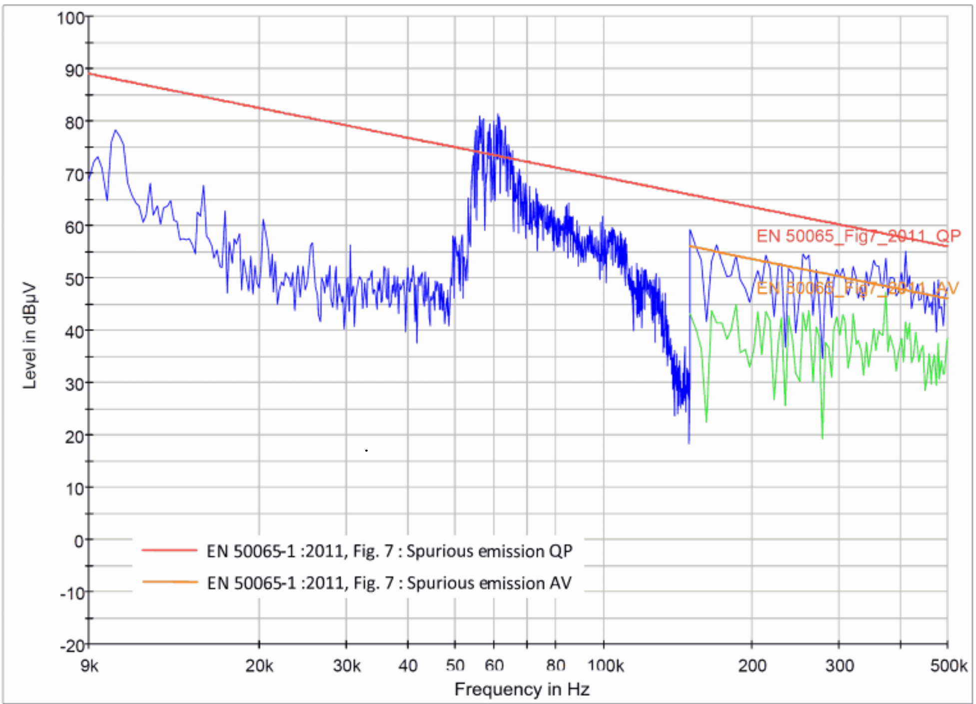


Figure 6 — Emissions from compact lamps

With these levels around 60 kHz, somehow close to the frequencies of broadcast time-signal systems (e.g. 60 kHz, 77,5 kHz; see 7.1.5, Table 7) an EMI potential at least to such broadcast time-signal systems is given.

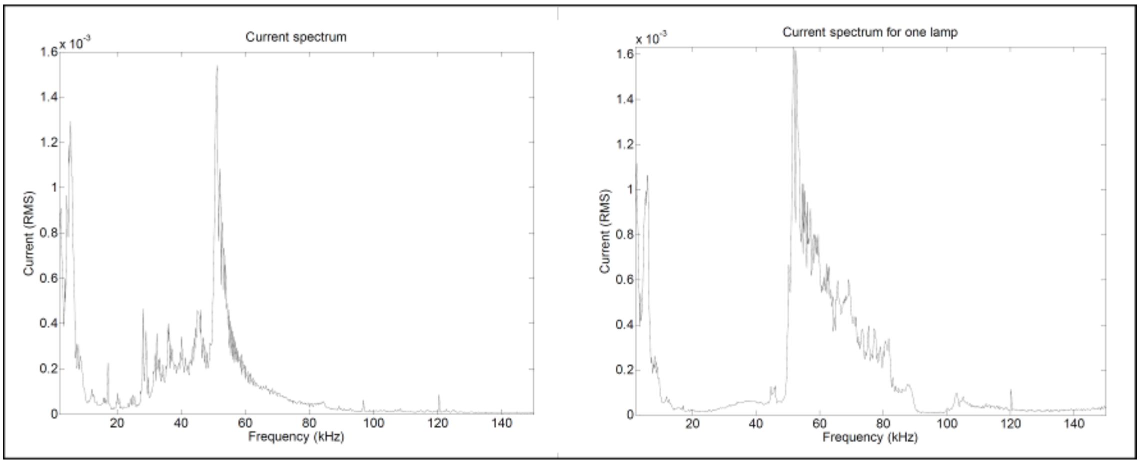
The edge at 150 kHz is due to the different measurement bandwidth, which is according to Figure 7 in EN 50065-1 [26], (CISPR 16-1-1 [52]):

– 200 Hz for 9 to 150 kHz;

– 9 kHz for 150 kHz to 30 MHz.

4.3.3 Fluorescent lamps

From reports about measurements in Sweden on emissions of up to 48 fluorescent lamps powered by high-frequency ballasts, in the frequency range 2 kHz to 150 kHz [53], [54], the following can be taken:



a) Current of one lamp ON

b) Filtered current of one lamp when all 48 lamps are turned ON

Figure 7 — Spectrum of emissions from fluorescent lamps

a) As Figure 7a) shows, the main component of the current in the considered frequency range feeding one lamp solely is the remains from the switching of the Automatic Power Factor Correction (APFC), with a wideband component decreasing with the frequency, from 50 kHz to about 90 kHz.

b) Figure 7b) shows the filtered current of one lamp when all 48 lamps are turned on; compared with Figure 7a), it can be recognized, that the maxima of the current amplitude are about equal but showing a somehow “wider” effect, due to several frequency alternating signals which are most likely remains from other lamps burning at the same time.

c) Figure 8 shows the spectrum of the total current feeding all 48 lamps ON. It can be recognized, that the resulting spectrum, divided by 48, shows almost no remains of the APFC switching in the current for one lamp shown in Figure 7a).

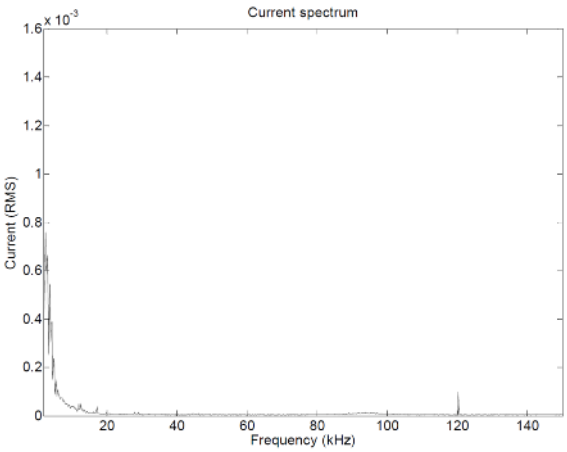


Figure 8 — Resulting spectrum of the total current feeding the 48 lamps

That shows that:

1) current spectrum components do not add linearly and
2) the general characteristic of the spectrum – except the peak at the switching frequency – is, besides its changes due to other electrical equipment connected and daytime, changing with the number of lamps ON.

d) Emissions are dependent on daytime.

It can be deduced that:

e) emissions from fluorescent lamps show peak currents in the considered frequency range, resulting in voltage components dependant on the network impedance at the relevant frequencies;

f) the resulting effect of such fluorescent lamps is variable with:

1) the number of lamps ON;
2) the structure and impedance of the related installation;
3) the degree of mutual reduction of spectral components due to phase-angle shift and transients between the lamps;

g) generally higher transient currents may flow between electrical equipment in a certain installation,

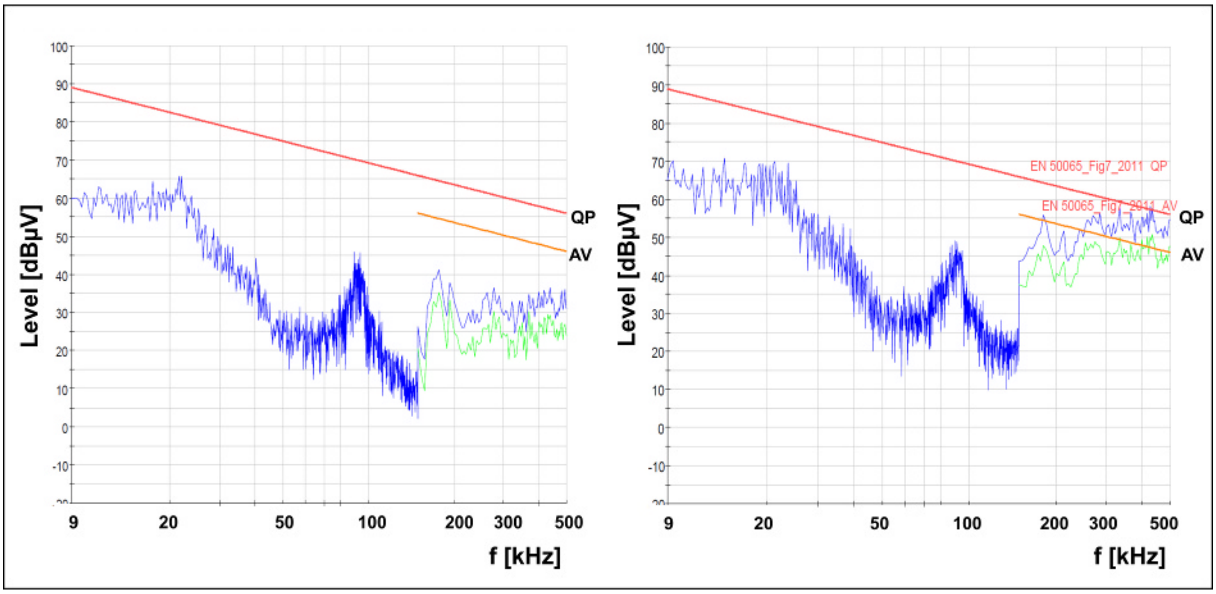
1) leading to some reduction of the effect of one of its current components;
2) flowing between such equipment but not going upstream, leaving the installation, but
3) possibly contributing to a disturbing effect to other electrical equipment connected to that installation (see also [48]) or to such connected to another installation, via H-field coupling (see 5.3).

4.3.4 LEDs

Measurements in an accredited Austrian test house, with up to 30 LED bulbs of different type connected to the supply network, showed to some extent remarkable emissions in the frequency range between 20 kHz and 100 kHz, with values up to around 107 dBµV at around 70 kHz.

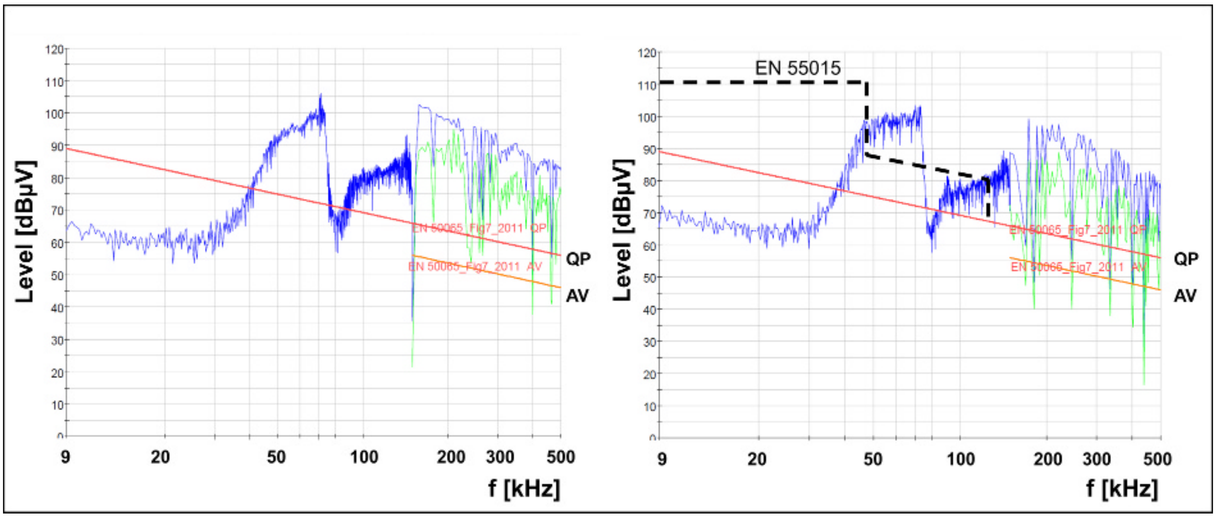
Figures 9 and 10 show measurement results with

– 1 and 30 LED bulbs of one type (“A”), with emissions far below any signal of PLC
– 1 and 3 LED bulbs of another type (“B”), with quite high emissions, those ones partly not meeting the limits given with EN 55015 [31].



1 LED bulb 30 LED bulbs

Figure 9 — Emissions from LEDs, type “A”, 8 W in relation to spurious emission limits for MCS according to EN 50065-1:2011, Figure 7 (QP, AV)



1 LED bulb 3 LED bulbs

Figure 10 — Emissions from LEDs, type “B”, 7 W in relation to spurious emission limits for MCS according to EN 50065-1:2011, Figure 7 (QP, AV) and to EN 55015

The edge at 150 kHz is due to the different measurement bandwidth, which is according to Figure 7 in EN 50065-1:2011 [26], (EN 55016-1-1 [52]):

- 200 Hz for 9 to 150 kHz;
- 9 kHz for 150 kHz to 30 MHz.

As can be recognized,

a) different types of LED bulbs show
   1) quite differing spectrum types of emissions, also with;
   2) quite different maximum values;

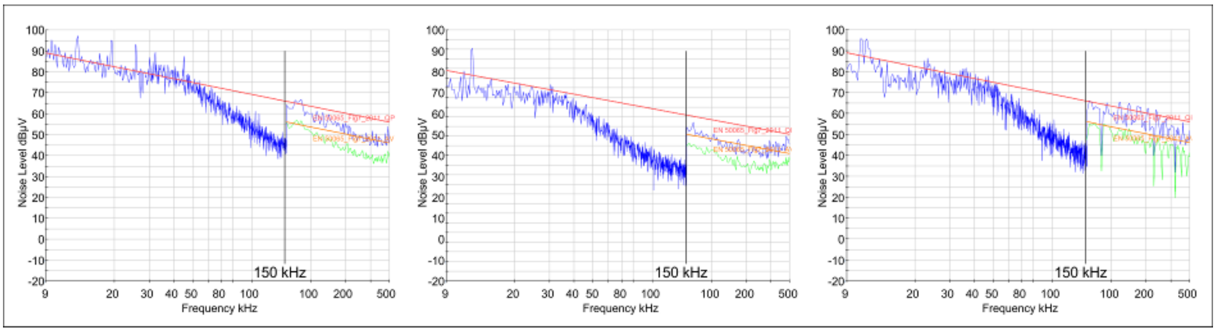
b) the measured peaks reach an order of magnitude of signal levels generally to be expected along the mains supply, due to attenuation along the supply network, or exceeding it, thus representing some danger of EMI with electrical equipment sensitive to such voltages including e.g. MCS and different broadcast time-signal systems (see 5.3.1);

c) deviating from what appeared as generally being valid for related EMI (see [53], [54]), measurements with a number of LEDs showed that, considering the peak values over the whole frequency range, the superposition of its emissions occurs in a different way from type to type – one time quite linearly, the other time with a decreasing factor.

Also, and in particular, with regard to the intended future proliferation of such bulbs, this effect should be considered and further investigated.

4.4 Portable mains powered tools

Conducted emissions from different hand tools have been investigated by an accredited test house at the equipments’ a.c. ports in the frequency range 9 kHz to 500 kHz [51].



a) Circular hand saw 1600 W **b) Impact drill 780 W** **c) Jigsaw 720 W**

in all cases sawing without load

Figure 11 — Emissions from portable mains powered tools

As can be seen from the measurement results,

a) at frequencies below 50 kHz, with its peaks, these emissions partly exceed the limits of EN 50065-1 [26] for spurious signal emissions out of band remarkably, by up to 14 dB.

b) the peak values, of:

1) up to 97 dBµV (Circular hand saw, Jigsaw),
2) up to 100 dBµV (Impact drill),

are only some 34 dB below the limits for intentional signal emission in-band.

Considering an attenuation of 40 dB to 80 dB for the signal along the supply network, exceeding of the factual signal level by the emission from such tools could occur.

4.5 Power electronic loads including inverters

4.5.1 General

As a Japanese research report of 1998 [55] mentions, power electronics equipment using inverters (e.g. an elevator, a lift, an uninterruptible power supply) are coming into wider use. These types of equipment have become widespread not only in factories, but also in commercial and residential areas.

In general, these types of equipment have a switching circuit operating at a switching frequency from several kilohertz to some tens of kilohertz. Large pulse currents are flowing in the switching circuit resulting also in high frequency noise currents. When noise suppression is not implemented, large noise currents are flowing into ground lines and power lines connected to the equipments. Such emissions from inverters may cause interference with other electrical equipment, due

– to its switching frequency and its harmonics,
– to its voltage shape in time domain
– to higher levels.

Related interference may cause degradation of performance of the concerned equipment (see also 5.2.3.3). Proved examples for such interference are:

– the display of wrong meter register values (see 5.2.2)
– communication loss in MCS (see 5.2.3.2.2, 5.2.3.2.3, 5.2.3.2.5 – 5.2.3.2.8, 5.2.3.2.10 – 5.2.3.2.14).

Further, EMI may occur due to electromagnetic waves being radiated around the supply lines and creating potential for interference to other equipment (see also 5.3).

As already reported in Study Report I, during laboratory tests in Hungary, disturbances to narrow-band PLC communication have been experienced with different types of equipment, besides compact fluorescent lamps and UPSs also inverter drives [1a].

Results of related measurements are presented below; for results of investigations and field measurements on related EMI cases see 5.2.3.3.

4.5.2 Austrian lab tests on inverters

Measurements in the laboratory of an accredited Austrian test house [51] concerning the emissions from inverters, using a standardized AMN, showed the following results**:**

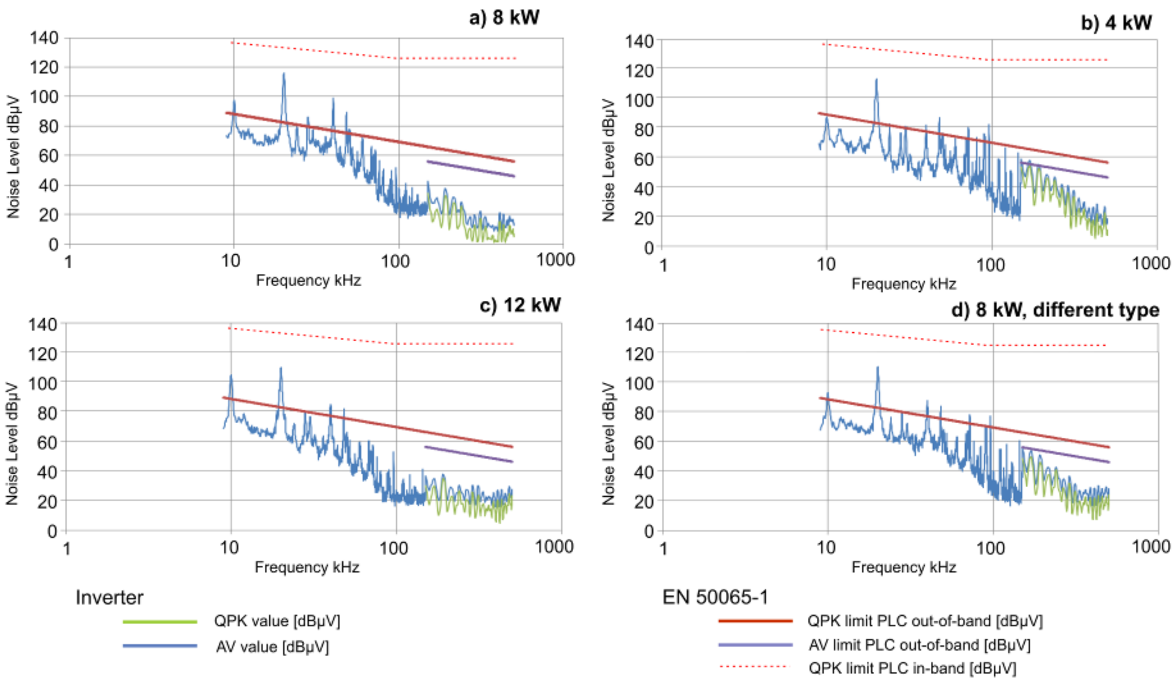


Figure 12 — Emissions from inverters 4 kW – 12 kW

As can be seen, quite irrespective of the infeed power, the emissions

– appear as being quite similar in shape and levels;
– show peaks according to the inverter's switching frequency and its harmonics;
– show mean values in the frequency range 9 kHz – 150 kHz from ~90 dBµV decreasing to ~22 dBµV, thus being somehow below the out-of-band limits for PLC defined in EN 50065-1 [26];
– are exceeding with its peaks the limits for spurious out-of-band emissions of a PLC-system as being standardized in EN 50065-1 [26], in the frequency range 10 kHz – 100 kHz several times, by up to some 36 dB.

Actual signal levels in the supply network, normally attenuated along the supply network by some tens of dB, may be disturbed.

4.5.3 Active Infeed Converters

In order to evaluate the effect of Active Infeed Converters (AICs) on PLC systems, on behalf of IEC SC 77A/WG 8 a laboratory test was carried out. The test configuration was as follows:

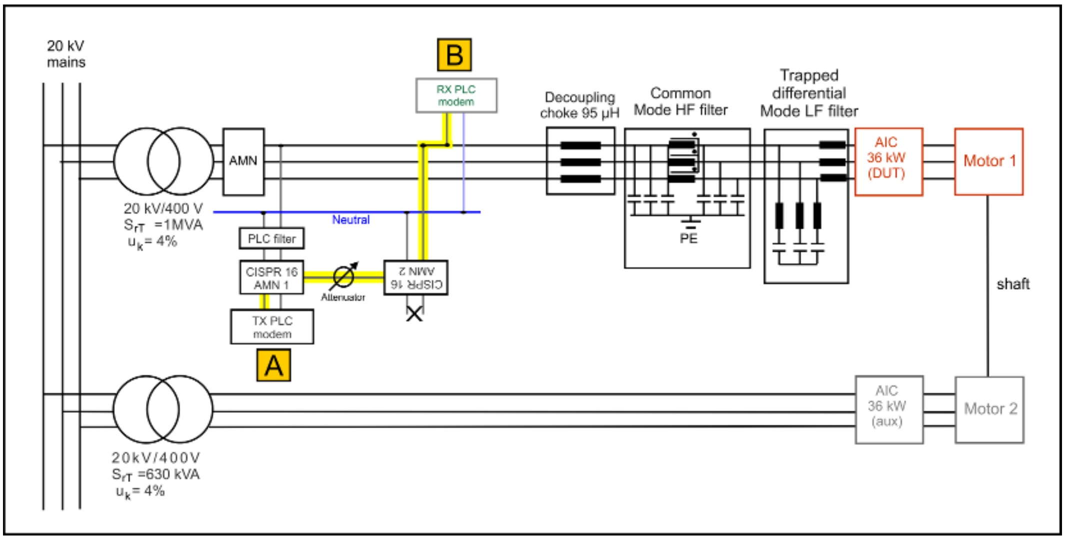


Figure 13 — Test set-up for the measurement of EMI from AIC to PLC

Both, Artificial Mains Network (AMN) and filters, have been used on the LV line; four types of AIC filter configurations have been applied:

- “filter 0”: decoupling choke 95 µH (choke size about 75% of the AIC’s size);
- “filter 1”: trapped differential mode LF filter (filter size similar to the AIC’s size);
- “filter 2”: trapped differential mode LF filter + common-mode HF filter (filter size about 10% of the AIC’s size);
- “filter 3”: trapped differential mode LF filter + common-mode HF filter + 95 µH choke simulating a purely inductive 95 m long LV line.

The AMN was not present in the first configuration -- "filter 0" --, but was present in the others -- "filter 1" to "filter 3".

The PLC signal path is highlighted in yellow.

The PLC technology that has been used during the test sessions was a first generation PLC technology, based on an S-FSK (Spread Frequency Shift Keying) modulation which principle consists in using two different carriers to code a binary ‘0’ or a ‘1’. The two carriers used to perform the S-FSK modulation were located at 63,3 kHz and 74 kHz and had an amplitude of approximately 118 dBµV.

The physical and data link layers of this S-FSK technology are standardized as EN 61334-5-1 [56] (PHY & MAC) and EN 61334-4-32 [57] (LLC).

As long as the AIC was switched off, the PLC communication operated properly in a wide dynamic range (55 dB to 60 dB).

As soon as the AIC was switched on, PLC communication failed in most of the test configurations when the receiver was close to the AIC (filter 0 without AMN, filter 1, 2 or 3 with AMN). Some successful PLC communications have been observed only when both transmitter and receiver were connected at the same place (no attenuation between transmitter and receiver, what does not reflect the reality in the field), but in this case, the dynamic range was nonexistent (close to 0 dB). This result was independent from the AIC operating mode, which varied between standby, consumer and regeneration mode.

However, when the noise source was attenuated by 15 dB, it has been observed that PLC communication with a dynamic range of approximately 20 dB has been achieved. However, it was not possible to evaluate which distance represents an attenuation of 15 dB.

The potential impact of disturbances generated by AICs in the frequency band 2 kHz – 150 kHz on PLC communications has been confirmed under laboratory conditions.

4.5.4 PV inverters

In the 3-phase installation of a building, emissions of two photovoltaic (PV) inverters 2,5 kW peak connected to phase 1 and another PV inverter in the close neighbourhood (200 m), connected to phase 2, have been investigated in Belgium with in-situ measurements [58], without standardized emission measurement.

Measurements on phase 1 clearly show a peak at 18 kHz (switching frequency of inverter I). That peak

- is about 60 dB below the fundamental and about 20 dB below harmonics 5 and 7 (the most important ones)
- is independent from the power generated by the PV system, but totally disappears in the evening, when the inverter is on “night shutdown”.

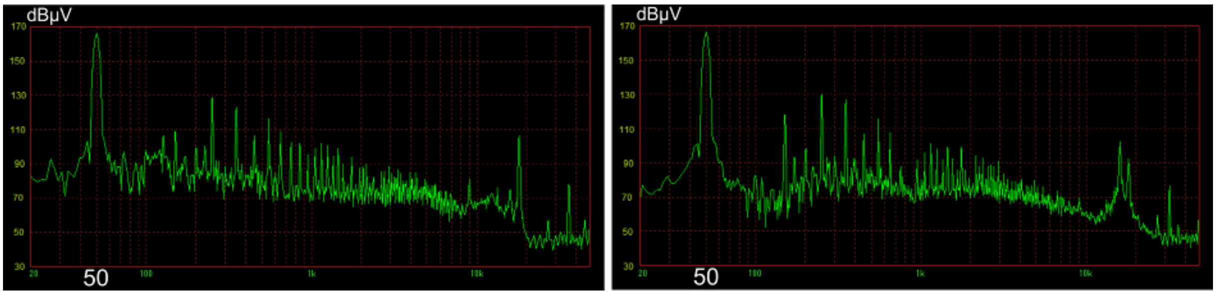
The frequency of 18 kHz is clearly due to the inverter; this is confirmed by the technical specification in the Appendix. Another peak (although another 30 dB lower) is visible at 36 kHz; it is a harmonic of the 18 kHz. Next to the 18 kHz peak, there is a 16 kHz peak, but at a lower level, stemming from the 2nd inverter (see Figure 14a)).

Measurements on phase 2 show an attenuated peak at 18 kHz (switching frequency inverter II; about 80 dB below fundamental), but there is another peak, more spread and about 70 dB below the fundamental. Harmonics at 32 kHz and 36 kHz are also visible (see Figure 14b)).

Measurements on phase 3 also show peaks at 16 kHz, 18 kHz, 32 kHz and 36 kHz, at levels slightly lower than on phase 2.

Internal frequency of the inverter (16 kHz or 18 kHz) however is well present, even at very low production levels. Its level is independent from the photovoltaic power produced; it only disappears when the inverter is shut down. The internal frequency (and to some extent its harmonics) tends to propagate along the whole LV distribution network, and is not blocked by the meters. The attenuation is around 10 dB.

Significant differences can be observed between both installations in this study: the 18 kHz from the first installation has a high phase-to-phase attenuation; the 16 kHz from the second installation has not only a higher level, but also a much lower phase-to-phase attenuation (15 to 20 dB on installation 1, less than 10 dB on installation 2). As a consequence, the 16 kHz switching frequency of installation 2 generates higher disturbances in the neighbourhood.



a) Location 1, Phase 1 **b) Location 2, Phase 2**

Figure 14 — Emissions from PV inverters in the frequency range 20 kHz to 50 kHz

As can be seen, the inverters generate emissions in the frequency range designated for MCS related to supply network applications (CENELEC-band A [26] (see also 3.2)); although the measurement was done in a frequency range up to 50 kHz only, it can be started from the assumption that also harmonics of higher order exist and the frequency range for narrow-band PLC according to EN 50065-1 [26] is concerned as a whole.

4.5.5 Italian lab and field measurements

In Italy, measurements have been performed on a number of generic market single phase inverters both terminated with a CISPR AMN as well as connected to different batteries of photovoltaic panels with a nominal power ranging from around 1 kW to 4 kW [59].

Figure 15 — Photovoltaic panels feeding a single phase inverter directly connected to an LV power line

Table 5 — Single phase LV inverter features

Nominal Power (kW)	PHV Module Power (kWp)	Phase
1,8	14,65	T
1,8	1,65	T
1,5	1,58	S
1,5	1,58	S
3,6	3,96	R
1,7	1,58	S
1,0	1,06	R

For the purpose of performing conducted voltage emission measurements at the mains port of apparatus, EN 55016-1-2 [52] defines a transducer known as Artificial Mains Network (AMN) or Line Impedance Stabilization Network (LISN) (Figure 16).

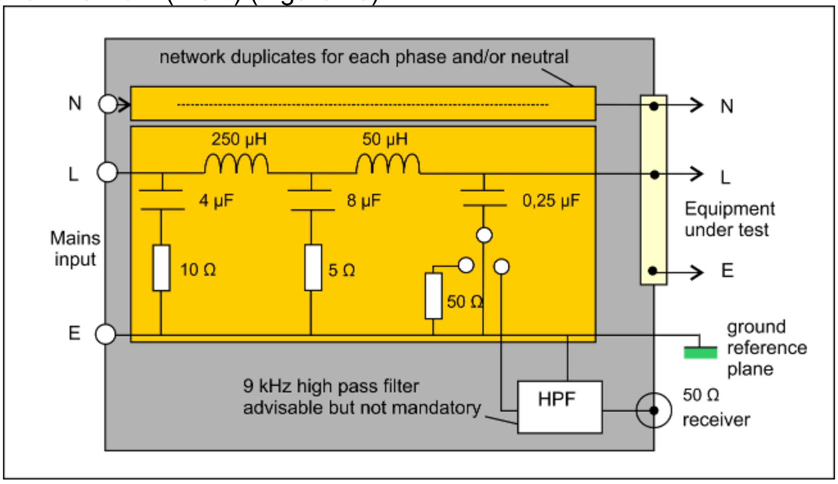


Figure 16 — Artificial Mains Network according to EN 55016-1-2

Figure 17 shows the frequency response of EN 55016-1-2 AMN/LISN:

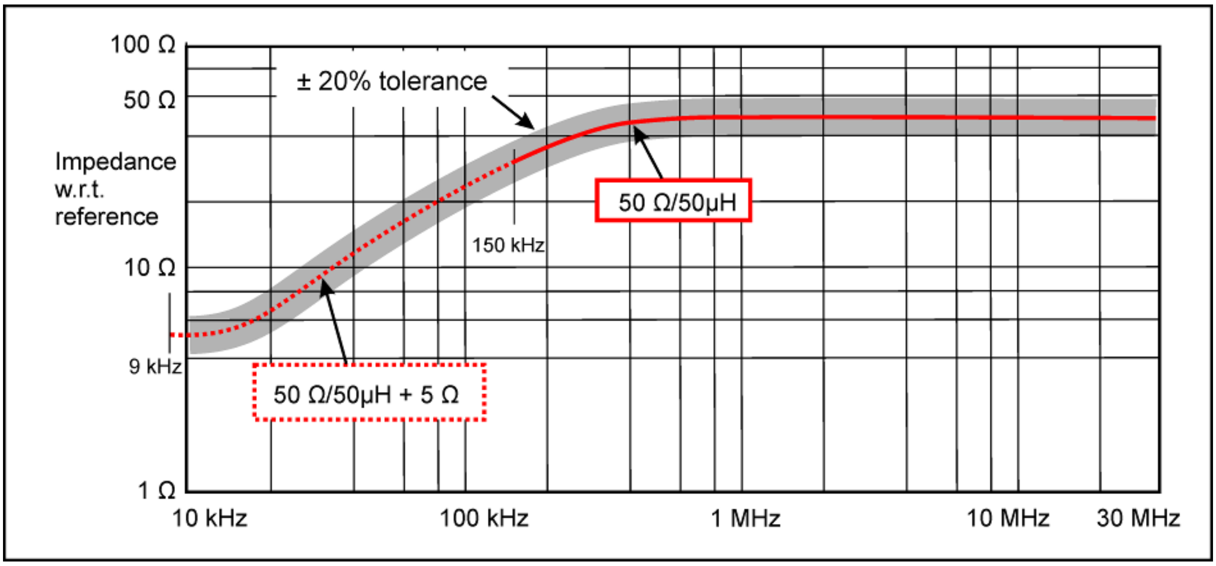


Figure 17 — EN 55016-1-2 AMN/LISN frequency response

With inverters having been grouped according to their features into four classes (i.e. inverters based on different switching technologies, whether an output transformer was present or not, output impedance, filters etc.), Figure 18 shows average characteristic emission levels measured, when applying the aforementioned CISPR-AMN/LISN.

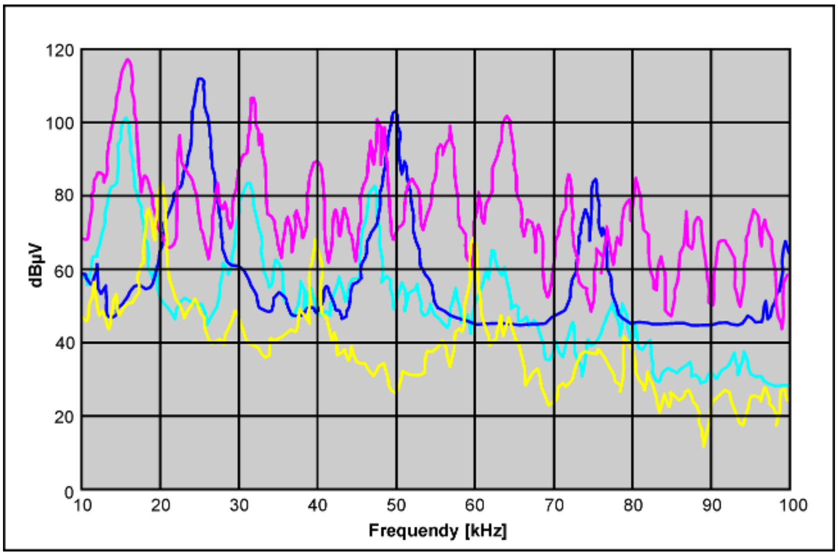


Figure 18 — Average emission levels for the four classes of inverters

Figure 19 shows the average background noise as cumulative result of several acquisitions gathered on a common point of the distribution grid feeding the photovoltaic plants under test.

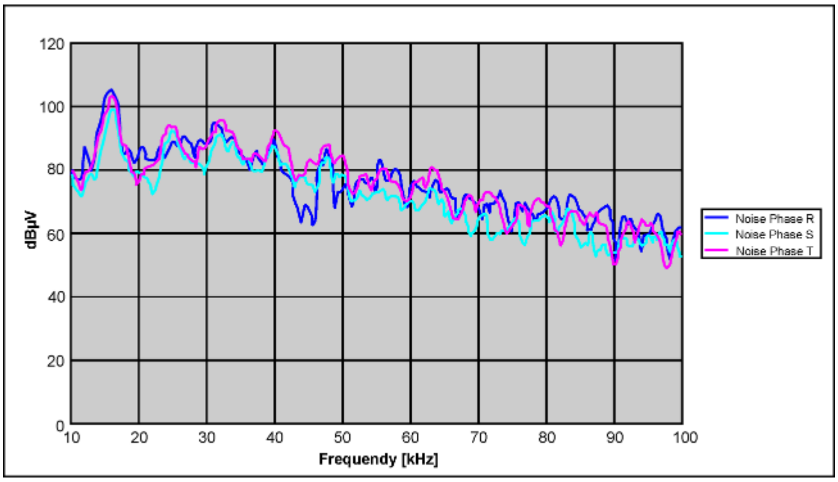


Figure 19 — Average background noise (Max hold mode)

Figure 20 shows the average of the contribution measured at the common test point of all inverters vs. background noise. Inverters have been also tested both at nominal as well as at max power to evaluate the effects on emission levels.

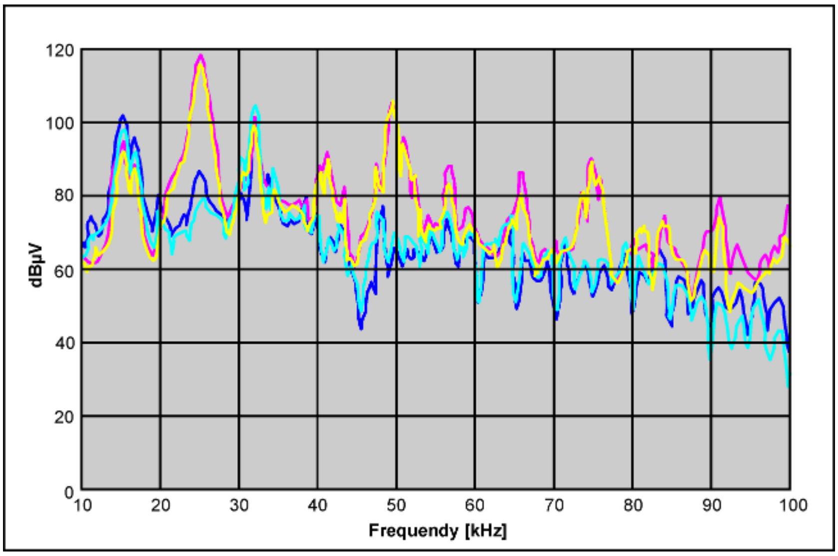


Figure 20 — Background noise (blue line) vs. Inverter emissions contribution

Further investigations over a large number of real plants are required to achieve the due confidence in the measurement and achieve a correct and more stable interpretation of the above results. However in general it seems the emission levels are quite independent from the power effectively generated.

The emission spectrum which is here measured up to 100 kHz -- indeed analysis should be extended at least up to 2 MHz -- presents a sort of periodic peaks and the levels in the range of frequency considered are in the order of magnitude of the PLC signals typically used by AMR applications.

4.5.6 Power electronics in an Intelligent Distribution Station

In a Dutch utility, measurements concerning interference and impedance have been performed in a so-called IDS (Intelligent Distribution Station). There, an adaptive transformer, using power electronics, and an ESI (Energy Storage Inverter) are applied; the ESI also uses power electronics for its adaptive control circuits.

These measurements showed also high emission levels; further, very low impedance levels were observed.

4.6 Power supplies

4.6.1 General

Today's power supplies normally operate with a small inverter, thus realizing a switch-mode power supply. As the measurement results in the following subclauses as well as the numerous EMI cases with power supplies described in 5.2.3.2 show, power supplies – from UPS down to quite small ones – represent a potential EMI source, with quite high emission levels.

4.6.2 Power supply with PLC signal on DC side

It can be expected, that any equipment powered by external AC/DC supplies can be affected by current/ voltage components stemming from non-intentional emissions or MCS signals, which might partly pass the mains adapter, or from current/voltage components generated in the adapter.

Related tests with rectangularly modulated (3 Hz, 100% AM) test voltages of 146 dBµV (20 Vrms) in the frequency range 3 kHz – 13 kHz [51] on a mains adapter of a notebook showed,

- that some percentage of the primary voltage is present with voltage components of some tens of kHz on the secondary side, having passed through the adapter;
- a level of the disturbance on the DC side of 3,4 Vpp (121,7 dBµV), 23 dB below the signal voltage level on the mains side (20 Vrms / 146 dBµV).

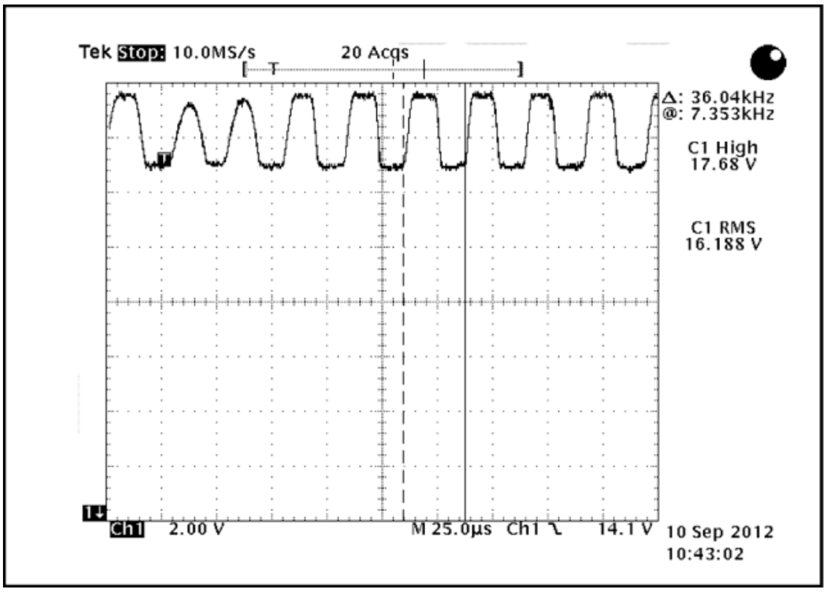


Figure 21 — Example of modulated DC output from laptop AC-DC converter supplied with 230 V/50 Hz, showing a disturbance voltage of 146 dBµV (20 Vrms)/ 36 kHz on DC side

In the investigated case, no malfunction of the notebook (touch-pad, battery-status) could be observed. There appears some potential for interference causing malfunctions, ageing or loss of performance to be given. Appropriate design of such power supplies, with application of a related filter circuit, would be advisable. The transfer of voltage components to the internal DC supply (12 V mainboard, 5 V main-board and USB ports) should be more investigated.

4.6.3 Power supply of a TV receiver

In Sweden [60], the power supply of a TV receiver has been found as causing an EMI, with a spike of 107 dBµV at around 65 kHz (Figure 22) (see also 5.2.3.2.6).

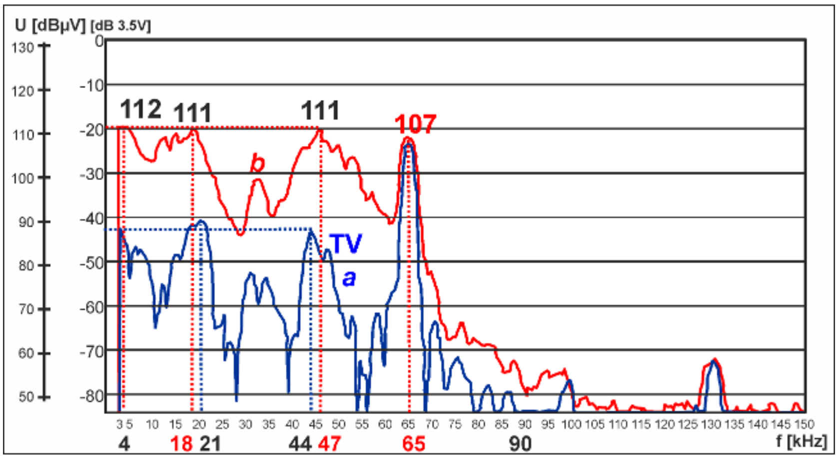


Figure 22 —Emission of a TV receiver's power supply (curve a) together with emissions from other equipment (curve b)

With unplugging this TV receiver, the 65-kHz-spike disappeared.

The emissions from the TV receiver together with those from other equipment show further peaks, with levels of 111 dBµV at ~ 46 kHz and at ~19 kHz, 112 dBµV at ~4 kHz and 99 dBµV at ~33 kHz.

The aforementioned voltage peaks covering the considered frequency range for supply network operational MCS are quite high compared with signal limits of MCS and with its order of magnitude exceeding signal levels normally being expected along the mains supply, due to attenuation along the supply network, thus representing some danger of EMI with MCS or even other electrical equipment sensitive to such voltages including different broadcast time-signal systems (see 5.3.1).

4.6.4 Power supply of a PC

By lack of dedicated equipment to measure differential noise, the following results of measurement of a PC power supply are for line to earth only. They can however be used to determine a "worst case", by assuming that the differential voltage is the highest of the two measurements + 6 dB.

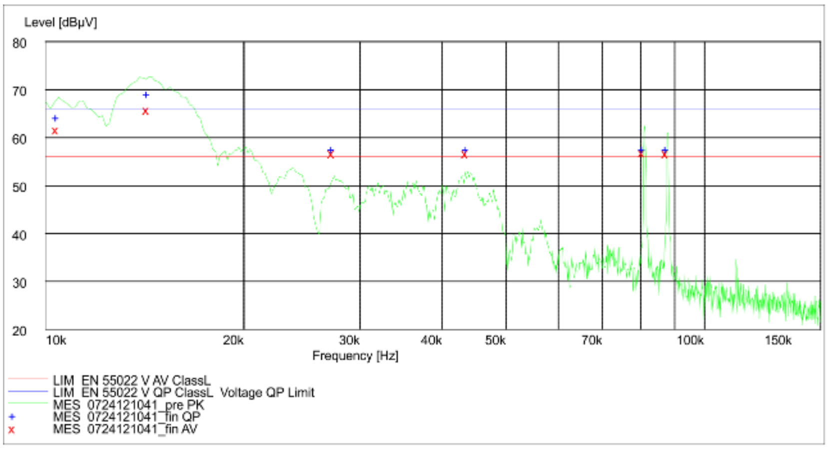


Figure 23 — Emissions from a PC power supply

As can be recognized, the measured emissions are mainly quite below the limits horizontally extrapolated from EN 55022 [61] (for frequencies > 150 kHz) and below the commonly accepted limits for cooking appliances, for lower frequencies, in EN 55011 [30]. However, it should be noted that the margin to these aforementioned limits is significantly reduced around the switching frequency of the power supply.

4.6.5 Power supplies in communication technology

In UK, a telecom operator started investigations on related EMI cases in 2007. Two years later, ~1 600 EMI cases have been reported from that period [63], which number has increased up until 2012 to more than 6 600.

Related to the period 2007 – 2009, Table 6 shows the different types of equipment that were identified as causing interference. In many cases back then the actual source has not been identified nor captured within any records system so this is compiled only where clear identification of the actual interference source was made and recorded.

Table 6 — British statistics on EMI cases 2007 - 2009

Satellite receiver	175	Serial distribution unit, Ethernet switches	8
Router	67	PLT	7
CCTV	46	Alarm equipment, Singpack power supply	6
Lighting	40	Factory machine	5
DVD/DVR	36	Printer, Scanner, TV aerial booster	4
TV	31	240 V to 110 V voltage inverter, Dimmer switch, Lift motor, WII, Sewage treatment plant	3
Monitor	30	Electric gate, Fax machine, Firewall box, Pole top electricity transformer, TV sender unit, USB hub	2
PC	24	UPS, Airconditioning unit, Cranes, Digital multiswitch system, Dog fence, Low energy home system, Ventilation system – motorfan, Environmental unit, Heating and watertimer, Switch-board, Paper sorting machine, Photo booth, Portable welder, Power inverter, Running machine, Plug, Drive motor, Single-phase to three-phase power convertor, three-phase inverter	1
Electric fence	22		
Power supply	22		
VCR	17		
Freeview box	13		
Switch system	10		
Water pump inverters	9		

This table, over all, shows a remarkable portfolio of types of electrical equipment – correlating with what is said in Clauses 3 to 5, in particular in 4.6 and 5.2.3.2. Nearly all of the items in that list have a power supply of the same type whether it be external or internal; from the items having been recovered and taken apart it may be deduced, that the actual interference source was the power supply (with suppression capacitor faults) in the majority of cases.

Figure 24 shows the result of measurements made on some of the faulty power supply units, from a faulty TV or satellite receiver, from 150 kHz up. As can be recognized, peak values of around 120 dBµV have been measured at 150 kHz. From measurements on other products, this behaviour has been recognized as a quite typical one (see also 5.2.3.2). As the frequency goes down, noise is increasing at a significant rate, which tendency can be estimated as continuing also for the frequency range below 150 kHz.

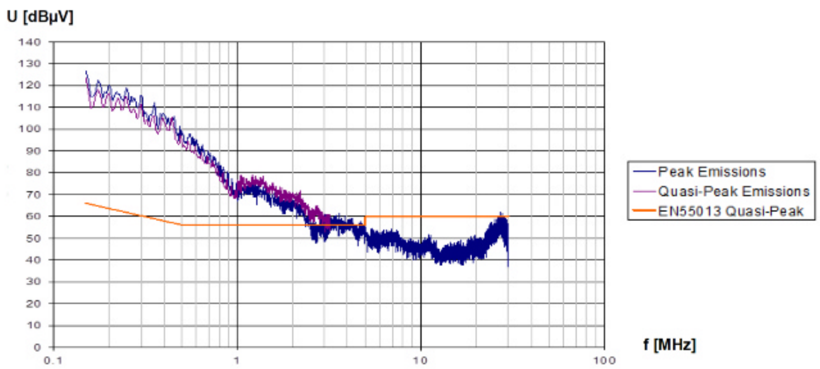


Figure 24 — Emissions from TV receiving equipment (150 kHz – 20 MHz)

For verifying the further increase of emission levels with decreasing frequencies below 150 kHz, measurements have been made in the frequency range 10 kHz – 150 kHz, with three different samples of equipment that this telecom operator has had issues with causing interference to his broadband network. Figure 25 shows the emission levels having been measured with a peak detector with a 10 kHz bandwidth and normal AMN, from:

- a faulty external switch mode power supply from a laptop PC;
- a faulty TV receiver;
- a small fluorescent light unit.

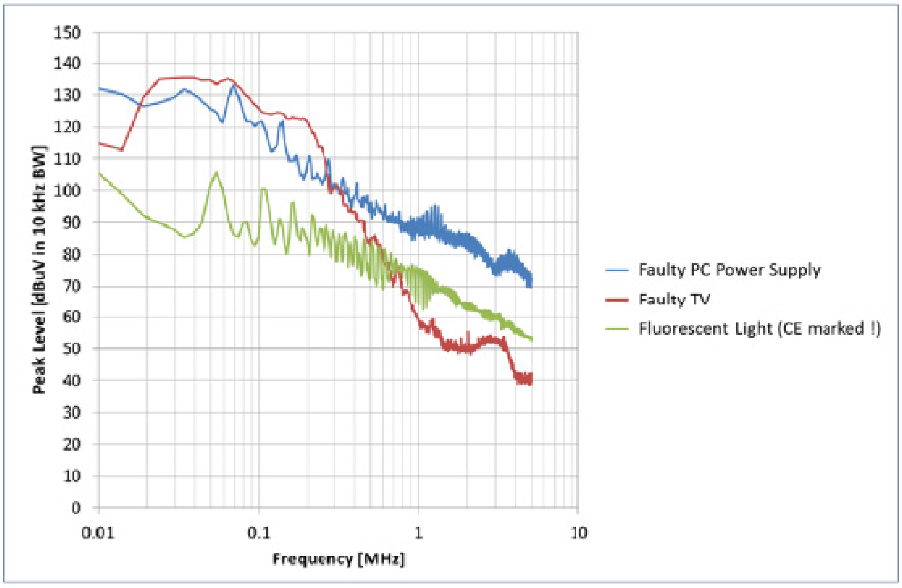


Figure 25 — Emissions from faulty PC & TV power supply, light unit (10 kHz – 150 kHz)

These results show for the frequency range 10 to 150 kHz:

a) increasing emission levels with decreasing frequency, down to some tens of kHz;

b) with a maximum level of ~ 135 dBµV from the faulty TV receiver, over a broader frequency range of ~ 25 kHz to ~ 65 kHz;

c) a maximum increase by ~ 95 dB from 150 kHz down to ~ 65 kHz, at the faulty TV;

d) an increase:

1) by ~ 63 dB, from 150 kHz down to 70 kHz, at the faulty PC power supply and

2) by ~ 52 dB, from 150 kHz down to 55 kHz, at the fluorescent light.

In the case of both items with faulty power supplies the devices continued to function normally to the end user.

The small light unit was CE marked but found to have relatively high emissions by design.

For the satellite receiver listed at the top of Table 6 this was predominantly one model of which at this time, according to information by the manufacturer, there were at least 100 000 devices in circulation. When investigating such EMI cases, common makes and models of equipment or power supply module are reported as being recognizable.

When considering that in many cases EMI is not identified as the cause of a fault, and even when being so, the faulty product is probably replaced without further investigation, it is possible that based on these recognitions, the reported EMI cases might be showing only the tip of an iceberg.

4.7 Other equipment — Rectifier in a cell tower

This measurement result stands as an example for emissions having been reported to have been measured in Sweden for several years at rectifiers in cell towers as well as with similar products applied in the telecom operator area [64]. It is reported that the expansion of 4G leads to an increased occurrence of related interference.

Figure 26 shows the emissions from a rectifier measured in a cell tower, showing peaks up to 125 dBµV, with peaks levels also of 111 dBµV at ~ 65 kHz and 125 dBµV at ~ 57,5 kHz.

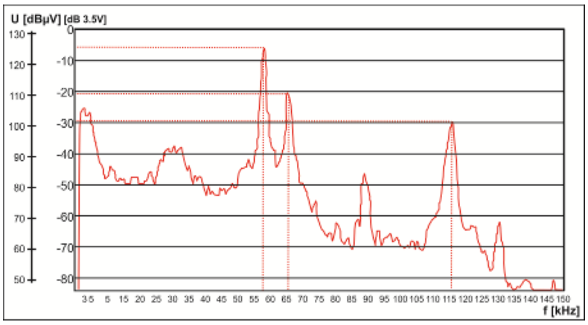


Figure 26 — Emissions from a rectifier in a cell tower

5 EMI cases, measurement and test results

5.1 General

This clause provides information about EMI cases and related investigation results reported from electricity suppliers and manufacturers from several European countries and Japan, over all from:

- 12 countries (AT, BE, DE, FI, FR, GB, HU, IT, JP, NL, NO, SE), and
- Universities from Finland, Germany, Great Britain and Sweden (see e.g. [17], [18], [48], [49], [53], [54], [65], [66])

reaching back to studies from the late nineties of the previous century, conducted in Japan [20]; see also related contributions to CIRED 2013 [50], [117].

Concerning the latter, following to related research activities, data having been made available from Tampere University of Technology (TUT) are based on results from investigations having been conducted in co-operation with 18 DNO's, those operating around 850 000 remotely readable meters at the time of the investigations.

For better comprehensiveness, this overview considers also EMI cases and investigation results having been reported with Study Report I of SC 205A [1a], referring to it for details.

Often, an actual complaint about degradation of performance or malfunction of network users' electrical equipment initiates investigations and measurements concerning EMI in the frequency range below 150 kHz. In such cases:

- the network user formed an association between a given disturbance effect and possible interference potential from the electricity supplier;
- the EMI case was reported to the electricity supplier or manufacturer, by a complaint.

It can be taken as a fact, that in some additional cases, such considerations are not made and no related information arrives at electricity suppliers or manufacturers. Therefore, it can be assumed, that the real number of related EMI cases shall be estimated at a higher order, by far.

Besides complaints by network users, the following reasons are a background for conducting related measurements and investigations in the matter in detail, thus forming also the basis for EMI cases and investigation results as reported below:

- general investigation on the EMI potential in the frequency range 2 kHz – 150 kHz;
- investigations due to distinctive features in the performance of electrical equipment, including the communication during operation of an AMR-PLC system;
- laboratory tests at electricity suppliers, manufacturers, universities or accredited test houses;
- detailed tests on equipment with possible EMI potential.

As anticipated, not every malfunction can be counted as an EMI case due to an interference following to the effect of conducted emissions to electrical equipment. When receiving information about degraded performance or malfunction of equipment appearing to have en EMI as its cause, a careful evaluation of the event shall be made – whether:

- the equipment involved were legitimately CE marked and the related standardized emission limits and immunity requirements were met;

- the event were indeed representing an EMI due to current/voltage components in the frequency range 2 kHz – 150 kHz, exceeding the immunity of an equipment in normal operation status;
- the event was caused by an ageing effect of some component of an equipment or another kind of defect of components, whilst the same product in normal operation status would not cause or suffer from a related EMI;
- the events were occurring due to other reasons than too high emissions or too low immunity.

Some of the investigation results described in the following highlight in particular the need for distinct investigation and the difficulty of ensuring a correct evaluation.

5.2 EMI due to conducted emissions

5.2.1 EMI to lighting equipment

It may have been the sort of interference having been recognized first, in Austria, Germany and The Netherlands, when network users complained to their electricity supplier about the incorrect operation of their lighting dimmers.

Several cases of incorrect operation due to the influence of PLC signals have been reported from Austria, Germany and The Netherlands. These EMIs appeared as unintentional step-changing of touch-dimmer lamps' (TDLs) light intensity including unintentional switching OFF and ON of that device [1a] (3.2.1.1, 3.2.1.2, 3.2.1.5, 3.2.1.7, 3.2.1.8, 3.2.1.9, 3.2.1.14, 4; see also [67]).

Results of related investigations [1a (3.3, 4)] showed, that the disturbing effect was obviously caused by the shape of the envelope of the MCS signal, i.e. the fast rise of the amplitude at start and its fall at the end of the AMR system's data transmission, in differential mode.

From Sweden, there was reported about several problems having been caused by switch-mode products, amongst others by fluorescent lamps with high-frequency ballasts [1a], [68].

Also new investigations at the University of Tampere, Finland, showed several cases of interference with TDLs and other lighting control systems.

5.2.2 EMI to electricity meters

Related EMI cases have been observed and investigated in Germany and Sweden [1a]. These interference led to abnormal meter register values during exposure. The causing disturbances, although not being constantly present in the power network cannot be defined as transient,

- are, apart from intended signalling, a specific type of conducted high frequency current "wavelike phenomenon" in the frequency range 2 kHz – 150 kHz;
- can be described as injections of currents/voltages into the distribution network by third party (auxiliary) equipment or electrical devices, like PV inverters, frequency converters, heat pumps, domestic electronic equipment, compact lamps, TV equipment, (defective) power supplies, automatic garage doors, refrigerators, dimmers;
- can vary in bandwidth from narrowband PLC-signals to larger bandwidths, such as switching frequencies from power supplies and broadband noise.

In Germany, related investigations have been made by IWES[5)] [18], within the research project OPTINOS[6)], in field as well as laboratory tests. During measurements it was recognized, that in a plant, within the measurement period of one week, the electronic meter displayed an energy level of ~ 18,5 % below the real energy fed into the public grid by the PV inverter [1a].

As reported, meters may show such malfunctions due to the presence of a push-pull-disturbance, which obviously leads to an over-modulation of the meter. Presence of a modulated signal results in a reduction of this interference effect, as during modulation there occur phases with lower disturbance levels.

In 2010, the Swedish Board for Accreditation and Conformity Assessment (SWEDAC) reported:

5) Fraunhofer IWES Institute for Wind Energy and Energy System Technology, Kassel.

6) Testing and Optimising of Test and Certification Procedures for Quality Assurance and Harmonisation of Norms at PV Inverters.

- that electronic meters had shown wrong display of metered electric energy due to conducted disturbances;
- that the related meters were conform with the harmonized meter standards EN 50470-1 [69] and EN 50470-3 [70] and were therefore legitimately CE-marked;
- their assumption, that the aforementioned meter standards would not meet the ERs of the Measuring Instruments Directive (MID) 2004/22/EC [71], Annex I and MI-003;
- that the disturbance effect had been caused by other electric equipment connected to the supply network, like heat pumps, TV equipment, defective power supplies, compact lamps;
- that with regard to the disturbing components in the supply voltage being quite widespread, a revision of the relevant harmonized standards appeared as being necessary.

In their response [72], ESMIG, the European Smart Metering Group:

- stated their awareness of the problem, which, in the light of the expected mass deployment of meters in the near future, deserves particular attention;
- confirmed the lack of standards specifying immunity requirements and test methods either and the need for a coherent approach to all equipment that is connected to the electricity network, including the specification of emission limits for any such equipment;
- announced an activity to find an interim solution until the necessary basic standards will have been established – what has been done in the meantime (see Clause 6, resulting CLC/TR 50579 [2]).

5.2.3 EMI to mains communicating systems (MCS)

5.2.3.1 General

As mentioned in Clause 3, Table 1, one of the main effects from EMI with MCS in the frequency range 2 kHz – 150 kHz is a communication loss within the MCS, between the data concentrator and the meters connected, caused by NCE. In the following, some related EMI cases or related interference potential are described.

5.2.3.2 Power supplies

5.2.3.2.1 General

In 2009, the Swedish National Electrical Safety Board (Elsäkerhetsverket) had reported about several problems having been caused by switched mode products, amongst others by power supplies [1a], [68] (see also 5.2.3.5.2). Below, a number of additional EMI cases, having been reported from Finland, France, Sweden and The Netherlands, are presented.

5.2.3.2.2 TV antenna system

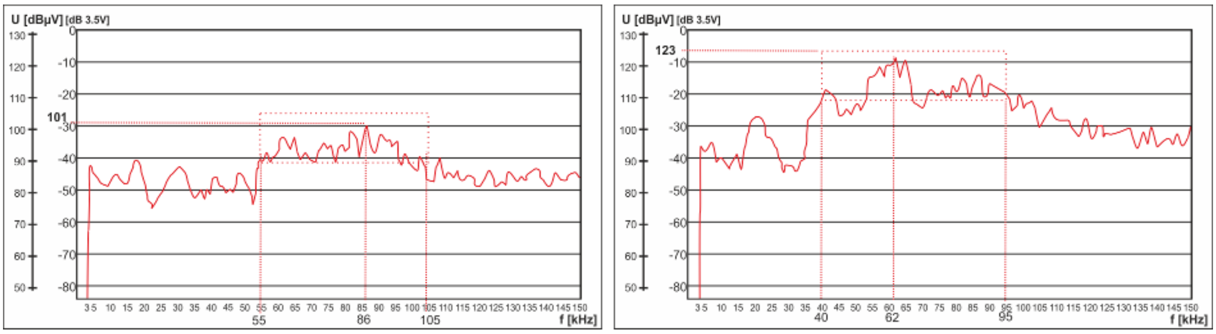
In 2009, during related investigations, Tampere University [66], [73] found small plug-in power supplies of communal aerial or cable TV systems as a common cause of PLC problems in several cases, whereby a single power supply may block the PLC communication of tens of energy meters.

5.2.3.2.3 UPS for computers/servers

In The Netherlands, a correctly CE-marked uninterruptible power supply, used as a power back-up for computers/servers, caused disturbance to PLC signals (9 kHz – 95 kHz), resulting in data loss [1a].

5.2.3.2.4 Camera surveillance system

An AMR system lost contact with 15 out of over all 74 electricity meters connected to a related substation. In this EMI case, having occurred in Sweden, the interference source was localized to be the voltage converter to the central unit of a camera surveillance system. Moreover, when the voltage converter was plugged in, the remote control to the recorder did not work [74].



a) Substation   Phase L2   b) Incoming cable

Figure 27 — Emissions from a voltage converter of a camera surveillance system, with the voltage converter as an interference source

While the emission spectrum measured in the substation (Figure 27a) showed a mean value of ~ 90 dBµV, with peaks up to 101 dBµV at ~ 86 kHz, (Figure 27b)) shows the spectrum on phase L2), at the incoming cable, where the emissions reached values up to 123 dBµV around 62 kHz.

In a remarkably wide range of some 50 kHz, the emissions are mainly between 83 dBµV and 101 dBµV in the substation and between 107 dBµV and 123 dBµV at the incoming cable.

When the voltage converter was replaced, everything worked properly again (emission spectrum at incoming cable, on L2, see Figure 28).

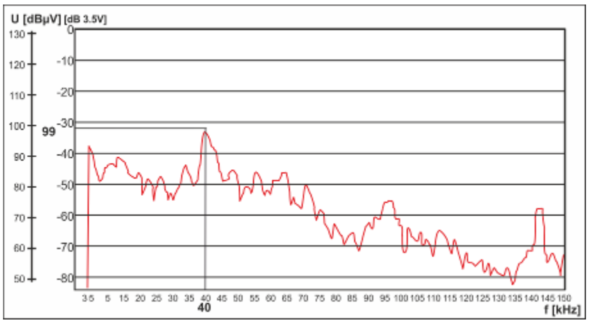
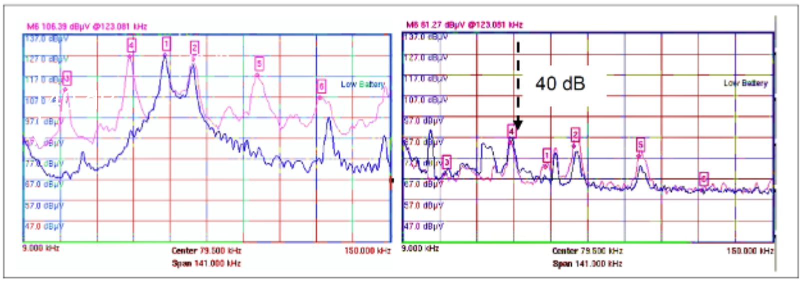


Figure 28 — Emissions from a voltage converter of a camera surveillance system after replacement of the voltage converter Incoming cable, Phase L2

Still, a peak of 99 dBµV appears at ~ 40 kHz, but what is obviously outside the operating frequency band of the AMR system.

5.2.3.2.5 Satellite receiver amplifier

In France, measurements have been made concerning a communication loss between concentrator and AMR-PLC, which had not occurred during installation phase. After having switched off the data concentrator, spectrum measurements to assess the noise in different locations of the building resulted in the recognition, that the disturbing noise, with levels up to 127,2 dBµV at ~ 60 kHz was generated by the amplifier of a collective satellite TV antenna (Figure 29). After changing the amplifier’s power supply, the data collection from the meters operated ordinarily.



Spectrum of the mains supply with

TV amplifier — disabled / enabled

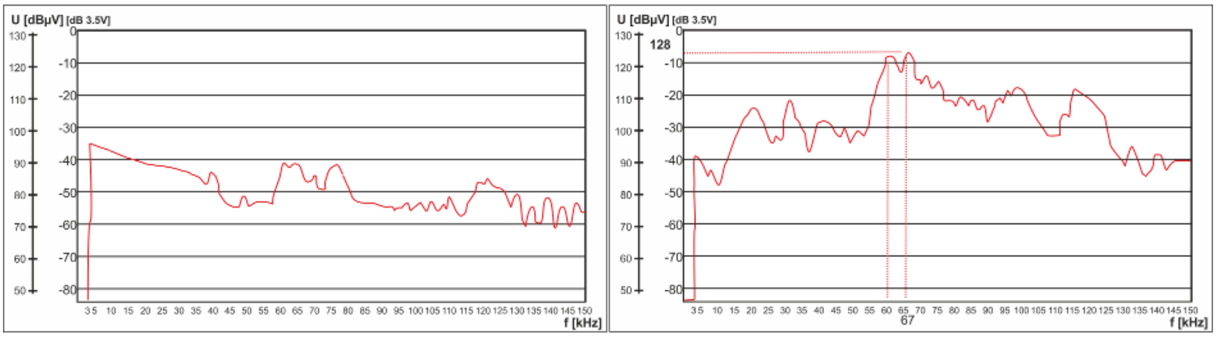
a) with defective power supply (smart metering enabled)   b) with new, correctly operating power supply (smart metering disabled)

Figure 29 — Noise from a satellite TV amplifier

5.2.3.2.6 TV receiver

During operation of a digital TV receiver, the AMR system in the related Swedish supply area lost contact to 230 (~ 55 %) of over all 420 electricity meters connected to the substation. Investigation of this EMI case showed the voltage converter supplying the TV receiver as being the interference source [75] (see also 4.6.3).

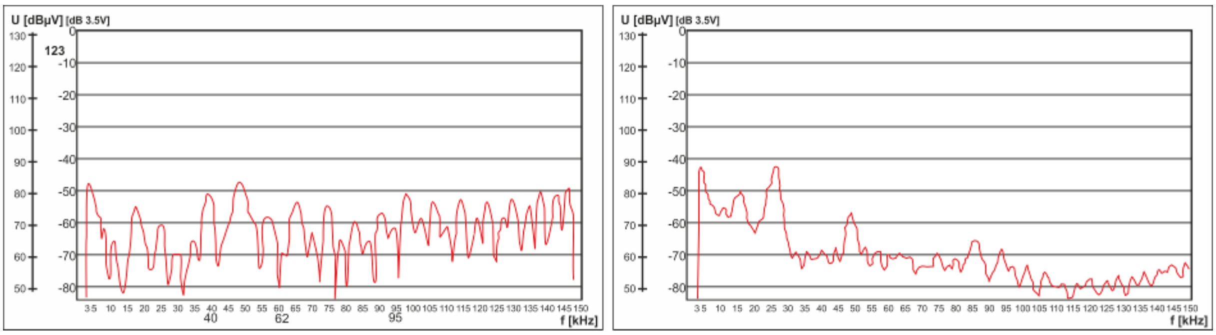
When viewing at the emission spectrum measured in the substation – being quite similar over all three phases -- and then to that one measured at the incoming cable, remarkably – by up to 40 dB -- higher emissions in the frequency range 20 kHz to 140 kHz can be recognized (Figure 30).



a) Substation **b) Incoming cable**

Figure 30 — Emissions from a voltage converter of a digital TV receiver Phase L1

After replacement of the voltage converter by a new one, all meters communicated with the AMR system again (emission spectra see Figure 31).

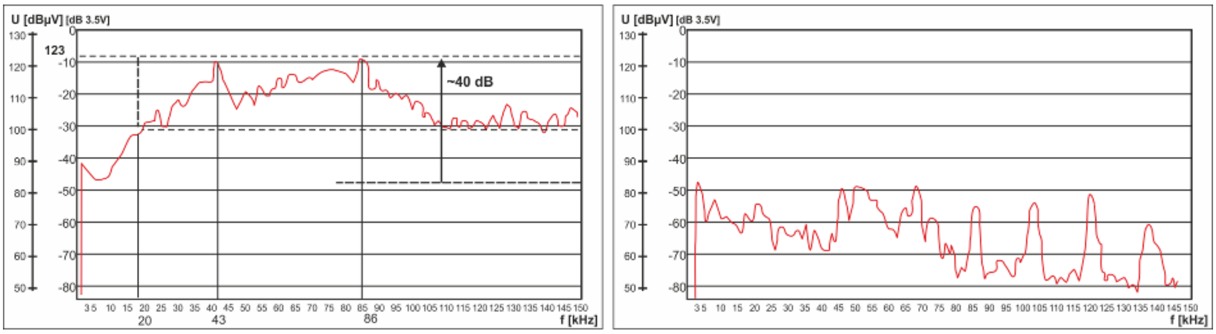


a) Substation **b) Incoming cable**

Figure 31 — Emissions from a voltage converter of a digital TV receiver after change to a new voltage converter, Phase L1

5.2.3.2.7 DVD player

A DVD player connected to an outlet in a nursing home was identified as the interference source when in an AMR system in Sweden 190 out of 225 (~ 84 %) electricity meters connected to a substation lost its communication with the system [76]. It may be assumed that the EMI source was the voltage converter of the player.



a) Connected **b) Disconnected**

Figure 32 — Emissions in a nursery home with a DVD player, Phase L3

Figure 32 shows the measured spectrum on phase L3 at the incoming power cable during interference and after disconnection of the DVD player. As can be seen, the DVD player causes emissions covering the frequency range 20 kHz – 150 kHz with values ≥ 100 dBµV, with peaks up to 123 dBµV at ~ 86 kHz and 121 dBµV at ~ 43 kHz, thus being ~ 40 dB higher than the highest spectral peak without the DVD player connected.

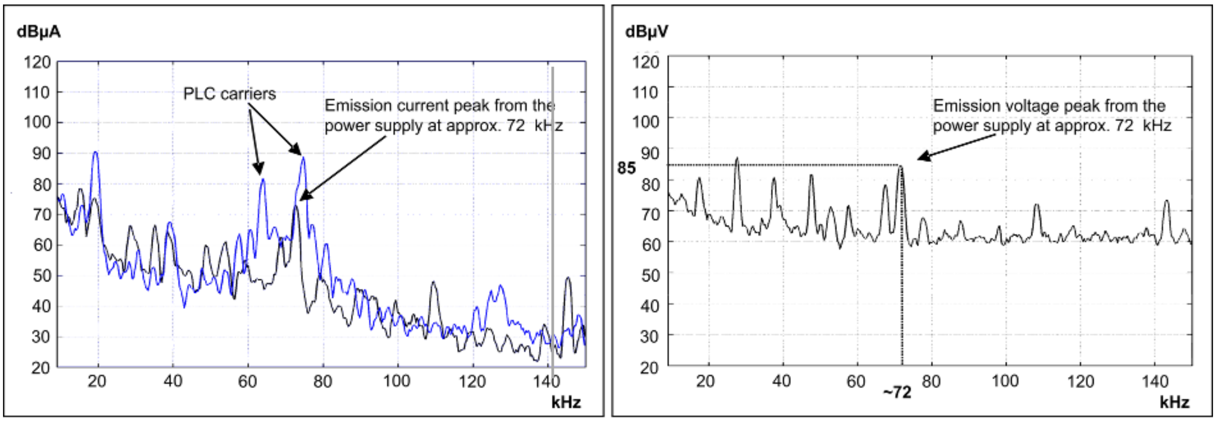
After disconnection of the DVD player, all meters communicated with the system again.

5.2.3.2.8 LAN router / switch

In Finland, relatively new power supplies of a LAN router/switch in a block of flats as well as of a PC were found as blocking the PLC communication.

As related investigations of Tampere University of Technology [66] showed, in most of these cases the power supplies were intact, but with its switching frequencies quite close to the carrier of the PLC system, due to the resulting disturbance voltage blocking the PLC communication.

Figure 33 shows the PLC signal current vs. the emissions from a PC power supply as well as the emission voltage from the power supply.



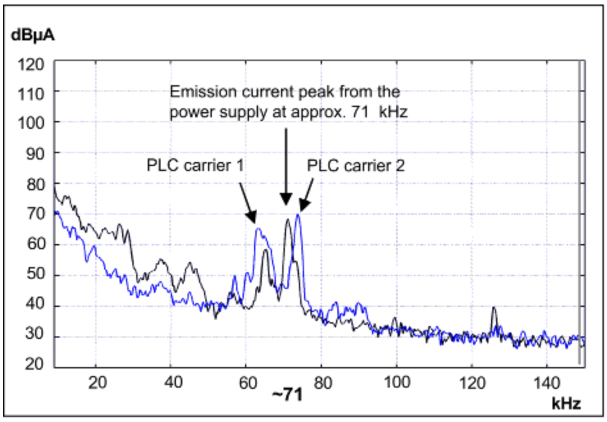
a) PLC signal current & emission current from power supply **b) Emission voltage from power supply**

Figure 33 — PLC signal and emission spectrum from a LAN power supply, blocking communication

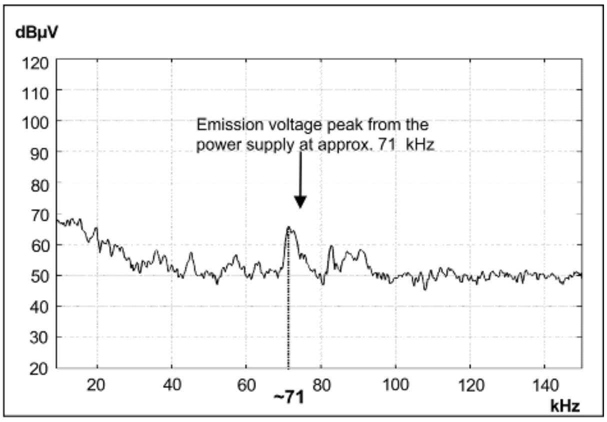
As amongst others can be seen from the chart, with only numerical consideration of emission levels and not considering any additional EMI potential through waveshapes, emissions with levels also much lower than such ones proposed to be recommended e.g. with IEC/TS 62578 Ed.2 [46], even lower than EN 55011 [30] limits, could cause EMI – in this case with MCS.

5.2.3.2.9 PC

During the aforementioned investigations of Tampere University of Technology [66], measurements at a PC power supply provided the results shown in Figure 34:



a) PLC signal current & emission current from power supply



b) Emission voltage from power supply

Figure 34 — PLC signal and emission spectrum from a PC power supply, blocking communication

5.2.3.2.10 4G/LTE base station

During the investigations of Tampere University of Technology [66], also several cases have been found where the switch-mode power supply unit (PSU) of a new 4G/LTE mobile phone base station has interfered with a PLC-system. All the base stations studied were connected to the public low voltage network.

In all the cases the switching frequency of the power supply was approx. 44,5 kHz and the 2nd harmonic approx. 89 kHz (Figure 35).

The second harmonic was between the frequencies of the AMR-PLC system used by the distribution network operator (DNO) and blocked the PLC communication. In places where the base station was located in the same building together with the DNO's PLC data concentrator, the power supply blocked the communication with practically all the meters assigned to that concentrator.

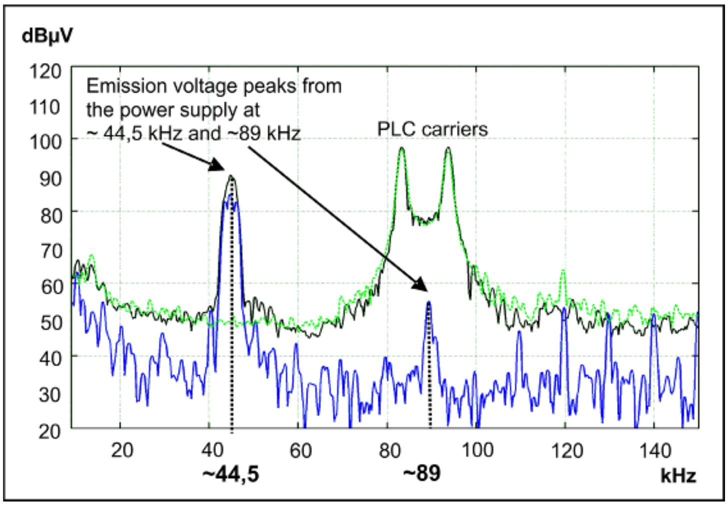


Figure 35 — Emission spectrum from a 4G/LTE base station power supply, blocking communication

The 4G/LTE base station operator claimed that the supply was tested, and fulfilled the EMC requirements; therefore he was reluctant to replace the power supplies or to make any corrective measures, at his cost.

So far, the DNO has installed additional EMC filters into the feeder of the supply to get the PLC working and paid for the costs of the installation. In most cases this has solved the communication problem.

The Finnish National Committee took the EMI cases described in 5.2.3.2.8 - 5.2.3.2.10 once more as a rationale for requiring the establishment of emission limits for the frequency range below 150 kHz.

5.2.3.2.11 Ageing effect

During related investigations made by Tampere University [66] the PLC signal level received by the meters was in the order of magnitude of 80 dBµV up to (relatively high:) 90 dBµV, while small plug-in switch-mode power supplies of communal aerial or cable-TV systems showed emission levels > 110 dBµV at frequencies of 75 kHz and 86 kHz of the PLC system.

In laboratory studies the main cause for the resulting interference was found to be the ageing (drying out) of the smoothing capacitor between the rectifier and the DC/DC converter of the power supply, its capacitance being having changed to a value of 4,7 nF instead of its rated value 33 µF, thus having lost its value by a factor of nearly 8 000.

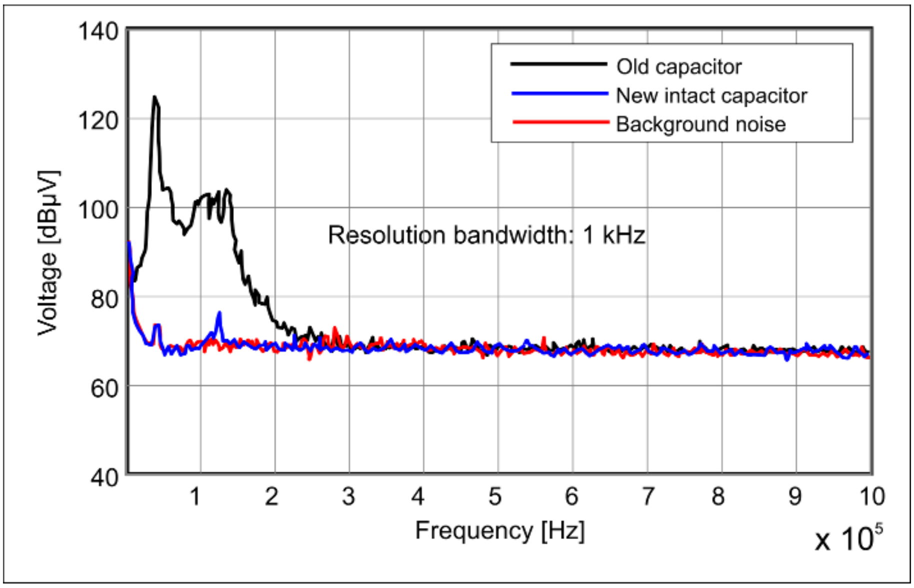


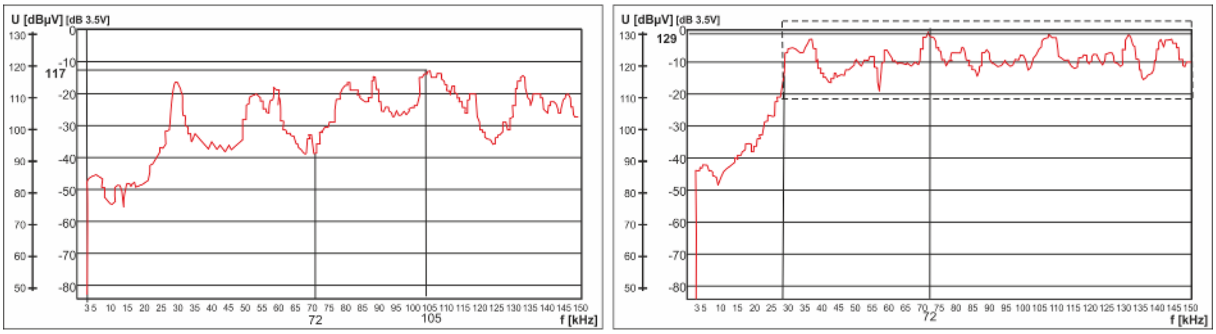
Figure 36 — Emission spectrum of a power supply

Changing the capacitor into a new one removed the interference.

5.2.3.2.12 Battery charger/Voltage converter

A battery charger/voltage converter in a municipal Swedish pump station was identified as a source of interference with an AMR system. During interference, 300 (~ 93 %) out of 321 electricity meters connected to a substation lost communication with the AMR system [77].

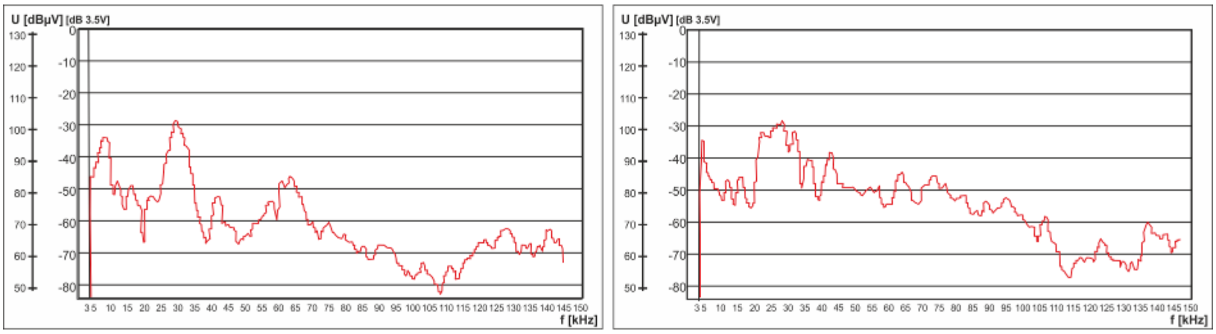
Figure 37 shows the emission spectra at the substation and at the incoming power cable, on phase L1, thus highlighting the remarkable additional emissions load through the battery charger/voltage converter inside the pump station. At the incoming power cable, for the range from ~ 28 kHz to 150 kHz, the emission level is above 111 dBµV, with peaks up to 129 dBµV.



a) Substation   b) Incoming power cable

Figure 37 — Emissions from a battery charger / voltage converter in a pump station, Phase L1

After disconnection of the charger/voltage converter, all meters communicated with the AMR system again (emission spectra see Figure 38).



a) Substation   b) Incoming power cable

Figure 38 — Emissions after disconnection of the battery charger / voltage converter Phase L1

5.2.3.2.13 Antenna amplifier

During EMI investigations by University of Tampere an antenna amplifier of a cable TV network causing wideband disturbances at frequencies from 9 kHz to 1 MHz has been found (see Figure 39). In this case, the cause for the disturbances was the ageing or fault of the integrated power supply of the antenna amplifier.

The amplifier interfered to the reading of most AMR-PLC in the region fed by the same 20/0,4 kV distribution transformer for the block of flats where this amplifier was installed. A total of approximately 330 m fed by the transformer and assigned to the data concentrator located at the transformer could not be read.

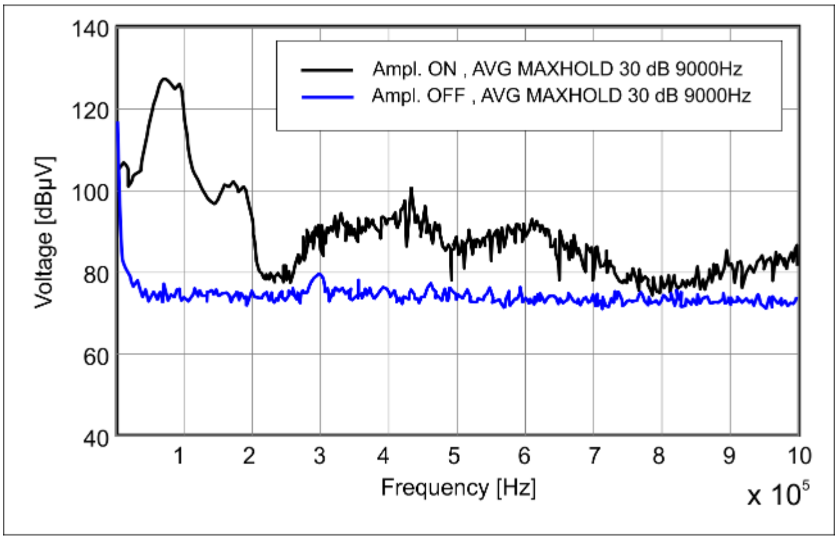


Figure 39 — Spectrum of emissions from an antenna amplifier (9 kHz – 1 MHz)

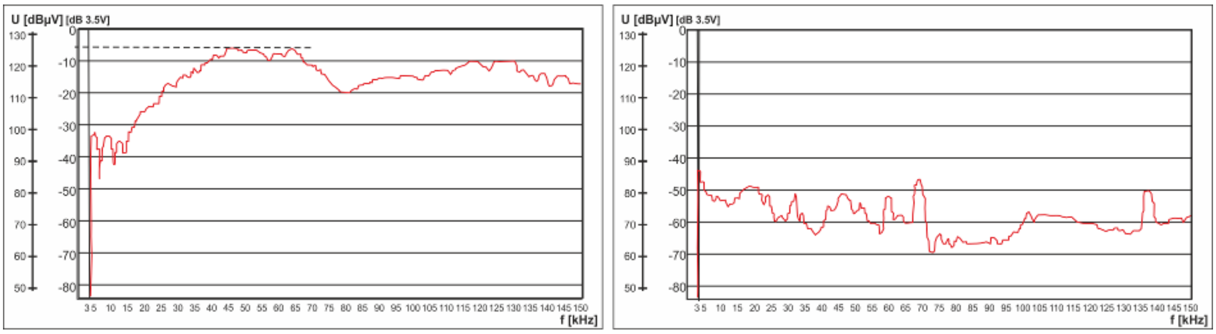
As a mitigation measure the amplifier was replaced with a new one.

5.2.3.2.14 Short range effects

Many of the aforementioned EMI cases showed loss of communication between a data concentrator and a lot of meters, due to the interference caused by some NCE, actually its power supply.

Another EMI case, having been investigated in Sweden [78], shows a rather limited radius of interference. The disturbance level, stemming from the emissions from a power supply used in a substation, decreases at a short distance from the substation, but has still sufficient EMI potential to interfere with the local meters, resulting in a loss of its reading function.

Figure 40 shows the emissions from the power supply, measured at the substation (a)) and at a supply point in a short distance from this substation (b)).



a) Measured at the substation **b) Measured in a short distance from the substation**

Figure 40 – Emissions from a power supply in a substation

5.2.3.3 Power electronic loads containing inverters

5.2.3.3.1 General

Further to what has been reported from the Swedish National Electrical Safety Board (Elsäkerhetsverket) in 2009 about several problems having been caused by switch-mode products such as frequency inverters for speed control of motors in fans and pumps [1a], [68], in the following, new investigation results from Austria, Finland, Sweden and The Netherlands on related EMI cases are presented.

5.2.3.3.2 Frequency inverters in an industrial plant

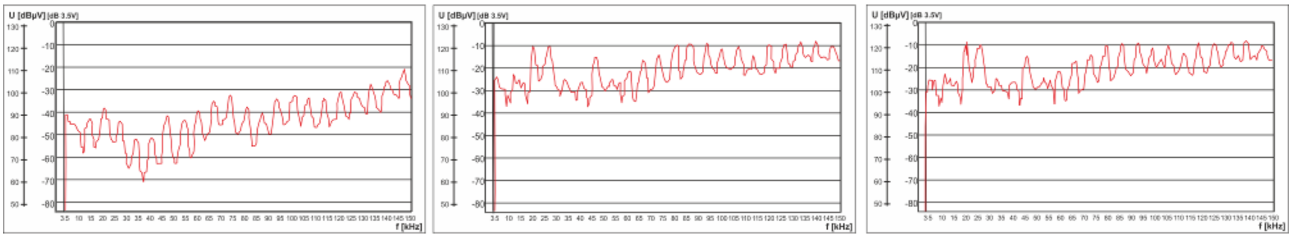
In Finland, an AMR concentrator at a transformer station near a small industrial plant could not communicate with all the meters assigned to the concentrator using PLC as a result of disturbances caused by frequency inverters of the plant (PWM switching impulse disturbances) [1a].

5.2.3.3.3 Frequency-controlled ventilation

In Sweden, the frequency-controlled ventilation system inside a farmer's pig stable was found to be the source of interference with the local AMR-PLC system. 6 electricity meters out of 40 connected to the local substation experienced a loss of communication [79].

Related measurements in the substation as well as at the incoming cable in the pig stable, performed on all three phases, showed

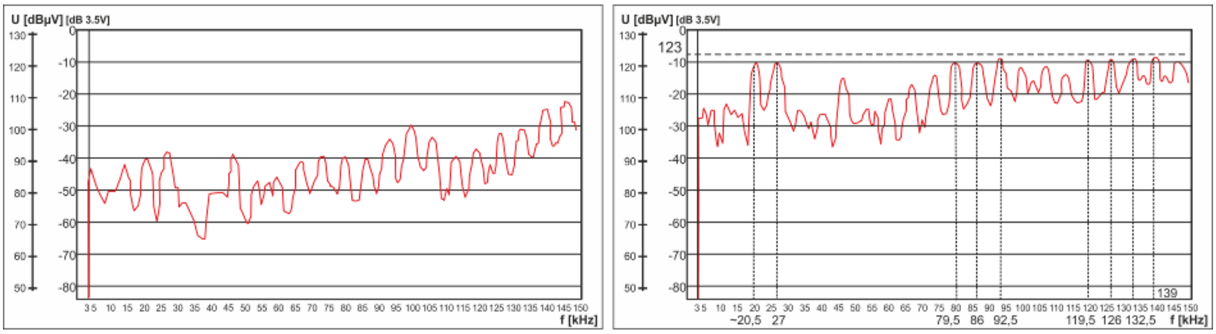
– quite similar shape of spectrum over the three phases and per phase at both sites, quasi identical on phases L2 and L3, with peaks at the inverter switching frequency and its harmonics (Figure 41)



a) Phase L1 b) Phase L2 c) Phase L3

Figure 41 — Emissions from a frequency-controlled ventilation system. Incoming power cable, before mitigation

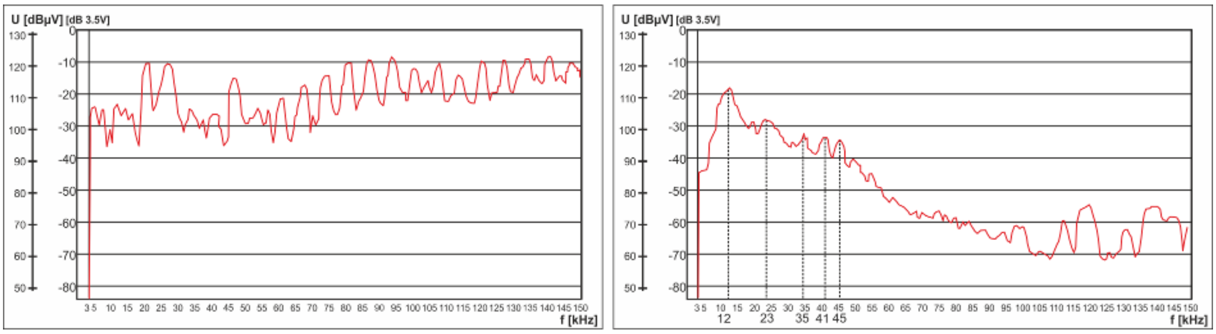
– lower emission levels at the substation than at the incoming cable in the pig stable, thus proving the EMI origin being situated in the latter, with levels up to 123 dBµV (L2) at ~ 139 kHz, 132,5 kHz, 126 kHz, 119,5 kHz, 92,5 kHz, 86 kHz, 79,5 kHz, 27 kHz and 20,5 kHz (Figure 42),



a) Substation, Phase L2 b) Incoming cable, Phase L2

Figure 42 — Emissions from a frequency-controlled ventilation system, before mitigation

Mitigation measures have been taken after a dialog with the manufacturer of the ventilation system, the reseller and the local electrician, by mounting an EMC filter after the breaker. Then all meters communicated with the system again. This measure resulted in an improvement of the disturbance situation in general (Figure 43),

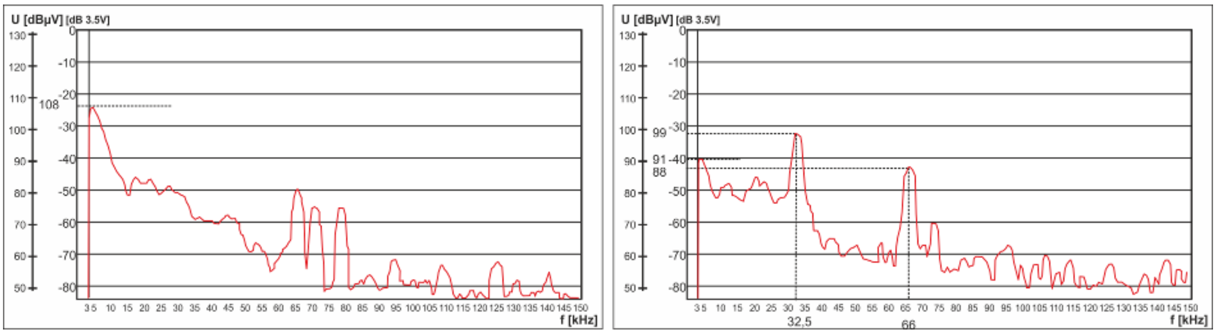


a) Substation, Phase L2 **b) Incoming cable, Phase L2**

Figure 43 — Emissions from a frequency-controlled ventilation system, with EMC filter mounted

with reductions of the peaks at the multiples of the switching frequency in the frequency range obviously related to the AMR-PLC system, from around 50 kHz to 90 kHz, but still showing:

- a peak of 113 dBμV at the incoming power cable at around 12 kHz (L2);
- a peak of 103 dBμV at the incoming power cable at around 23 kHz (L2);
- peaks of ~ 97 dBμV at the incoming power cable at around 35 kHz, 41 kHz, 45 kHz (L2);
- an increased peak at the substation at around 3,5 kHz, with a value of 108 dBμV (Figure 43), thus being increased by ~24 dB compared with the value without EMC filter and 16 dB higher than the values at the same frequency on L2 and L3;
- a peak of 89 dBμV at 66 kHz on L2.



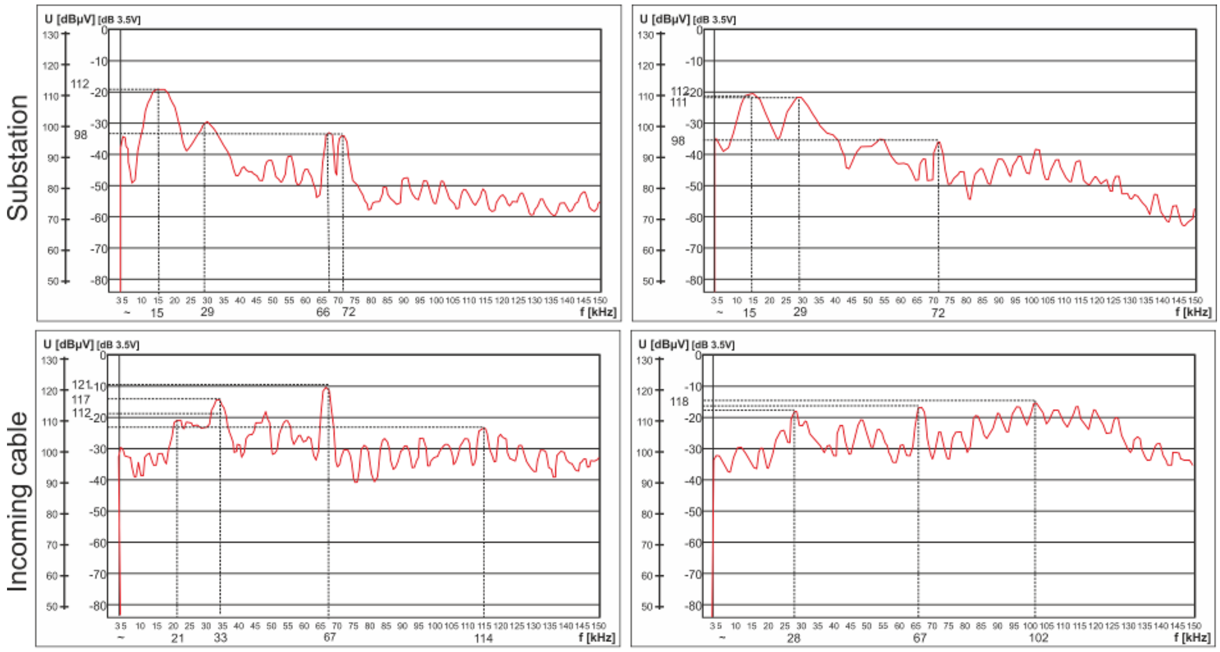
a) Phase L1 **b) Phase L2**

Figure 44 — Emissions from a frequency-controlled ventilation system at the substation, with EMC filter

As reported, with mounting an EMC filter after the breaker, the EMI to the AMR-PLC-System could be managed to work properly again. Anyhow, with the remaining peaks as before-described and its (high) levels – being in the order of magnitude of the practically occurring MCS levels along a supply network or even exceeding it --, other electrical equipment when being sensitive to such emissions could experience EMI.

5.2.3.3.4 Frequency-controlled ventilation II

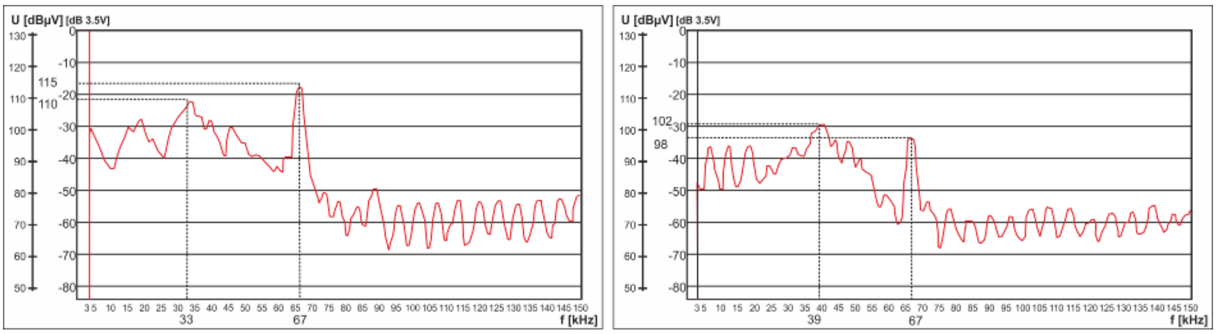
An EMI case has been reported from Sweden, where in an AMR system 26 out of 120 electricity meters connected to a substation lost contact with the system [80]. The interference source was found to be a frequency-controlled ventilation system in the basement of an apartment building. Figure 45 shows the emissions measured at the substation and at the incoming cable, on phases L2 and L3, where the highest peaks occurred.



a) Phase L2 b) Phase L3

Figure 45 — Emissions from a frequency-controlled ventilation system

Installation of an EMC filter after the breaker resulted in all meters communicating with the system again. Figure 46 shows the emissions at the incoming cable after that measure. In the substation the emissions appeared reduced to ≤ 91 dBμV over the whole frequency range, but restricting this effect only to frequencies above ~70 kHz, obviously, with regard to the interfered communicating system.



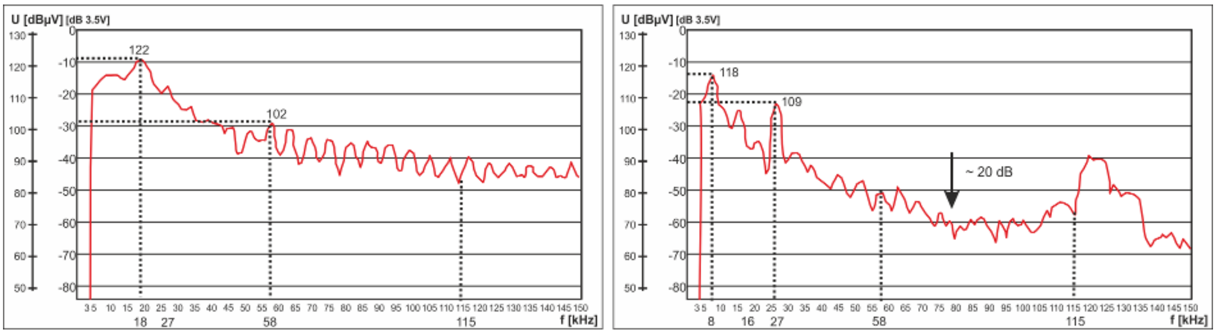
a) Phase L2 **b) Phase L3**

Figure 46 — Emissions from a frequency controlled ventilation system, with EMC filter

5.2.3.3.5 Frequency-controlled water pump

Measurements have been made at a Swedish municipal pump station, whose two large frequency-controlled water pumps had been located to cause EMI with the communication of an AMR system. In this case, 44 out of 81 electricity meters being connected to the related substation had lost contact with their concentrator [81]. The emissions were measured on the three phases at the incoming power cable as well as at the substation, before and after taking mitigation measures.

Figure 47a shows the emissions without EMC filter, Figure 47 b) after installation of two EMC filters.



a) Without EMC filter **b) With EMC filters**

Figure 47 — Emissions from a frequency-controlled water pump Incoming power cable, Phase L3

After installation of two EMC filters, all the meters communicated with the system again.

5.2.3.3.6 Inverters in a waste water treatment plant

In Austria, emissions from several 10-kVA-converters have been measured [82] at the related trans-former station in a frequency range from 20 kHz to 160 kHz. At a frequency of ~20 kHz, values from 5 mV (70 dBµV) to 70 mV (97 dBµV) have been measured; this shall be seen in the context with signals of an MCS getting attenuated along a supply network with 40 dB to 80 dB in general.

In the frequency range 25 kHz to 55 kHz, the spectral current components on the triple-parallel cable have been measured with up to 6 mA. According to Ampère's law, that results in a magnetic field-strength of 160 µA/m in a distance of 20 cm. Compared with the measurements related to interference with the time-signal system DCF77 due to the H-field from a PLC system close to a wire (see 5.3.1), that shows comparable values to such H-field-strengths being caused by inverters.

During the mentioned measurements, a deterioration of the communication to the meters, i.e. a partial communication loss between electricity meters and data concentrators, was recognized.

5.2.3.3.7 Inverter in a heat plant

Austrian measurements on the emissions from a wood crushing drive and from a frequency inverter for infeed into the supply network, conducted by an accredited test house [82] at the related busbar in summer, showed broadband emissions (20 kHz – 160 kHz) with levels up to 92 dBµV.

Similar measurements conducted by the related electricity supplier in winter showed levels up to 100 dBµV. Inside the heat plant, emission levels up to 200 dBµV have been measured. These emissions have a disturbing effect to the PLC system operated in this supply area, with partly loss of communication, in particular in winter; that due to the emissions from the drive and the frequency inverter, without external filters, generating a situation related to the signal-to-noise (S/N) ratio, which may deteriorate the function of an MCS.

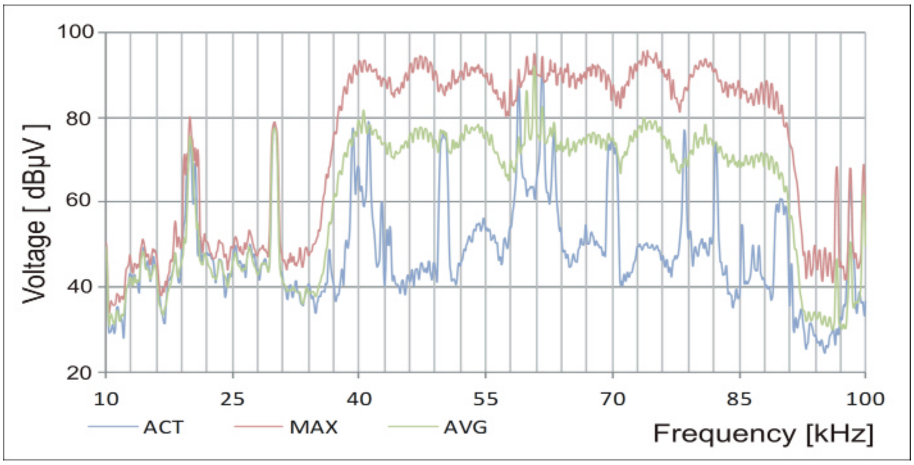
5.2.3.3.8 Several inverters in a rural supply area

Measurements have been conducted in a local rural supply area in Austria [82], with:

a) several (9) inverters:
   1) of one and the same type series;
   2) of different power (4,6 kWp to 14,26 kWp; 4,6 kW single phase, else 3-phase);
   3) being operated together with several PV systems connected to that supply area;

b) an MCS

being installed at the related transformer.



AVG, MAX = MCS-Signal Ø, max + supply voltage ACT = Supply voltage without MCS

Figure 48 — Emissions from several inverters, measured with and without MCS in operation

Emission levels were measured with:

- 100 dBµV with PLC system in operation;
- a mean value of 40 dBµV without PLC signal, with peaks of another 40 dB, i.e. peak levels of 80 dBµV.

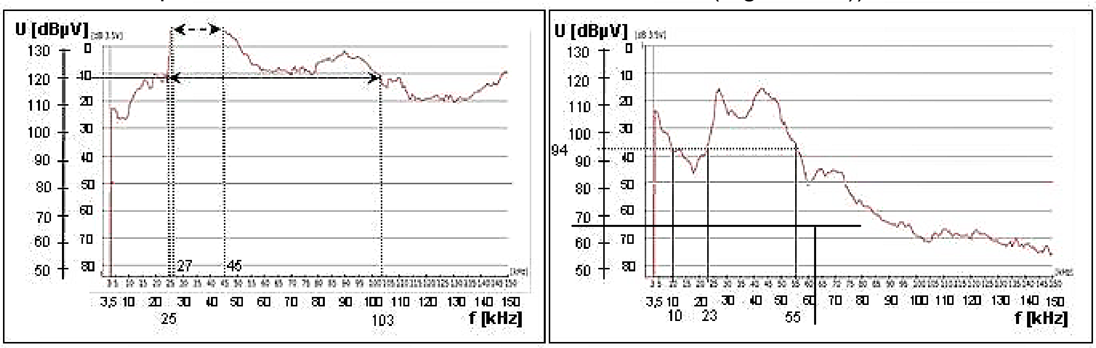
Measurements at one inverter showed emissions with a mean value of 40 dBµV, with additional peaks of 44 dB, i.e. peak levels of 84 dBµV.

5.2.3.3.9 Commercial washing machine

A large scale washing machine for central laundry rooms have been found in several cases in Sweden to cause interference with the communication between the local AMR system and the related electricity meters [83]. Inside the machine there is a frequency control that handles the shifting of the engines RPM. Every time the RPM is shifted, an interference occurs.

The measurements were taken directly at the machine, what explains the very high noise levels, with values

- quite above 138 dBµV from around 27 kHz to around 45 kHz;
- above 120 dBµV on from around 25 kHz to around 103 kHz (Figure 49a)).



a) Without EMC filter **b) With EMC filter**

Figure 49 — Emissions from a commercial washing machine

After installation of an EMC filter, the emissions were reduced (Figure 49b), thus ensuring proper operation of the AMR system communication; such filters are intended to be used in further cases of EMI due to the operation of such washing machines in future.

The charts show the emissions measured directly at the washing machine, thus explaining the very high levels, showing generally values above 80 dBµV in the frequency range up to 74 kHz, with peaks of 116 dBµV, at frequencies around 28 kHz and 43 kHz.

Taking a practical upper level of 94 dBµV of MCS signals in a supply network (i.e. 134 dBµV infeed level limit at the PLC equipment minus 40 dB), after the installation of the EMC filter, for the frequency ranges 3,5 kHz – 10 kHz and 23 kHz to 55 kHz, the emissions from this commercial washing machine still show levels equal to or exceeding these practical intentional signal limit on the mains.

Since the disturbance is only present during washing procedure and most people do not wash during night, the problem was to locate possible other EMI sources connected to the same substation during daytime without closing the central laundry rooms.

5.2.3.3.10 Variable Frequency Drives in a pump station

In a Dutch utility, with some ten thousand of AMR-PLC in the field in 2009, communication between all 180 smart meters installed in this supply area and the data concentrator in the LV/MV transformer station got completely blocked.

Analysis of this EMI case showed variable frequency drives (VFD, 21 kVA) in a pump station within this supply area as representing the interference source; actually higher harmonics of the VSDs interfered with the narrow-band signal of the AMR-PLC system operating in Cenelec band A (see 3.2, Figure 7).

Even when the switching frequency of the VFD was modified to values so that the PLC signal spectrum (around 86 kHz) got situated in between the harmonics of the VFD's switching frequency (as in Figure 50), PLC communication was not possible.

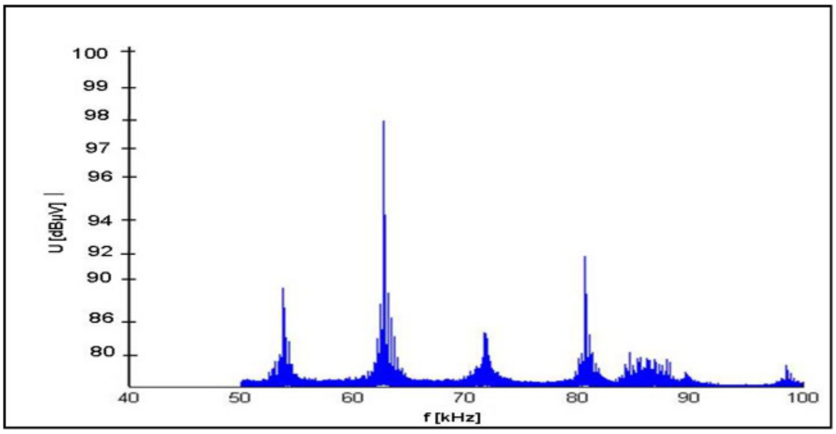


Figure 50 — Harmonics of VFD switching frequency and PLC signal

Not only the (non-intentional) emissions from the VFD were a problem; also the low impedance, to a large extent also caused by the VFD, thus preventing the PLC transmitter to generate adequate signal levels, contributed to the overall EMC problem.

5.2.3.4 Lighting equipment

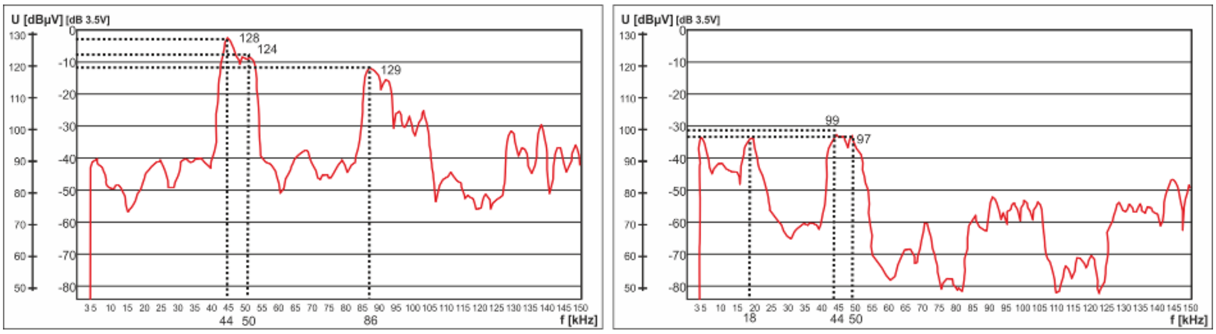
5.2.3.4.1 Energy efficient lighting

In Finland, an AMR concentrator at a transformer station could not communicate with all the meters assigned to the concentrator as a result of disturbances caused by energy saving lamps installed at a public toilet next to the transformer station.

5.2.3.4.2 Fluorescent lights

In late December 2011, in a Swedish supply area, the AMR system lost contact with 8 out of 109 electricity meters connected to the substation [84]. As the reason for this interference four fluorescent lights (2 x 36 W) have been found.

Spectrum analysis of this interference, which was constant when luminaires were lit, showed quite high emissions in the frequency ranges around 47 kHz and 86 kHz, which exceeded the limits of EN 55015 [31]. Figure 51 shows the spectrum before and after installation of an EMC filter on phase L1, where the highest emissions were measured. Measurement at the substation showed that the interference was not sufficiently high to reach the substation.



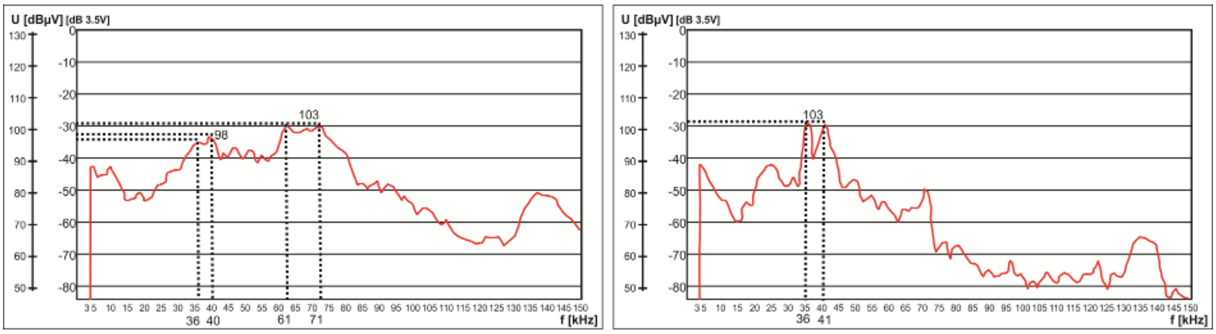
a) Without EMC filter b) With EMC filter

Figure 51 — Emissions from fluorescent lights at incoming cable, Phase L1

After installation of an EMC filter all meters communicated with the system again. Anyhow, the remaining emission levels up to 98 dBµV (Figure 51b) are still higher than what shall be expected as intentional signal level of an MCS along the line and by far higher than the limits for spurious emissions from MCS in the operational frequency band.

5.2.3.4.3 Emergency lighting

In a Swedish supply area, beginning of 2012, the AMR system lost contact to 55 out of over all 315 electricity meters connected to the substation [85]. The cause of this interference was found with two emergency lights, having caused emissions on the incoming power cable with the highest peaks at around 61 kHz to 71 kHz and with values up to 103 dBµV (Figure 52 a)).



a) Without EMC filter b) With EMC filter

Figure 52 — Emissions from an emergency light at incoming cable, Phase L1

After installation of an EMC filter, reduced disturbance values were measured in the upper frequency range, but the peaks in the frequency range below 50 kHz still exceeding the emission limits of EN 55015 [31] (see also below). Further, the following facts appear as being remarkable:

– While the EMC filter has reduced the emissions above some 45 kHz, for lower frequencies, like around 36 kHz and 40 kHz, the emissions were somehow increased (103 dBµV instead of 99 / 98 dBµV) (Figure 52 b)).

– The interference from the emergency light was constant even when run in battery mode.

5.2.3.5 Other EMI sources and impacts

5.2.3.5.1 Fibre switch

In a Swedish EMI case, 89 electricity meters (~ 94 %) out of 94 lost communication with the AMR-PLC system. Related measurements located the interference source to be a new fibre switch (Figure 53) in the power company’s own broadband facilities in a substation [86].

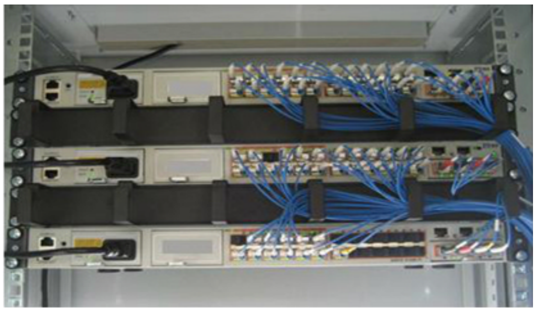


Figure 53 — Fibre switch in a broadband cabinet in a substation

With similar spectra over the three phases, the emissions measured in the substation showed several peaks, with highest values on L1, at ~95 kHz (112 dBμV) and at ~18 kHz (104 dBμV) (Figure 54).

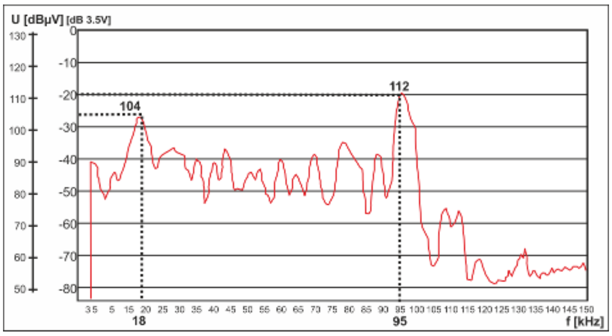
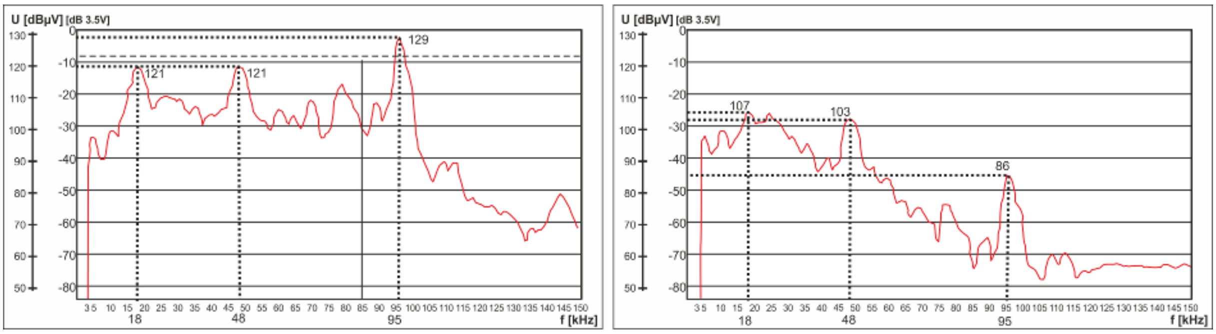


Figure 54 — Emissions from a new fibre switch in a substation (Busbar, Phase L1)

Measurement of the emissions in the substation at the outlet supplying the switch, on phase L1 again, showed even higher peaks at 95 kHz, with 129 dBμV, and at 18 kHz, with 121 dBμV, as well as an additional remarkable peak at ~48 kHz, also with 121 dBμV (Figure 55 a)).



a) Without EMC filter **b) With EMC filter**

Figure 55 — Emissions from a new fibre switch in a substation (outlet supplying the fibre switch, phase L1)

After mounting a single-phase EMC filter at the outlet supplying the fibre switch, the spectrum showed lower emission levels, with an attenuation of around 15 dB in the lower frequency range and of 10 dB to more than 40 dB above 50 kHz (Figure 55 b)).

Then, all meters communicated properly again.

5.2.3.5.2 Signal attenuation by IT equipment

In 2009, the Swedish National Electrical Safety Board (Elsäkerhetsverket) reported about several problems having been caused by switch-mode products such as frequency inverters for speed control of motors in fans and pumps, power supplies and fluorescent lamps with high-frequency ballasts [1a], [65].

In their reply to an Enquiry of CENELEC SC 205A, Elforsk[7)] [87] reported about one case with failed communi-cation between meters and concentrator which was located near the public distribution transformer.

Investigations showed that a server used by a customer (in a school) caused attenuation to the communication signal in the CENELEC A band [26]. Following to that, sometimes all meters in one LV sub-station area have been unreachable; at other times only a few meters failed to communicate.

Mitigation was realized by moving the server to a different phase, what reduced the attenuation for the communication signal sufficiently for ensuring proper communication.

As also described in [17], loads like household appliances can form a low impedance path for signals in this frequency band.

The theory, that end-user equipment can form a low impedance path for currents in the frequency band between 9 kHz and 95 kHz has been tested in the laboratory at EMC on SITE, Lulea University of technology. It has been found that for frequencies between 9 kHz and 95 kHz the total impedance seen from the communication device depends strongly on the loads connected to the grid.

It was found that different loads had an impact on the impedance level of the channel and thereby the propagation of the high frequency current. As is described, in interaction with a strong EMI source, a non-linear load can pollute the entire frequency band between 9 kHz and 95 kHz, assigned for operational communication for and over the LV supply network.

Indeed, such EMI is not caused by emissions. Nevertheless it is an interference caused by some electrical equipment to another one, in this case caused by the effect of the impedances of all equipment being connected to a certain supply area and effecting to the intentional signal currents/ voltages of an MCS and therefore, by nature, quite varying with time (see also 3.1 and 3.4).

5.2.3.5.3 Circuit breaker

Without an effect to the power quality, during manual operation of a 400-A-circuit breaker, temporarily there occurred a disturbance to the communication with the meters of an AMR-PLC system. As a reason, small arcs during operation of the circuit breaker, generating a noise from 20 mV (86 dBµV) to 100 mV (100 dBµV) were assumed to be recognized.

5.2.4 EMI to medical equipment

5.2.4.1 General

With regard to the indispensable correctness of medical equipment's function and the finding that also in standards related to medical equipment no specifications are provided concerning the specific characters of the frequency range 2 kHz to 150 kHz, investigations have been made also on EMI to such equipment.

5.2.4.2 Ultrasonic equipment

Interference effects to the monitor of a diagnostic cardiological ultrasonic equipment led to investigations, whether these EMI would be caused by an MCS being operated in the related supply area [88].

It was recognized, that another, CE-marked monitor, which was connected to the same point of common coupling (PCC), had caused these EMIs, by emissions in the MHz-range. Additional tests showed, that the monitor figuring as the interference source did not conform with the EMCD.

Another monitor of identical construction as the interfering one showed no emissions of this kind in the frequency range 150 kHz – 20 MHz, and the previously observed interference did not occur.

7) Svenska elföretagens forskning och utveckling AB.

When operating the PLC system at the considered PCC, with higher signal levels than the previous emissions from the monitor, no such EMI could be recognized in the frequency range 30 kHz to 90 kHz.

It is assumed, that

- the signal voltages with frequencies below the ultrasonic range are not relevant for related interference;
- the emissions from the interfering monitor were caused by an ageing effect of a filter component.

5.2.4.3 Electrocardiograph (ECG)

A test with an ECG in Austria showed a small impact of a PLC signal to the quality of displayed graphs, although no deterioration to the diagnostic evaluation of the electrocardiogram and therefore no functional loss occurred.

5.2.5 EMI to earth leakage circuit breakers (ELB)

A specific EMI case relates to the very low part of the considered frequency range: 2 kHz to 9 kHz. From Japan, EMI cases are reported with ELBs, which showed malfunction due to overvoltages in the frequency range 2 kHz – 9 kHz [55]. Due to these overvoltages, overvoltage protection was activated by the super-imposed high-frequency voltage disturbance, and supply interruption occurred.

The primary interference source was recognized as being household appliances, having a switching circuit to control its operating voltage, with operating frequencies in the range from 2 kHz to 9 kHz. The voltages at the switching frequency as well as on its harmonics were amplified by the capacitive impedances of other devices connected to the related installation. Resonances in this LV supply system led to an increase of the supply voltage by up to 35 % above the value in normal condition.

Mitigation of this EMI was realized by a redesign of the household appliance having represented the interference source, for reducing the disturbing current emissions.

With regard to the lack of standardized emission limits for the related frequency range, considerations are being made in Japan to establish a related Technical Specification (TS).

5.3 EMI due to radiated field strength from conducted emissions/signals

5.3.1 Broadcast time-signal systems

In Austria, several network users complained about malfunctions of their radio clocks and broadcast time-signal-based heat controls. Related EMI cases occurred at different locations, with partial loss of receipt or wrong time base (error up to several hours) for the clock or control circuits of systems like a heating system [89].

At least three options are given for the cause of an interference with the signal of a broadcast time-signal system (here: a DCF77 system):

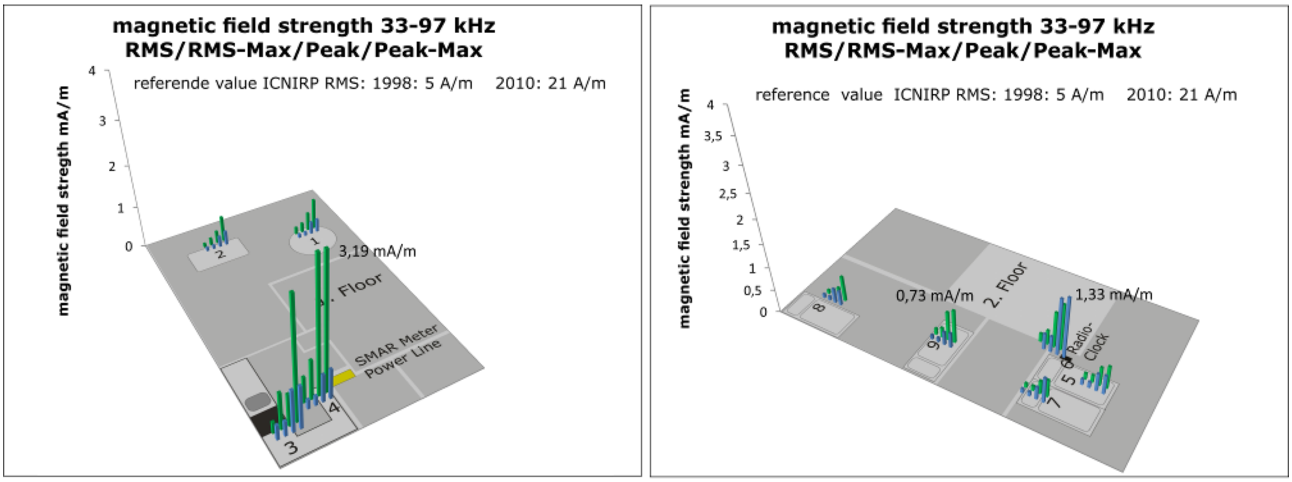
1) the field strength received from the DCF77 transmitter is below the receiver threshold;
2) conducted NIE or MCS-signals are interfering to the DCF77 receiver;
3) received field strength from DCF77 transmitter still above the receiver threshold, but a magnetic field strength due to conducted emission currents from other sources overlapping and causing a malinterpretation of the DCF77 signal telegram.

Concerning an EMI case with malfunction of a DCF77 clock, measurements of the magnetic field have been made in the frequency range 33 kHz – 97 kHz on two floors of a one-family house,

- on the 1st floor, where the smart meter was installed;
- on the 2nd floor, where a DCF77-radio clock was operated.

one time with the MCS in operation and the other time with the MCS switched off.

Operation of the radio clock with battery supply proved that option b) was not applicable.



a) 1st floor, where the meter was installed **b) 2nd floor**

due to PLC signal measured without PLC signal

Figure 56 — Magnetic field strength, measured on two different floors

These investigations showed, that

a) as having been proved already with battery-operation of the radio clock, no interference due to conducted emissions was given;

b) magnetic field strengths due to signal currents from an MCS close to the electricity meter, mains supply lines or household equipment, measured with values from 100 µA/m to 3,19 mA/m rms max overlapped the field strength of the local radio signal from DCF77, measured with 3 µA/m – 5 µA/m;

c) due to the magnetic field strength following to the PLC signal:

   1) either the DCF receiver cannot (sufficiently) recognize the DCF signal, or

   2) the DCF receiver receives a mixture of a low DCF-signal level and of a field strength due to a higher current component from the mains, what may lead to an erroneous interpretation of the DCF signal telegram and with that to a wrong processing of this telegram for a time information.

In any case, the reported malfunction:

– was not caused by a conducted interference mechanism;

– may be caused by any current somehow close to the frequency of a broadcast time-signal system – that not only relating to DCF77 (see also 5.3.1);

– is dependent on the geographical and topographical situation of the site concerning reception of a radio service for time-signals, in the considered case of DCF77.

Concerning the protection of broadcast time-signal systems see 7.1.5. A precise specification for minimum field strength for the DCF77 time signal is lacking; this would depend on the desired operational area of the system which is not clearly defined.

Regarding the expected field strength for DCF77, the operator, Physikalisch-Technische Bundesanstalt (PTB) gives some hints on his website [90].

Up to a distance of around 500 km between the receiver and the DCF77 transmitter near Frankfurt a field strength of 1 mV/m or above can be expected from the surface wave propagation. Of course, the value at a specific location also depends on the local situation, e.g. influenced by the geographic environment and the position within a building.

Due to similar strength of surface and ionospheric wave propagation in distances between 600 km and 1 100 km the resulting field strength varies according to possible additive or subtractive combination of both paths, depending on their relative phase angles. As these are not constant, the field strength can go up and down slowly.

Above 1 100 km distance, wave propagation is no longer relevant, almost constant field strength can be expected. In the area up to 2 000 km distance to the DCF77 transmitter levels of 100 µV/m or above are realistic.

According to the website of PTB the signal strength that is expected at distances up to 2 000 km is “sufficient for typical DCF77 receivers”. Looking at examples for DCF77 receivers and related data sheets from manufacturers’ websites, values of 30 µV/m can be found for minimum field strength. These values correspond to the assumption of PTB.

The distances within the borders of Germany to Frankfurt are slightly higher than 500 km, resulting in field strength of around 1 mV/m or above there. Austria is located also in a distance of around 500 km, but due to the hilly terrain larger attenuation of the signals might be present. For application of DCF77 within the entire European area, the full range of receipt levels and receiver sensitivity were to be considered.

Data about the selectivity of the receivers and susceptibility for disturbing signals at the receiver frequency or at a nearby frequency was not available.

Conversion from electric to magnetic field strength is possible for idealized free-space propagation in far field conditions by dividing through the wave impedance Z_0 that is approx. 377 Ω. The above mentioned value 1 mV/m calculates to approx. 2,7 µH/m that is slightly below but close to the values that were measured in Austria for the DCF77 signal as shown above.

In real environment a precise conversion between electric and magnetic field strength is almost impossible due to influence of surrounding material and the large wave length of the signal. Large deviation from the ideal case might occur.

5.3.2 EMI with a contactless magnetic card reader

A Japanese report describes an EMI case, where a contactless magnetic card reader lost its reading function due to the radiated magnetic field from an UPS [20]. The card reader was installed closely to the UPS of another network user, separated only by a wall (Figure 57).

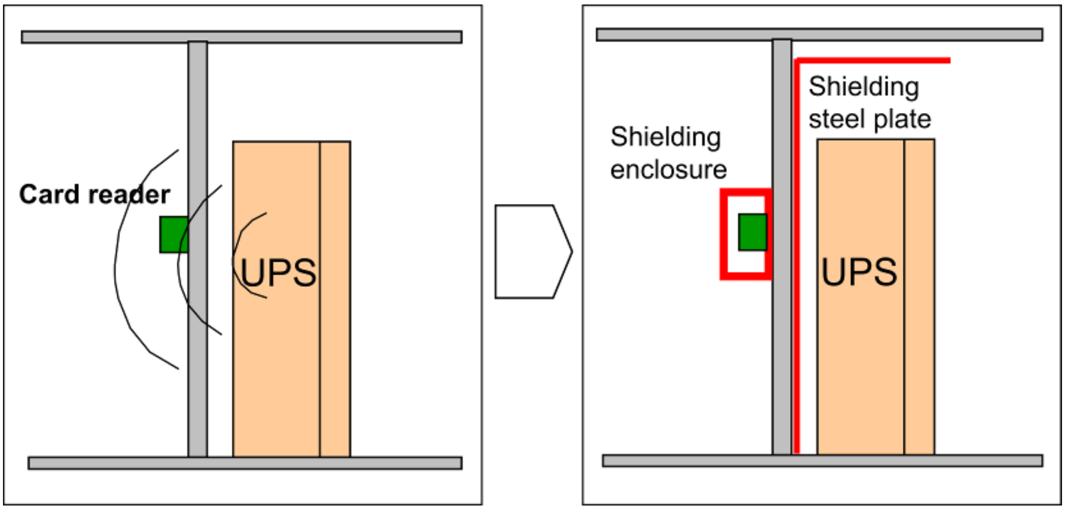


Figure 57 — Magnetic card reader and UPS

The IGBT of the 50-kVA-UPS operated with a switching frequency of 8 kHz, while, with 15,6 kHz, the operating frequency of the card reader was close to the 1st harmonic of the UPS’ switching frequency.

Mitigation was achieved by shielding both equipment, actually by installing a shielding enclosure around the card reader and a shielding steel plate behind and above the UPS.

5.3.3 EMI with mobile radio receivers

Another EMI case with interference via the radiated magnetic field was described from Japan, with EM noise from different devices in a substation getting radiated from the overhead MV supply network and interfering with the radio reception in a car [20].

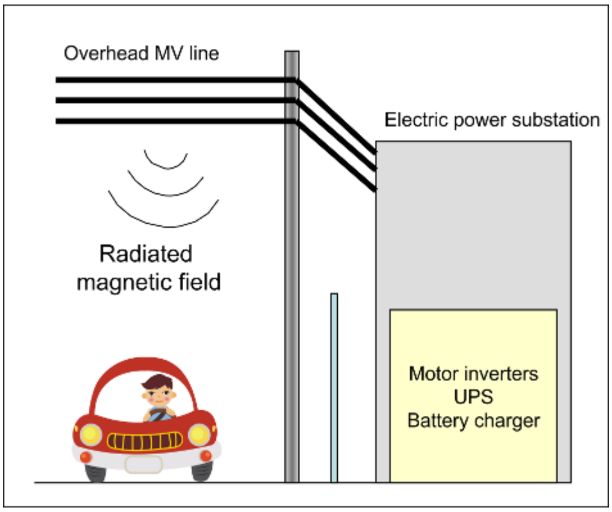


Figure 58 — Interference with mobile radio

Mitigation was achieved by setting EMC filters or ferrite cores at the output terminals of the disturbance emitting equipments in the substation.

5.3.4 EMI with a traffic control system

Another EMI case, with interference with a traffic control system via the radiated magnetic field from switching currents from a UPS, was described in a Japanese report [55]. Figure 59 shows the situation and highlights the interference mechanism.

A traffic control system is operated with a UPS, with a rated power of 10 kVA, a BiMOS transistor as the switching device and a switching frequency of 15,6 kHz. The UPS' enclosure is grounded as is also one line at transformer's LV side. The radio frequency of the control system is close to the 5th harmonic of the switching frequency of the UPS.

The UPS' switching noise

– generates currents on switching frequency and its harmonics flowing from the grounded UPS enclosure through the earthline and through the grounding of the secondary side of the trans-former, thus causing a disturbing magnetic field,
– causes direct radiated interference to the antenna, resulting in an interference with the signal received from the buses.

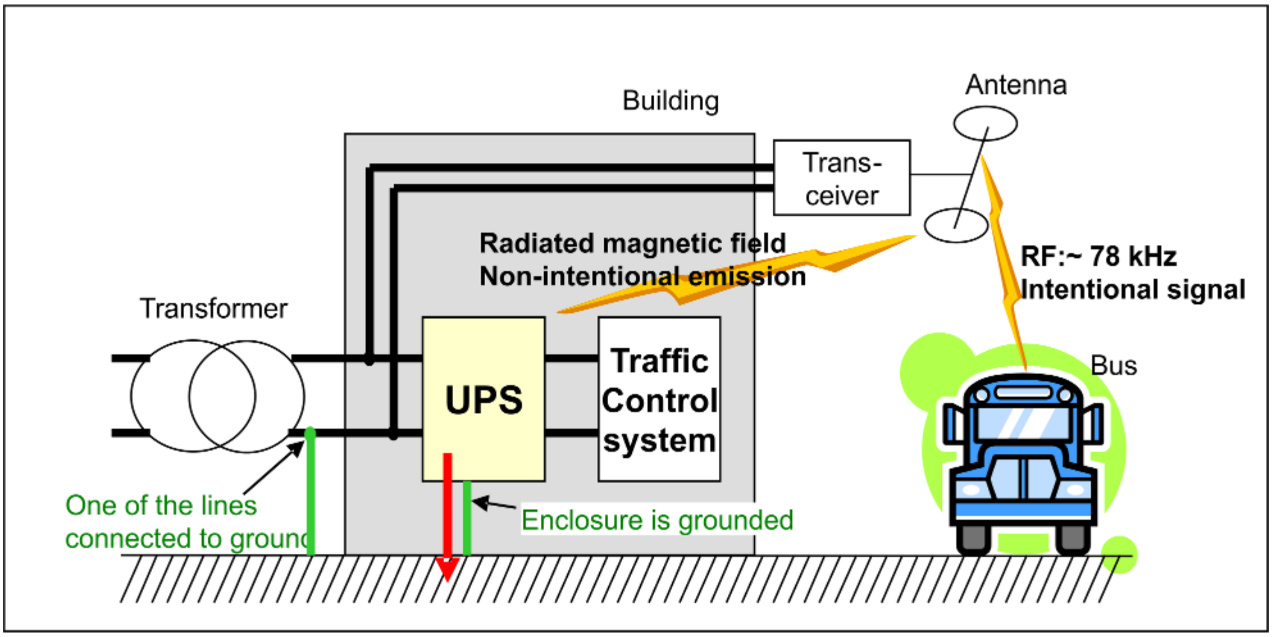


Figure 59 — EMI to a traffic control system

Mitigation was realized by inserting a ferrite resistor into the earth line from the enclosure.

5.3.5 Relation field strength: Conducted current emissions

Based on significant data having been collected regarding the conducted and radiated field values observed on numerous buildings from around the world, field trials have been made by the Power Line Communications Systems Research Group of the Open University, Manchester.

Analysis of the results has demonstrated that contrary to a direct correlation between the radiated field and the magnitude of the CM current there appears to be little correlation between the circuit LCL and the circulating CM current. This may demonstrate why previous research has failed to indicate any direct use of the LCL measurement in determining radiated field strength.

5.4 Summary

Taking into consideration the overall number of electrical equipment on the market/in operation, a relatively small percentage of it appears as being involved in related EMI cases, that indicating, that in the absence of related normative specifications, the major part of electrical equipment:

– sufficiently meets immunity requirements;

– does not generate emissions resulting in EMC problems.

However – apart from the technical point of view – the known EMI cases shall be considered from the following perspectives:

a) Only a small percentage of occurring EMI cases get known, through complaints by network users, so that the overall number of occurring EMI cases will be quite higher;

b) The known cases show:

    1) some thread for EMC and the proper function of a broad spectrum of devices in general and

    2) that high NIE in the frequency range 2 kHz to 150 kHz, without consideration of MCS, might jeopardize a safe roll-out of smart metering and smart grid projects. Upcoming new circuit technologies like for inverters, e.g. intended to be applied for DGU, may generate emissions which could even exceed signal limits having been standardized more than two decades ago.

Measurements and investigations show:

c) Irrespective of electrical equipment being legitimately CE-marked or not, EMI cases do occur, also due to a lack of standardized specifications for emissions and immunity.

d) Different sorts of equipment are involved in related EMI cases, as a source or victim of interferences, what may justify to set related EMC (emission, immunity, compatibility) standards and to review related Product standards.

e) Not every complained event, which appears as representing an EMI case with conducted background in the frequency range 2 kHz – 150 kHz, has its background in EMI in that frequency range. Careful investigations on and evaluation of such events are necessary.

f) Radio transmission of time-signal systems like DCF77 in Europe are operating in the considered frequency range without standardized specifications concerning S/N and minimum reception level for normal operation. Generally, in areas where MCS are operated or NIE are generated around the DCF77 frequency, loss of function or maloperation in the vicinity of electrical lines/equipment may occur. With increasing distance from the transmitter station, this issue becomes more sensitive, requiring also consideration of the installation location/situation of a DCF receiver. In case of low DCF signal levels on site several meters of distance to electrical lines/equipment is required for safeguarding normal operation.

g) Proven EMI cases show above all EMI potential with:

h) maloperation of different electric equipment due to discontinuous NIE from general electric equipment as well as from intentional MCS signals:
    1) wrong metering data due to NIE from different electric equipment;
    2) MCS maloperation due to insufficient margin from NIE to PLC signals;
    3) MCS maloperation due to the combined effect of NIE and the combined effect of different loads;
    4) maloperation of broadcast time-signal systems or electronic circuits controlled by such time-signals, due to the influence of MCS signal voltages/currents or of magnetic field strengths due to conducted emission currents (see 5.3).

i) Need for a careful assurance of co-existence between MCS and NCE, by considering sufficient margins between NIE and intentional signals (level-coordination), for covering uncertainties like changing load impedances, cumulative effect of emissions.

j) EMI problems caused by network users' equipment to MCS seem to occur in a few percent of the installed meters. That would be conform with a previous finding reported by The Netherlands [1a].

k) EMI problems caused by network users' equipment to PLC are more common than EMI problems caused by PLC to network users' equipment.

l) Common causes of communication problems in energy meter PLC have been variable speed drives (VSDs), lamps equipped with electronic ballasts and single phase devices with switch-mode power supplies.

m) Due to:
    1) the time-varying disturbance behaviour on the supply network in the considered frequency range;
    2) lacking regulation/standardization on the issue,

   successful operation of MCS in the commissioning stage does not guarantee that it will be given also in future.

n) As potential basic causes of related EMI problems there were identified:
    1) ageing of components in network users' devices;
    2) installation flows, in particular in VSDs;
    3) impact on the propagation of communication signals due to low impedance seen from communicating devices in the frequency band 3 kHz to 95 kHz. Time varying low impedances are due to electronic loads, VSD or AIC connected to the grid;
    4) devices, which contrary to the given declaration of conformity with the ERs of the EMCD, did not meet these requirements;
    5) lack of emission limiting standards as well as of comprehensive consideration of the specific EMC characteristics in the frequency range below 150 kHz in immunity standards.

6 Standardization for the frequency range 2 kHz to 150 kHz. Conformity and time

6.1 Standardization situation

According to:

– what is said in Clause 3 about the actual application of technologies for electric and electronic products and the factually changed situation of supply network use,

– the last actual recognitions about EMI in the frequency range 2 kHz – 150 kHz,

the standardization scenario shall be considered with regard to:

– the development of technology application;

– NCE and communication products.

In Study Report I [1a], some twenty standards which might be relevant for EMI in this frequency range have been analyzed concerning its actual relevance and its potential to ensure EMC with regard to these interference ([1a], item 6), with emphasis on EMI between AMR-PLC and TDLs.

With regard to the 'increasingly acknowledged' fact, that EMI in the frequency range 2 kHz to 150 kHz is not focussed on AMR-PLC or Smart meters / Smart grids, as it may have appeared at first sight, but covers a quite larger spectrum of electrical equipment, as an EMI source or victim, in the following, the overall situation in standardization concerning this frequency range, applicable for such EMI cases, is highlighted.

Figure 60 shows the actual standardization situation for the frequency range 2 kHz – 150 kHz concerning emission limitation & values and power quality (PQ) levels.

NOTE With regard to the ongoing standardization process on the issue, it may be noted, that the current status of the standards indicated below can be obtained by reference to the national committees.

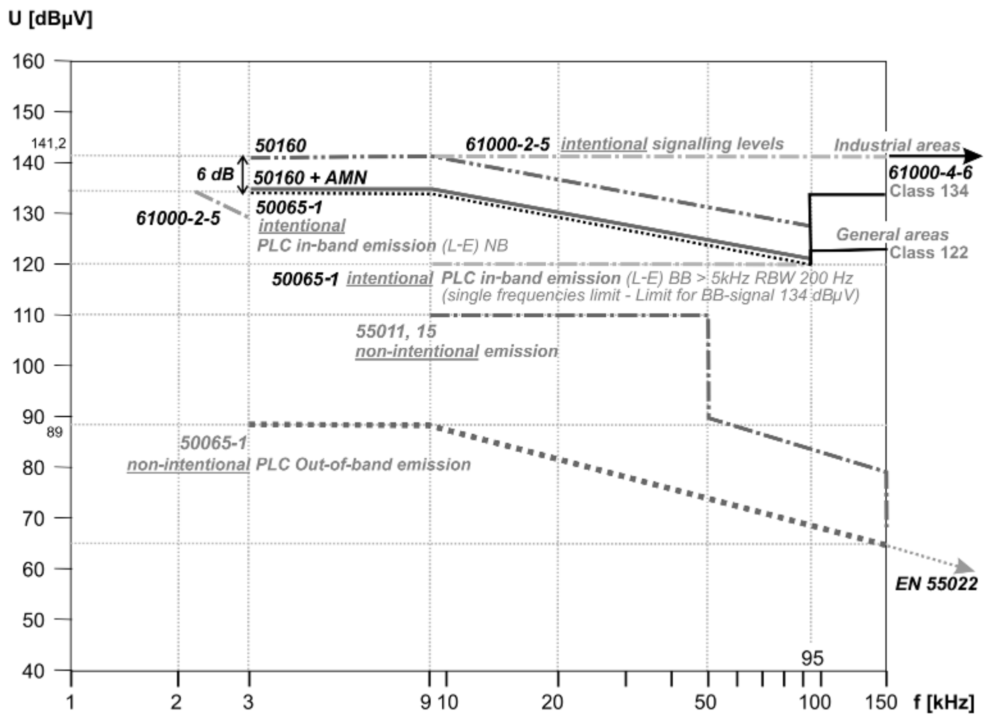


Figure 60 — Standardized emission limits & values and PQ levels for the frequency range 2 kHz – 150 kHz

As can be seen, at present **emission limits** are set only for:

– NIE from lighting equipment (EN 55015) [31];

– NIE from induction cooking equipment (EN 55011) [30];

– intentional signals from mains communicating equipment (EN 50065-1) [26];

– non-intentional (spurious) emissions from MCS [26].

Some description of intentional signals from MCS, providing information about levels for signalling voltages in power systems and frequency ranges, is also given in IEC/TR 61000-2-5 [91]; IEC/TR 61000-2-1 [92] provides general information on MCS including also the possible influences of network disturbances – at that time of publication (1990) focussing on harmonics and interharmonics.

Proposals for setting emission limits – see e.g. [65] -- have not been considered in standardization up until now.

In March 2012, an initiative has been started by IEC/TC 22[8)] to establish emission limits for an additional product, Active Infeed Converters (AIC); that was intended to be done in the course of the revision of IEC/TS 62578 Ed.1 [46]. Document 22/199/CD [46a] proposed the recommendation of emission limits for AICs, for three application environments according to categories C1 – 3 defined in the Product Standard EN 61800-3 [94] for PDS of rated voltage < 1 000 V.

- C1: intended for use in the first environment, i.e. domestic premises, including establishments directly connected without intermediate transformers to a LV power supply network which supplies buildings used for domestic purposes;
- C2: which is neither a plug in device nor a movable device and, when used in the first environment, *is intended to be installed and commissioned only by a professional*;
- C3: intended for use in the second environment, that including all establishments other than those directly connected to a LV power supply network which supplies buildings used for domestic purposes, and not for use in the first environment.

Figure 61 shows the emission limits proposed with document 22/199/CD, in relation to the up until now existing emission limits & values and PQ levels.

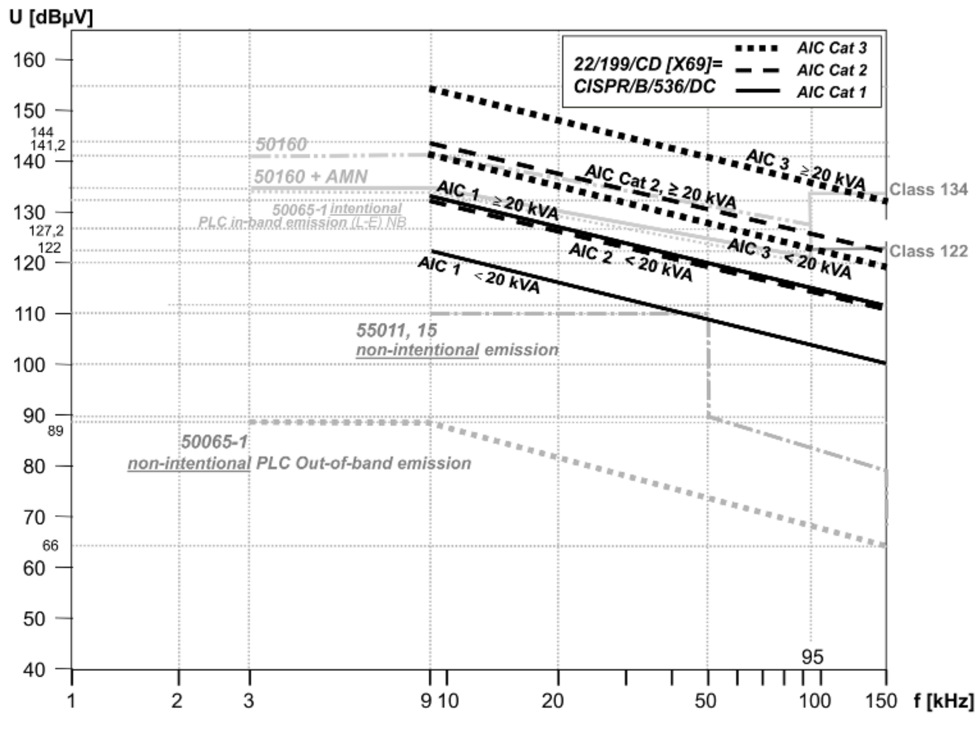


Figure 61 — Proposed emission limits for AICs ([46a])

8) TC 22: Power electronic systems and equipment.

This draft has been circulated also by CISPR/B[9)] as CISPR/B/536/DC [46b], for National Committees' (NC) comments.

Based on 8 responses received, the result showed one NC being in favour, three ones objecting with regard to the high proposed emission limits and four NCs drawing attention to compatibility needs with existing systems like MCS and time–signal systems.

In February 2013, a modified draft has been submitted for vote on a Draft Technical Specification (DTS). With this document 22/211A/DTS [46c], instead of emission limits, emission values have been proposed as design recommendations, which should be considered by manufacturers of AICs; these draft specifications consider somehow lower values for the different application environments as well as an increasing rate of reduction for frequencies above 50 kHz. Figure 62 shows the proposed design recommendations for AICs categories 1 to 3 according to EN 61800-3 [94] related to emissions.

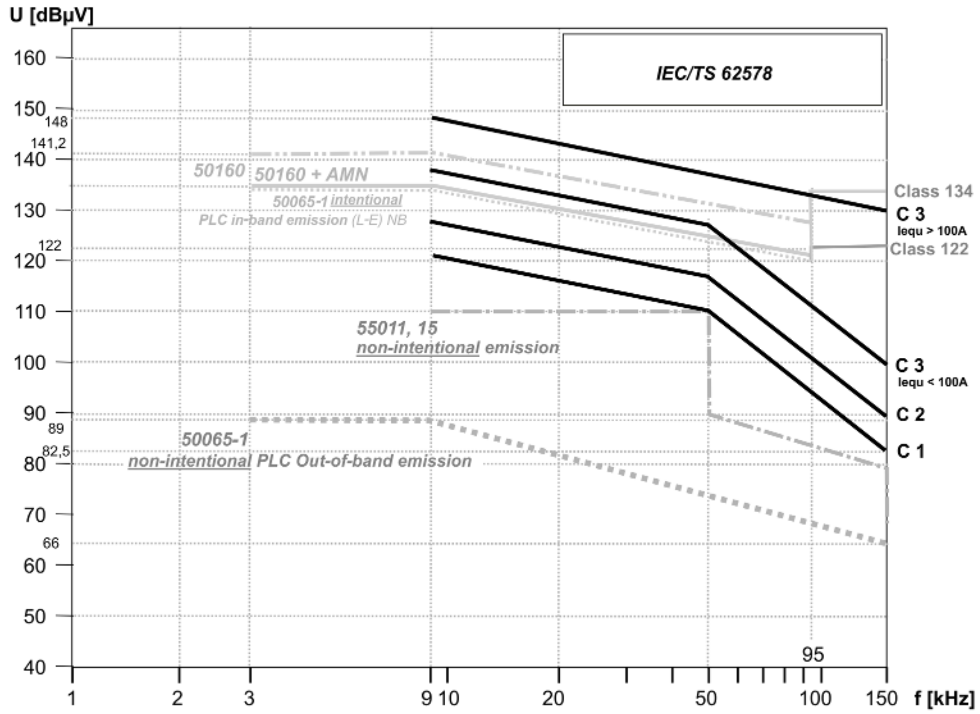


Figure 62 — Emission values proposed by TC 22 for AIC design ([46])

1st environment	domestic premises, including establishments directly connected without intermediate transformers to a LV power supply network which supplies buildings used for domestic purposes Examples: Houses, apartments, commercial premises or offices in a residential building
2nd environment	environment that includes all establishments other than those directly connected to a low voltage power supply network which supplies buildings used for domestic purposes Examples: Industrial areas, technical areas of any building fed from a dedicated transformer

9) CISPR: Comité International Spécial des Perturbations Radioélectriques
CISPR/B: Interference relating to industrial, scientific and medical radio-frequency apparatus, to other (heavy) industrial equipment, to overhead power lines, to high voltage equipment and to electric traction.

Based on the proposed emission limits – now: values -- for AICs, some discussion on:

- the utilization of the frequency range 2 kHz to 150 kHz by electrical equipment in general;
- the protection of MCS with its intentional signalling on frequencies according to EN 50065-1 [26] to NIE from other equipment

with position papers and contributions from IEC/CLC TC 13[10)], TC 22, TC 57[11)], CLC SC 205A, Eurelectric[12)], ESMIG[13)], SM-CG[14)] as well as ACEC[15)] and SMB[16)], has been started, thus also having some impact on the work on setting compatibility levels for the considered frequency range.

From the point of view of lacking emission limits for most types of products and with regard to the relevance of basically high emission levels from AICs, such an emission limitation may appear as some progress. On the other side, the proposed values for NIE from AICs appear as not being compatible with signals from MCS, thus having potential to jeopardize the intended operation of such, as having been proved also with some lab test (see 4.5.3).

After document 22/211A/DTS having failed the vote, in March 2014, TC 22 circulated another Draft Technical Specification, IEC 22/235/DTS [46d], with all EMC specifications, actually (unmodified) emission values recommended for consideration when designing AICs, having been moved to an Informative Annex, which was approved.

Besides some partial specifications in Product standards, not covering the whole area of EM phenomena in the frequency range 2 kHz – 150 kHz, immunity requirements have been specified for MCS only, for a long time – for the three application environments of residential, industrial and electricity supply environment [33] – [35].

Several proposals for setting immunity requirements as well as emission limits – see e.g. [65], [95] – provide information about possible completion of standardization.

In 2012, CLC/TC 13 published a CLC/TR 50579 [2] on immunity testing**,** thus making available a first specification comprehensively considering needs for immunity to conducted disturbances, for the specific product electricity meters. That also in reaction to some upcoming consciousness of EMI relevance in the considered frequency range to electronic meters and discussion on related critical remarks concerning degradation of metering performance by SWEDAC[17)], in their Report [19] (see also 5.2.2).

Concerning compatibility levels, the recent versions of EN 61000-2-2 [29] (for LV supply networks) and EN 61000-2-12 [96] (for MV supply networks) cover only signalling, and within that signals from ripple control systems (110 Hz to ~ 3 kHz; Meister curve), while further signalling systems (3 kHz – 20 kHz, 20 kHz – 148,5 kHz) are still mentioned as being under consideration.

Besides the lacking coverage of mains signalling with compatibility levels, at present no specification in this standard is dedicated to EM phenomena in the frequency range 2 kHz to 150 kHz in general.

As having been recommended by Study Report I [1a], following a related task given by SMB, IEC SC 77A/WG 8[18)] is reviewing the standards EN 61000-2-2 [29] and EN 61000-2-12 [96] for setting compatibility levels for the frequency range 2 kHz – 150 kHz; that facing several problems with regard to the factual utilization of the frequency range by several types of equipment (see 3.2, Clauses 4 and 5), mostly not being limited in its emissions by any standard at the time – that likewise as related immunity standardization is limited as previously described.

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10) IEC/TC 13: Electrical energy measurement, tariff- and load control;
CLC/TC 13: Equipment for electrical energy measurement and load control.

11) TC 57: Power systems management and associated information exchange.

12) Eurelectric: The Union of the Electricity Industry.

13) ESMIG: European Smart Metering Industry Group.

14) SM-CG: Smart Metering Co-ordination Group, reporting to CEN-CENELEC-ETSI and in charge of answering the M/490 mandate.

15) ACEC: IEC Advisory Committee on Electromagnetic Compatibility.

16) SMB: IEC Standardization Management Board.

17) SWEDAC: Styrelsen för ackreditering och teknisk kontroll (Swedish Board for Accreditation and Conformity Assessment).

18) 77AWG8: Description of the electromagnetic environment associated with the disturbances present on electricity supply networks.

With regard to the ongoing work in IEC/SC 77A/WG 8 and 6[19]:

a) ACEC/SMB, CISPR and CLC:TC 210 are expectant the setting of acceptable compatibility levels, as a basis for future consideration of related completion of their standards;

b) with regard to the recognitions from this Techncial Report and considering the work results of SC 77A/WG 6 and WG 8:
   1) CLC/SC 205A envisages a related review of the EN 50065-2 series [33] – [35];
   2) CLC/TC 8X envisages a related completion of the power quality standard EN 50160 [97].

In 2013, emphasizing the need for standardized compatibility levels, as a basis for the future setting of emission limits and immunity requirements, ACEC/SMB has set some targets for IEC SC 7A WG 8, requiring amongst others the provision of a first draft by end of 2014

Measurement and test methods were specified concerning immunity from conducted -- up until now only -- asymmetrical disturbances in the frequency range 0 kHz – 150 kHz (EN 61000-4-16 [32]) for:

– continuous and short-term CM voltages at the frequency of the electricity supply;
– short-term CM voltages at the frequency of the electricity supply;
– continuous CM voltages;

over the frequency range 15 kHz to 150 kHz, but not providing any immunity requirement:

– for continuous differential mode voltages;
– for discontinuous voltages in common and differential mode for the frequency range below 150 kHz, like EN 61547 [98] (being solely applied for conformity testing of TDLs).

When starting the closure of the recognized gap in standardization, besides work on setting compatibility levels, IEC/SC 77A/WG 8, also IEC/SC 77A/WG 6 started work on a standard for immunity testing to differential mode disturbances, which specifies tests on immunity to conducted, differential mode disturbances and signals in the frequency range from 2 kHz to 150 kHz, thus as a completion opposite to EN 61000-4-16 for CM. The related EN 61000-4-19 [99] has been approved and published in 2014.

Already with regard to its scope – “conducted immunity requirements of electrical and electronic equipment to electromagnetic disturbances coming from intended radio-frequency (RF) transmitters in the frequency range 9 kHz to 80 MHz” – somehow more restrictive than the title “Immunity to conducted disturbances, induced by radio-frequency fields”, EN 61000-4-6 [100] is not applicable for EMI due to emissions coupled from a line via the radiated H-field.

Moreover, in Clause 6 of this standard tests “for induced disturbances by electromagnetic fields coming from intentional RF transmitters in the frequency range 9 kHz to 150 kHz” are stated as not being required.

Therefore, at present no test standard for immunity testing on differential-mode emissions is available.

Finally, the change in using the electricity supply network with new technology equipment/systems is followed also by some power quality challenges in the distribution network [101]. As can be seen in Figures 1 (4.2.7, for LV) and 2 (5.2.7, for MV) of EN 50160:2010 [97], concerning the considered frequency range, this PQ standard provides only signalling voltage levels per carrier frequency for a frequency range up to 95 kHz, which shall not be exceeded in public power supply network; so, related limits are provided related to the MCS signals, actually its carrier frequency only:

– without covering NIE in the frequency 2 kHz to 150 kHz,
– without considering the specific characteristics of voltages/currents in the frequency range 2 kHz to 150 kHz like waveshapes and coupling method,
– without covering the frequency range 95 kHz to 150 kHz at all.

Related completion of EN 50160 (see also the actual Application Guide to EN 50160 [97]), Annex A, has been envisaged by CLC/TC 8X/WG 1[20].

19) 77AWG6: Low frequency immunity tests..

20) TC 8X: System aspects of electricity supply;. WG1: Physical Characteristics of electrical energy.

Some problems arise due to products not being compliant with the existing standards. Ensuring compliance is considered an important first step to minimize EMI problems.

6.2 Conformity and time

As the investigation results described in this Technical Report, in particular concerning power supplies (see 4.6, 5.2.3.2) show, a problem appears to be given concerning the real behaviour of CE-marked electrical equipment in the supply network over time; that with regard to some change of the characteristics of components in electrical equipment after some time of operation.

Concerning EMC, with the CE mark there is ‘declared’ that an electrical equipment/system meets the ERs of the EMCD [14]. In fact, this declaration is related to the instant of performing the conformity test respectively of the declaration of conformity.

The market, with merchandisers, network operators and network users, trust in this CE mark, deducing from its presence, that the related equipment/system meets the (standardized) requirements for operability more or less without problems.

Change of characteristics of components applied in a certain device, over time -- be it due to a failure but, in particular, be it due to an ageing effect (see 5.2.3.2.11) -- may result in increasing NIE and, with that, network disturbances, thus possibly causing EMI to other equipment/systems. Such a development results in the fact that a related equipment/system, which has been legitimately CE-marked and – from the perspective of the valid rules for CE-marking – still validly bears the CE mark, on from some time does not further meet the ERs of the EMCD.

The EMI cases described in 5.2.3.2 and the statistics reported in 4.6.5 may convey an imagination of what kind of a sleeping problem appears as being arising with e.g. the lot of power supplies on the market; and the problem is not such one related to power supplies only.

From the aforementioned, it may be deduced, that attention should be dedicated to the choice of high-quality components, for ensuring an EMCD-conform operation of equipment/systems over time – to say: over the expectable lifetime of the device.

7 Options for improved safeguarding EMC

7.1 For equipment / systems in general

7.1.1 Filter application

Item 7.1 of Study Report I [1a] provided some explanation on possible mitigation measures on the basis of filters to solve EMI problems. As described there, mitigation by filtering:

a) may serve as an appropriate means for punctual case-by-case solutions, but appears as not being practicable without further ado nor being an economical solution for broader application.

   Anyway, filters applied to meet standardized requirements are today focused on frequencies above 150 kHz, without consideration of its characteristic below 150 kHz; therefore some need for filters designed with appropriate attenuation respectively blocking characteristic concerning NIE below 150 kHz and related standards defining related requirements would be given.

   Concerning blocking filters,

   1) test results with universal blocking filters for equipment showing problems for designing such filters with an appropriate ability to carry related currents without having knowledge of the single equipment
   2) its effect, making it impossible for an MCS signal to penetrate into the customer premises, for reaching single devices, such as information displays and major loads intended to be controlled for the network user,

   were to be considered.

b) needs to consider its effect on possible resonances or shunting effects (see 3.1), thus possibly realizing some EMC mitigation but at the same time causing loss of communication for an MCS operated in the same supply area.

As stated, for technical, comfort as well as economical reasons, filtering appears not to be the solution for broader application to ensure EMC in the considered frequency range.

In particular,

- when considering the overall problem for ensuring EMC in this frequency range and therefore proactive avoidance of EMI;
- with regard to the given situation of frequency utilization;
- taking account of the specific phenomena in this frequency range;
- facing the given problems when considering a concept for compatibility levels for this frequency range;

other options for safeguarding EMC in this frequency range may be needed to be considered; that amongst others based on relatively new concepts as e.g. a change from “flat limits and values” to specifications considering a concept taking account of the main needs for operation of certain equipment and/or the effect of waveshapes of discontinuous emissions.

In the following, some overview of other solutions for safeguarding EMC in the considered frequency range, different from filtering, is given; that:

- in 7.1.2 to 7.1.5 for equipment / systems in general;
- in 7.2 for PLC in particular.

7.1.2 Move from PLC to RF

With regard to the increasing field of EMC problems in the frequency range 2 kHz to 150 kHz and with the co-existence between NIE from electrical equipment and intentional signalling of MCS, MCS are sometimes challenged whether its application were conform with the very goal of using electricity supply networks.

Moreover, with reference to e.g. the US situation for information transmission for smart grids/meters, with a huge majority of wireless RF solutions, application of the same solutions is sometimes required for Europe.

In the US, the PLC solutions failed due to the quite different design of low voltage grids compared with European networks. As an example, a 10-kV-system supplies a 3-kV-grid feeding the single phase transformers providing 220/110 V to a rather small number of customers. PLC installation at 3-kV-level requires transmission via transformers with limited operating distance or expensive coupling components to the low voltage level.

Indeed, in Europe the related factual situation is quite opposite to the US, showing some 70 % – 80 % of AMR applications using PLC for transmitting the data from the meter to the utility’s EDP, the balance largely using mobile phone networks.

Further, on the one hand European people accepted mobile phones but on the other hand some people feel fear about RF installations like mobile phone base stations as well as GSM or UMTS modems. It happens during the smart meter roll-out, that customers are asking whether the new system were operating with any radio transmission. Those people are often more concerned about the RF-installation at the transformer station than about PLC or any other issues together with smart meters(SM).

7.1.3 Frequency allocation management

As described in 3.2, for Europe, according to EN 50065-1 [26], the frequency range 2 kHz to 150 kHz is designated to narrow-band MCS, for supply network purposes.

In 7.5 of ITU-T[21)] Rec. G.9955 [103]:

- containing “the physical layer specification for narrowband OFDM power line communications transceivers for communications via alternating current and direct current electrical power lines over frequencies below 500 kHz”,
- dealing with “grid to utility meter applications, advanced metering infrastructure (AMI), and other Smart Grid applications such as charging of electric vehicle, home automation, and home area networking (HAN) communications scenarios”,

21) ITU-T: Telecommunication Standardization Sector of ITU.

- supporting "indoor and outdoor communications over low voltage lines, medium voltage lines, through transformer low-voltage to medium voltage and through transformer medium-voltage to low-voltage power lines in both urban and in long distance rural communications",

ITU[22)] provides also related frequency band specifications; there, support of at least:

- one of the CENELEC bandplans ("frequency band between 3 kHz and 148,5 kHz allowed to be used for power line communications ……..."),

or

- one of the FCC[23)] bandplans ("frequency band between 9 kHz and 490 kHz allowed to be used for power line communications"),

is required.

With regard to the given situation for ITU region 1 (see also IEC/TR 61000-2-5 [91]), for Europe, application of frequencies out of the CENELEC bands is required.

As the investigation results described in 5.2.3 show, MCS are facing NIE from NCE, thus jeopardizing or blocking the proper function of MCS by EM interference, and therefore also the future-proof deployment of this technology for smart metering and smart grids purposes.

Up until now, the disturbing effect of NIE from NCE, generating conducted disturbances in the frequency range 2 kHz – 150 kHz, appears to not have been considered sufficiently in related standards or regulations. In particular, no compatibility levels are available as a general basis for the setting of emission limits and immunity requirements (see 6.1).

Extending the frequency range for MCS to an upper frequency of 500 kHz might be seen as a solution for interference-free operation of MCS, but as above-mentioned, is not possible for Europe at present (see also 7.1.5 and 7.2).

As the now started discussions on frequency utilization in the frequency range 2 kHz – 150 kHz (see 6.1) show, co-existence between MCS and other, NCE has become an issue, which will need to be solved. Besides safeguarding a sufficient level margin from NIE to signals, one of the options for a related concept could be to establish a frequency allocation management, separating frequency application for the two different types of emissions – intentional and non-intentional – in e.g. two part-ranges, thus considering the technical conditions of the different technologies and their emphases in frequency application.

For Europe -- not only, but also with regard to the political will for increasing deployment of smart grids/smart metering and more energy efficient systems (see e.g. [5] – [12], [104] - [113]) -- it appears as being advisable

- to review regulations on frequency allocation in particular in the frequency band up to 500 kHz to provide an improved basis for disturbance-free frequency use by communication systems – with consideration also of further existing broadcast as well as of NCE;
- to (re-) consider the protection of radio services and MCS operating on frequencies in the CENELEC bands (see 3.2 and 5.3.1) – e.g. by establishing regulatory rules, also considering cases of so-called near-far-problems (see 7.1.5).

Aside from the technical solution, a related concept would have to deal with the organizational aspect, i.e. the level on which related solutions would need to be established – European/international standards, international / European or national regulation.

7.1.4 Move to broadband lines

As another counter-argument to PLC as technology for information transmission, in particular for smart grids/metering purposes, sometimes there is argued, that broadband lines would easily cover the needs of such information transmission, and therefore realization of (narrow-band) PLC systems could be omitted. Basically, that would be technically correct, but were to be realistically evaluated in terms of available coverage of network users today and in the medium future.

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22) ITU: International Telecommunication Union.

23) FCC: Federal Communications Commission, USA.

With regard to the aforementioned challenges on PLC, the given situation for using the supply network for information transmission in comparison with meshed RF networks is highlighted and background for choosing PLC as the data transmission technology for smart grids/metering is explained from the European point of view.

As a consequence, it can be summarized, that:

a) PLC technology is used for operational purposes of electricity suppliers since decades, with developing technological steps in detail;
b) PLC technology is standardized since decades, with related emission limits as well as immunity requirements (see 3.2 and 6.1);
c) at present, the large majority of smart metering/smart grids projects in Europe is based on PLC technology, with regard to:
    1) technical and economical reasons;
    2) to an unrestricted coverage of metering points in terms of topography and locations inside buildings.

Therefore, for overall ensuring EMC for electrical equipment/systems, it is necessary, to consider PLC technology when setting EMC requirements for NCE.

7.1.5 Notching on transmitter side vs. selectivity on receiver side

Below 150 kHz, in some European areas up to 500 kHz, bands are used for radio navigation, inductive applications, active medical implants, MCS and broadcast services, to some part with same bands for different applications.

According to the Radio Regulations (RR) of ITU, with the general footnote 5.56, the frequency range 72 kHz – 84 kHz is dedicated to the Primary services FIXED, MARITIME MOBILE (footnote 5.57) and RADIONAVIGATION (footnote 5.60).

Footnote 5.56 says that

> "*The stations of services to which the bands 14-19.95 kHz and 20.05-70 kHz and in Region 1 also the bands 72-84 kHz and 86-90 kHz are allocated may transmit standard frequency and time signals. Such stations shall be afforded protection from harmful interference. In Armenia, Azerbaijan, Belarus, Bulgaria, the Russian Federation, Georgia, Kazakhstan, Mongolia, Kyrgyzstan, Slovakia, the Czech Republic, Tajikistan and Turkmenistan, frequencies 25 kHz and 50 kHz will be used for this purpose under the same conditions. (WRC-07)*".

That means that "Secondary Services" according to the RR shall protect such "Primary Services" and themselves have no right for protection (against interference from other radio services). On national level that means, that no radio services may be licensed which could interfere with such "Primary Services" and therefore also with such time-signal systems.

As described in Clauses 4 and 5, EMI to signals of such services may lead to customers' complaints; that not only due to wrong display of time on radio clocks but also to degradation or loss of function of control circuits of systems like heating systems etc. As also explained, EMI to time-signal systems may be caused by any equipment with specific emissions in the considered frequency range, different from radio services.

Table 7 gives an overview of public broadcast time-signal services and radio navigation systems being in operation with frequencies in the considered range around the globe.

Table 7 — Broadcast time-signal services in the long-wave range

f [kHz]	Service-ID	Country	Transmitter location	Operator
20,5 23 25,1 25,5	RJH69 RJH77 RJH63 RJH99 RJH66 RAB99	Russia	Vileyka (Belarus), Archangelsk, Krasnodar, Nizhny Novgorod, Bishkek (Kyrgyzstan), Khabarovsk	All-Russian Scientific Research Institute for Physical and Radiotechnical Measurements
40	JJY-40	Japan	Mount Otakadoya/Fukushima	JJY
50	RTZ	Russia	Irkutsk	
60	JJY-60	Japan	Mount Hogane/Kyushu Island	JJY
60	MSF	England	Anthorn, Cumbria	NPL
60	WWVB	USA	Fort Collins	NIST
66,6	RBU	Russia	Moscow	
68,5	BPC	China	Shanqui City, Henan Province	NTSC
77,5	DCF77	Germany	Mainflingen	PTB
100	BPM	China	Pucheng County	NTSC, Chinese Academy of Sciences
162	TDF	France	Allouis	CHFM, LNE
198	BBC	England	Droitwich, Worcestershire	BBC

In Switzerland, the service HBG (75 kHz) has been closed in 2011.

Further, radionavigation systems like LORAN-C (100 kHz), actually being used mainly for sea and flight navigation, were to be considered. After shutting down related services in the US in 2010, this service is used by the Northwest European LORAN-C system (NELS), with transmitters in France, Germany, Ireland, The Netherlands and Norway, for broadcasting corrective signals to the GPS signal (DGPS).

This service can be used also in the North Pacific area (including the Bering Sea), the North Atlantic, the Mediterranean Sea and the Persian Gulf and is being applied for the Saudi Positioning System (SPS), installed by the Saudi ports Authority.

In case of interference from another, non-radio-equipment to such a time-signal system, evaluation of harmful interference would be up to the related authority being responsible for EMC matters. Basis of the assessment of interference with radio services is, that electrical equipment is constructed in a way, that electromagnetic disturbances cannot reach levels which hinder an intended operation of radio and telecommunication equipment.

Anyhow, for the DCF77 system, any specification of a minimum field strength is lacking.

Basically,

- for any equipment/system generating emissions in the considered frequency range, including MCS in case of using such frequencies, the option of applying a notching mechanism could be taken into account; for achieving a comprehensive effect of such a measure any equipment/ system generating emissions in the frequency range 2 kHz to 150 kHz would need to apply such a notching mechanism;
- for narrow-band PLC systems it could be advisable to renounce from using such frequencies as carrier frequencies.

In areas with dense use of frequencies for radio services in the range up to 150 kHz, there may be practically no “free space” that could be used for other intentional or NIE, if the allocated frequencies were notched. Considering that, products would have one very broad notch resulting in very low level of emissions, due to the permanent limitation of emissions, what would take notching ad absurdum.

In other areas, in which no such applications are simultaneously present at a given point, dynamic notching could be a way to protect the frequencies used at a given place at a given time; that would represent a solution only for intentional emission sources like MCS, because dynamical notching is hardly realizable in NIE sources, due to their static operational emitting behaviour (e.g. fixed switching/converting frequency).

For practicable realization of dynamic notching, MCS would need the availability of a specified minimum intentional signal level coming from radio services and being induced into wires as common or differential mode voltage components, as a threshold for activation of dynamical notching. With regard to the possibility, that an MCS could detect emissions coming from non-intentional sources which would not be necessary to be protected by dynamic notching, the problem of distinguishing an intentional signal level coming from radio services or the aforementioned NIE should be reliably solved.

However, it should be noted, that the effect of emission notching related to such broadcast time-signal systems depends on:

- the selectivity of the time-signal-receiver. In case of receivers with low selectivity, notching does not solve so-called near-far-problems;
- a near-far-problem is given, if a low-level signal from a transmitter at a long distance to the receiver shall be received in the presence of a high-level signal with a frequency different from the one of the wanted signal. In such situations the automatic gain control at the input of the receiver keeps the gain low to match the stronger signal to the receiver’s dynamic range. At the same time the weak signal often dips below the receiver’s sensitivity threshold. The lower the spatial or frequency selectivity of a receiver the more probable is a near-far-situation;
- the level of emissions/noise at the receiver, from other emission sources;
- the level of the time-signal at the receiver.

Therefore this solution offers limited effect only.

Basically, increase of selectivity of receivers – be it in frequency or space (directional (active) antennas) – reduces the probability of EMI problems between wired and wireless systems essentially.

7.2 For PLC in particular — Move to higher frequencies

Different developments in the recent past show some striving for the application of higher frequencies for MCS. That not only with regard to the intended achievement of higher data rates, but also for avoiding EMC problems with NIE in the frequency range 3 kHz – 148,5 kHz, as being standardized with EN 50065-1 [26].

One of these developments consider a shift to higher frequencies, e.g. to the range 100 kHz to 500 kHz or to the MHz-range.

As already explained in 7.1.3, concerning frequencies above 148,5 kHz, for Europe, this shall be seen in the light of the following issues:

a) For ITU region 1[24)], including Europe, the frequency range above 148,5 kHz, up to 500 kHz, is reserved for broadcast services. Therefore, for the frequency range 3 kHz to 525 kHz, for which IEC 61000-3-8 [36] (see also IEC 61334-3-1 [37]) specifies:

   1) frequency bands designated to different applications (where appropriate);
   2) limits for the terminal output voltage in the operating band;
   3) limits for conducted and radiated disturbance, in the frequency range from 3 kHz up to 400 GHz;

   and gives the method of measurement, this standards refers to EN 50065-1 [26] and the CENELEC bands.

   Other applications, like e.g. power line carrier over HV lines, shall be harmonized concerning its frequency application with locally operating radio services, like e.g. for flight surveillance systems.

b) On principle, as already IEC/TR 61000-2-1 [92] mentions – but only for MCS -- PLT emissions as well as NIE from NCE cannot be considered as being confined to the mains power distribution lines, but can be radiated over considerable distances, with the potential to disturbingly affect electronic circuits or radio communications (see also [114]).

24) Europe, Africa, Near East (without Iran), Russia, Georgia, Armenia, Aserbaidschan, Kasachstan, Turkmenistan, Usbekistan, Tadschikistan, Kirgisistan, Mongolia.

Table 8 gives an overview of the use of band above 150 kHz for broadcast and aircraft navigation in Europe:

Table 8 — Utilization of band above 150 kHz for broadcast and aircraft navigation in Europe (CEPT[25])

Frequency band	- Europe (ECA) -
148,5 – 255 kHz	Broadcasting
255 – 283,5 kHz	Aeronautical Radionavigation, Broadcasting
283,5 – 315 kHz [a, b]	Aeronautical Radionavigation, Maritime Radio Navigation (radio beacons)
315 – 325 kHz [b]	Aeronautical Radionavigation, Maritime Radio Navigation (radio beacons)
325 – 405 kHz [b]	Aeronautical Radionavigation
405 – 415 kHz [b]	Radionavigation
415 – 435 kHz [b]	Aeronautical Radionavigation, Maritime Mobile
435 – 495 kHz [b, c]	Maritime Mobile, Aeronautical Radionavigation
495 – 505 kHz [c]	Mobile

[a] Additional allocation: in Region 1, the frequency band 285.3-285.7 kHz is also allocated to the maritime radio navigation service (other than radio beacons) on a primary basis.

[b] Civil-military sharing.

[c] In the maritime mobile service, the frequency 490 kHz is, from the date of full implementation of the GMDSS (see Resolution 331 (Rev.WRC-97), to be used exclusively for the transmission by coast stations of navigational and meteorological warnings and urgent information to ships, by means of narrow-band direct-printing telegraphy. The conditions for use of the frequency 490 kHz are prescribed in Articles 31 and 52. In using the band 415-495 kHz for the aeronautical radio navigation service, administrations are requested to ensure that no harmful interference is caused to the frequency 490 kHz (WRC-97).

Although there is sometimes reported about a decreasing application of this frequency range for LW broadcasting services, with regard to the following examples it appears that that does not prove true (see also Table 8):

- There are still flight surveillance systems in operation, which use this frequency band.
- BBC service on 198 kHz is an active service that has listeners in the UK and many other parts of Europe. This seems to be the situation also with other countries.
- It is noted that in the UK the service is also used to switch electricity meters between high and low tariffs.
- It is reported that Denmark has a new transmitter in this band.

And it appears that the LW broadcasting service is a continuing matter.

Besides the applicability of frequencies up to 500 kHz from the frequency allocation point of view, the aspect of higher efforts needed to overcome the higher attenuation along the mains line (e.g. the possible need for higher transmitter power, higher number of repeaters) were to be considered.

25) Conférence Européenne des Administrations des Postes et des Télécommunications.

8 Conclusions

Summarizing the results of the investigations described in this Technical Report, the following conclusions can be drawn:

1 Technological change in equipment design and control as well as in the application of electrical energy and, following to that, in using the electricity supply network has led to a quite changed scenario in emissions in the electricity supply network; a fact, which, amongst others, has led to some need for adaptation of standards to the actual needs.

Changed scenario in electricity application

2 Dependant on the different types of equipment/systems connected to the supply network at a certain time, as a consequence of the applied technologies,

Increasing distortion of the original sine wave of the supply voltage

- apparatus/systems consuming electric energy, generating NIE;
- DGU with its ancillary systems;
- MCS, with their intentional signals,

increasingly contribute to some modification of the original sine wave, to a somehow different shape, which shall be considered for its possibly disturbing effect on the operation of other electrical equipment. With regard to the different types of such emissions, i.e. NIE, (intentional) signals, or a combination of both and following to the cumulative effect of the additional voltage components, for ensuring EMC, a need for appropriate setting of compatibility levels as well as for establishing related emission limits, immunity requirements and test methods appears as being given.

3 It may be taken as an additional proof of the existing EMC problem and as an additional justification to this Report activity, that also on other levels, like universities in Finland, Sweden and UK, related investigations have been made, its results being conform with the recognitions of this TR.

Broader investigation activity, also by universities

4 It may have appeared that EMI in the frequency range 2 kHz to 150 kHz

EMC issue for several types of equipment

- are occurring only very rarely,
- might be solvable from case to case
- need not to be considered in standardization.

Already Study Report I [1a] expressed the assumption, that the recognized EMC problem might not be limited to a few types of equipment/ systems like AMR-PLC, TDLs and inverters.

Also

- IEC/TR 61000-2-1 [92] mentions related EMI potential – but focussed on MCS only
- in Recommendation Com-1 of their Report “Standards for Smart Grids”, the CEN/CENELEC/ETSI CEN/CENELEC/ETSI SG-CG [24] (see also [25]) mentioned the EMI potential between domestic appliances and PLC devices operating in the frequency range below

150 kHz.

EMC problem of larger dimension proved

The investigation results having been obtained in the meantime from EMI cases and being described in Clause 5 of this Technical Report confirm, that in fact the considered EMC problem is not focussed on some single types of equipment like MCS, TDLs and inverters but concerns some spectrum of different electrical equipment figuring as potential sources or victims of related EMI -- with the conducted as well as the radiated path (see conclusion No. 7) to be considered -- and the EMI potential shall be seen as a quite larger one.

A specific position in this EMC issue is held by MCS and in particular AMR-PLC systems applied for smart metering/smart grids purposes, as related equipment may figure as an EMI source or victim, thus – as also lighting equipment is doing -- forming a bridge between EMI sources and victims, but not to be taken as an indication for representing the sole type of equipment/system to be considered.

5 Several types of electrical equipment show peaks of non-intentional voltages/currents in the frequency range 2 kHz – 150 kHz with quite high values, sometimes reaching an order of magnitude close to the signal values from MCS to be expected on the supply network or even exceeding it, thus having potential to cause

High NIE levels

- EMI with different sorts of NCE not being (sufficiently) immune to emissions in the considered frequency range (see e.g. 5.2.1, 5.2.4, 5.2.5, 5.3) or
- a deterioration of the functionality of MCS (5.2.3) or
- wrong metering of electric energy (5.2.2).

6 EMI problems caused by NCE to MCS are more common than EMI problems caused by MCS to NCE.

EMI due to MCS of minor occurrence

7 As shown, also emissions in the frequency range of some tens of kHz – be it non-intentional ones or signals from MCS – are not to be seen as confined to the mains power distribution lines, but can be radiated over considerable distances.

Conducted and radiated interference path to be considered

Therefore, besides conducted interference also interference via the radiated path shall be considered, following to currents from NIE or signals.

This interference potential concerns all equipment generating related emissions in the considered frequency range (5.3).

8 Interference via the radiated path, through coupling via the magnetic H-field, may result in EMI, e.g. with broadcast time-signal systems; that also when meeting the standardized signal limits for MCS with a more or less huge margin and despite the given attenuation of signal levels along a supply network.

EMI potential to broadcast time-signal systems

For the evaluation of EMI to broadcast time-signal systems, generally, any specification of a minimum field strength of the DCF77-signal in particular and of broadcast time-signal systems in general is lacking.

9 With additional measurements [47], once more and with somehow more detailed investigations (see 3.3), the impact of the waveshape of emissions, in particular the rise/fall time of the envelope of NIE or MCS signals, and therefore the relevance of the envelope of such emissions on the interfering effect to other electrical equipment has been confirmed.

Discontinuous emissions to be considered

10 Besides level and continuity of an emission (see conclusion No. 9), its disturbing effect -- actually the level where it starts to affect equipment -- is dependent also on the coupling method.

Coupling method as one essential parameter for EMI

Therefore, also differential mode voltages/currents should be considered when specifying immunity requirements and test methods [1a].

11 For the frequency range 2 kHz to 150 kHz, interaction between equipment connected to the supply network is somehow different from the situation below 2 kHz (see 3.4).

Specific interaction of equipment

12 Due to technological development, resonances in the considered frequency range, between equipment connected to the supply network, may increase in future (see 3.4).

Expected increase of resonances

13 Some of the cases of degraded performance, malfunction or even loss of function as described in this Report have been recognized as having been caused by defective parts of an equipment/system, that due to ageing or loss of function of a certain component (5.2.3.2.11).

Ageing of components as one key reason for EMI

Therefore, when receiving information about related EMC problems, careful evaluation of the event is needed, whether a classical EMI is the case, investigating the technical background with regard to the EMCD and related standards.

Ageing effects at components of electrical equipment (e.g. filter capacitors) may lead to a situation, where a previously legitimately CE-marked device may interfere with other equipment, at the time of the occurrence of EMI being no longer able to conform with the ERs of the EMCD (that were required when it was placed on the market) and the requirements of related standards.

14 Referring to the aforementioned, some larger EMI potential in this frequency range is given by – integrated or external – power supplies (5.2.3.2); that relates to

Power supplies as an EMI source

- power supplies of different equipment, generating emissions e.g. due to its circuit design or ageing/defective components
- mains adapters due to passing through of currents/voltages stemming from NIE or MCS, which might lead to performance problems at e.g. IT equipment.

With regard to that fact, it shall be considered, that a significant part of an electrical equipment might act as an EMI source (see 3.1, Table 2), even if the interference is not related to the main function of the device.

15 Concerning EMI cases, the present report deals solely with proven ones, which have undergone more or less detailed investigations and provided information about the actual interference source and mechanism.

Factual numbers of EMI cases by far higher

It can be taken as a fact, that due to lack of forwarding related information from network users -- to network operators, merchandisers or manufacturers and, further, -- to authorities or national/standardization committees, the factual number of related EMI cases shall be estimated at a quite higher order.

16 The main interference with PLC systems and therefrom resulting communication losses caused by NCE are:

EMI to MCS due to insufficient S/N and/ or impedance situation

- insufficient S/N ratio due to attenuation caused by shunting;
- time varying low impedances seen from MCS;
- insufficient S/N ratio due to NIE.

As a consequence of such, due to:

- the impedance situation in an installation or supply area at a certain instant or
- too high emissions from NCE,

a number of EMI cases show a more or less severe deterioration of the function of MCS.

Failing MCS communication due to insufficient S/N proved with AICs

As tests with AIC and MCS have confirmed, lack of sufficient S/N can result in failing MCS communication (4.5.2).

17 As regards standardization proposals for emission limits for AICs, investigations have shown, that even

EMI potential to MCS and emission specification

- with solely numerical consideration of emission levels and immunity requirements
- without considering any additional room through consideration of waveshapes,

emission levels quite lower than the maximum values recommended with IEC/TS 62578 Ed.2 [46], even lower than EN 55011 [30] limits, have potential to cause EMI, also and in particular with MCS.

Figure 63 gives an overview of the measurement values obtained during the investigations described in Clauses 4 and 5 of this Technical Report, with comparison to the limits and values specified in existing standards; lines between different measurement points mark a number of such points obtained with one and the same equipment, with different parameters.

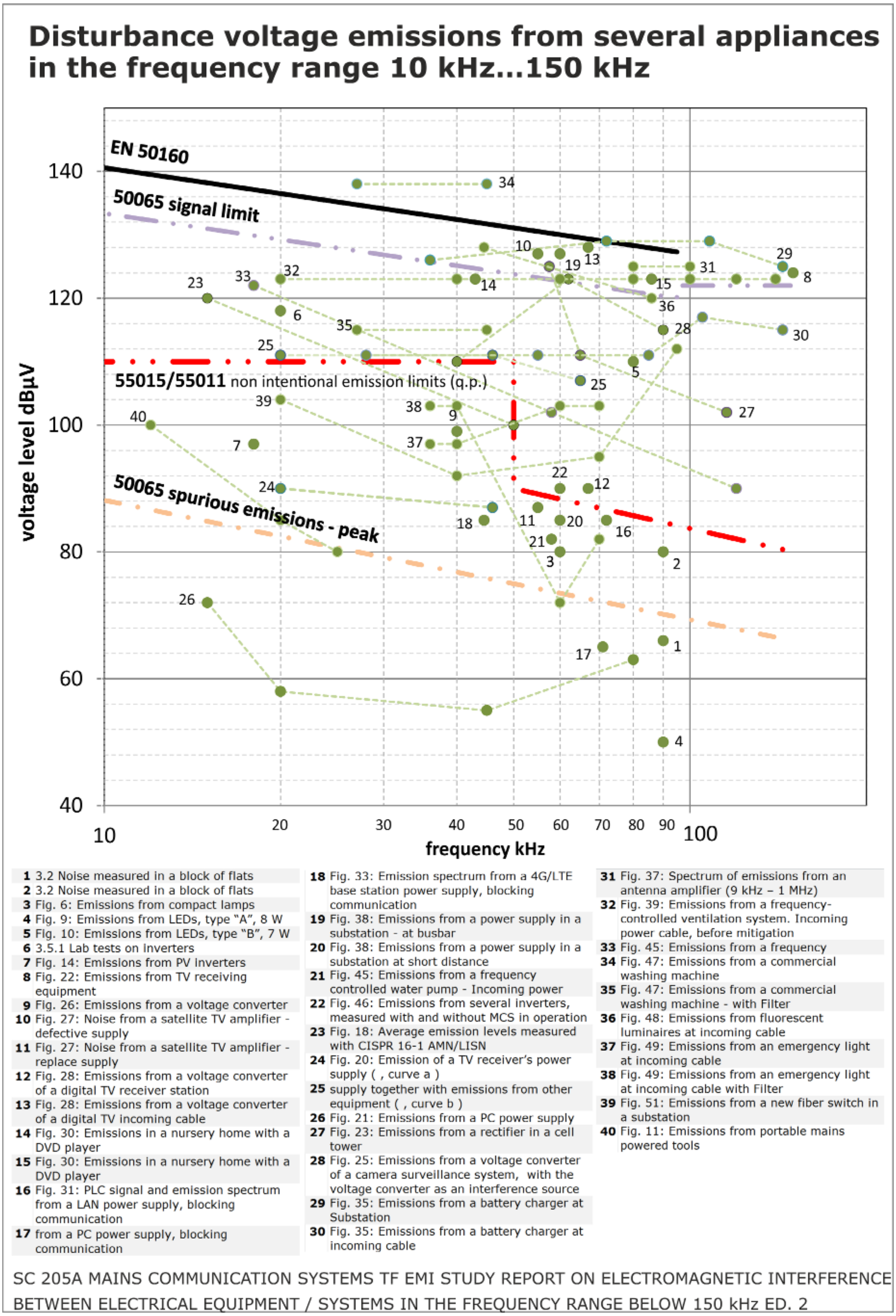

Figure 63 — Emission peak levels from investigations in this Technical Report, in relation to existing standardized limits and levels

9 Recommendations

With reference to the given scenario of utilization of the frequency range 2 kHz to 150 kHz, with NIE and with intentional signals from MCS, in the absence of enforceable rules for ensuring proper operation without interference through emissions as aforementioned, setting of appropriate rules for this frequency utilization appears as urgently needed.

In this sense, for

- safeguarding the undisturbed operability of electrical equipment with regard to phenomena in the frequency range 2 kHz – 150 kHz;
- ensuring a fair share of the considered frequency range for all equipment needing some use of it – be it non-intentionally or by intention, for signalling purposes –,

the needs and technically as well as economically given options for safeguarding an EMC-conform operation should be considered for completion of the present standardization building.

Based on the recognitions of Study Report I and this Technical Report and the conclusions in Clause 8 of this Technical Report, the following recommendations are made (see also [116]):

1. Due to the influence of electrical equipment connected to the supply network, the original sine wave of electricity supply, as being provided from generation, increasingly develops to a somehow different shape, which shall be considered for its possible disturbing effect on the operation of other electrical equipment in general.

   With regard to

   - the situation of emissions in the frequency range 2 kHz to 150 kHz, i.e. intentional signals, NIE or a combination of both, and the EMI potential of electrical equipment and systems in this frequency range
   - the recognitions from this Technical Report as well as Study Report I of SC 205A [1a],

   for the purpose of improved safeguarding EMC,

   - establishment of compatibility levels appears as urgently being needed (see ongoing work in IEC/SC 77A/WG 8); such compatibility levels should not cover only mains signalling, as having been done for this frequency range up until now, but the whole frequency range 2 kHz – 150 kHz with regard to any utilization of it, with mains signalling as one part of the issue

     Compatibility levels urgently needed
   - the
     - setting of related emission limits and immunity requirements (see also proposals in [65], [95]), based on such compatibility levels, as well as an
     - appropriate completion of test methods specifications related to differential mode emissions (see ongoing work in IEC SC 77A/WG 6) should be considered; that taking account of
       - the existing standards for signalling and NIE
       - the expectable development for such emissions.

     To set emission limits and immunity requirements where appropriate

     To complete test methods' standards

2. To consider as far a s possible the specific parameters being relevant for EMC in the frequency range 2 kHz – 150 kHz, at establishing related normative specifications – e.g. the impact of the coupling method and the effects caused by discontinuous voltages/currents.

   To consider specific EMC parameters for 2 kHz – 150 kHz

3. To consider new paths at establishing normative specifications as mentioned in recommendation 1, as far as they could offer options for better coping with the given task of ensuring co-existence in a land-scape of existing equipment/systems and their emissions, with only a limited basis of related standards at present.

   Up until now, the principle of "flat limits/values" was prevailing but it seems that with new technologies it might be appropriate to consider additional parameters (see 6.1), like e.g. designation of part- frequency bands, chimney approach to certain product groups. That with regard to the need for MCS to ensure a certain minimum S/N to non-intentional emissions, which might not be solvable with a

   To consider additional parameters at setting EMC values

concept of frequency utilization by all electrical equipment including MCS over the whole frequency range 2 kHz – 150 kHz.

4. To check, whether undisturbed operation of all equipment utilizing the frequency range 2 kHz – 150 kHz with NIE and with signals can be ensured on the basis of specifications in (voluntary) standards.

To consider effective rules for the utilization of the frequency range 2 kHz – 150 kHz.

5. With regard to ageing effects of electronic components in apparatus and systems (5.2.3.2.11, Conclusions 13, 14), lifetime aspects of such components have been recognized as a major issue when considering sources of EMI, thus drawing attention to the move

   - from an EMCD conformance of equipment, meeting all of the Directive's ERs at the time of declaration of conformity,
   - to technically modified circuits generating NIE which cause EMI to different electrical equipment and thus not being conform with the ERs of the EMCD that were required when it was first placed on the market,

   It is therefore recommended to consider lifetime aspects of components with relation to the expectable lifetime of devices, at equipment design as well as in related standards.

   It should be ensured that lifetime of components representing a CE-relevant EMC protection, e.g. capacitors of filters, power supplies, applied for a certain device, should exceed the lifetime of the other components of the device, taking account of the expected time of being in operation. E.g. a minimum lifetime of suppressing capacitors of 5 years would be recommended.

To consider EMI sources through ageing of electronic components

6. With regard to broadcast time-signal systems (e.g. DCF77, see 5.3.1), it appears as being advisable

   - to consider the frequencies being in use for time-signal systems around the world concerning emissions from any system
   - for narrow-band PLC systems to renounce from using such frequencies as carrier frequencies
   - in case of a PLC system with an operating frequency range including such frequencies, to notch such frequencies by means of a notching mechanism (see also 7.1.5), with regard to the local situation

To consider broadcast time-signal systems

7. Also, concerning broadcast time-signal systems, it might be advisable to consider the establishment of regulatory conditions for the protection of such systems, e.g. the specification of minimum field-strength values as a basis for assessing related EMI cases and decisions upon mitigation measures (see 5.3.1).

To consider regulatory protection for broadcast time-signal systems

8. Besides product standards dedicated to products prone to the generation of or susceptibility to emissions in the frequency range 2 kHz – 150 kHz, with regard to the recognitions of this TR, the following standards are recommended to be reviewed in particular:

   - EN 50065-2 series [33] – [35] for immunity of MCS;
   - the power quality standard EN 50160 [97], taking account of the specific parameters in 2 kHz – 150 kHz relevant also from the PQ point of view, including the thorough impact of waveshapes of current/voltage components on interference effects, instead of the sole indication of maximum voltages over (k)Hz;
   - standards dealing with electronic components – for consideration of the requirement of a sufficient lifetime of electronic components in relation to the expectable lifetime of devices (see 5.2.3.2.11).

To review standards

- **EN 50065-2-x**
- **EN 50160**
- **for electronic components**

9. To review installation rules, taking account of the recognized possi-bilities of mitigation measures for solving EMI cases, to better ensure EMC in installations and avoid EMI cases in advance (5.3.2 – 4).

To review installation rules

10. With regard to the results from measurements with LEDs (4.3.4) and the intended future proliferation of this lighting technology, with regard to the different results obtained concerning the cumulation of related emissions, the superpose-

To further investigate the superposition of emissions from LEDs

tion mechanism should be further investigated.

11. In the past, the co-existence of electrical equipment and emissions in the supply network were somehow easier to be understood and reasonably transparent and calculable.

    To consider shorter maintenance times for certain standards

    Nowadays and in particular in future, we cannot be sure how new technologies will lead to further changes in electricity application and therefore, how emissions in the supply network will develop. With regard to the increasing technological change in design of electrical equipment and its control, in future, adaptation of standards might be necessary within shorter periods.

12. With regard to
    - the recognized problems concerning co-existence between equipment generating NIE in the frequency range 2 kHz – 150 kHz and MCS
    - the substantial difference between NIE (disturbances) and intended signals corresponding with e.g. EN 61000-2-2 [29] and IEC/TR 61000-2-3 [115], a clear distinction between signals, representing intentional emissions, and NIE is recommended to be considered.

    To consider the differences between NIE and signals

13. Further investigations on EMI in the frequency range 2 kHz – 150 kHz appear as being of interest.

    Further investigations advisable

Annex A
(informative)

Acronyms and abbreviations

AC	Alternating Current
ACEC	Advisory Committee for Electromagnetic Compatibility (IEC)
AIC	Active Infeed Converter
AIT	Austrian Institute of Technology GmbH
AMI	Advanced Metering Infrastructure
AMN	Artificial Mains Network
AMR	Automated Meter Reading
AMR-PLC	AMR system using PLC for data transmission
APFC	Automatic Power Factor Correction
BBC	British Broadcasting Corporation
CD	Committee Draft
CE	Communauté Européenne
CENELEC	European Committee for Electrotechnical Standardization
CEPT	Conférence Européenne des Administrations des Postes et des Télécommunications
CFHM	Chambre francaise de l'horlogerie et des microtechniques, Paris
CISPR	Comité International Spécial des Perturbations Radioélectriques
CM	Common-mode (asymmetric coupling)
CSMA	Carrier-sense multiple-access
DC	Direct Current
DC	Draft for Comments
DGPS	Differential Global Positioning System
DGU	Distributed Generation Unit
DM	Differential-mode (symmetric coupling)
DNO	Distribution network operator
DTS	Draft Technical Specification
DVD	Digital Video Disc, Digital Versatile Disc
EC	European Commission
ECA	European Common Allocation (CEPT)
ECG	Electrocardiogram
EDP	Electronic Data Processing
EEC	European Economic Community
EED	Energy Efficiency Directive
ELB	Earth Leakage Circuit Breaker
Elforsk	Svenska elföretagens forskning och utveckling AB Swedish Electrical Utilities' R & D Company
EM	Electromagnetic
EMC	Electromagnetic Compatibility
EMCD	Electromagnetic Compatibility Directive
EMI	Electromagnetic Interference
EN	European Standard
EPBD	Energy performance of buildings
ER	Essential Requirement

ESI	Energy Storage Inverter
ESMIG	European Smart Metering Industry Group
ESO	European Standardization Organization
EuPD	Energy using Products Directive
EUT	Equipment Under Test
FCC	Federal Communications Commission, USA
GPS	Global Positioning System
HAN	Home Area Network
HF	High Frequency
ICT	Information and Communication Technologies
IDS	Intelligent Distribution Station
IEC	International Electrotechnical Committee
IEEE	The Institute of Electrical and Electronic Engineers
IEV	International Electrotechnical Vocabulary
ISM	Industrial, Scientific and Medical
IT	Information Technology
ITU	International Telecommunication Union
ITU-T	Telecommunication Standardization Sector of ITU
IWES	Fraunhofer Institute for Wind Energy and Energy System Technology, Kassel, Bremerhaven
JISC	Japanese Industrial Standards Committee
JJY	Space-Time Standards Laboratory, National Institute of Information and Communications Technology, Japan
LAN	Local Area Network
LED	Light Emitting Diode
LF	Low Frequency
LISN	Line Impedance Stabilization Network
LNE	Laboratoire national de métrologie et d’essais, Paris
LORAN	Long Range Navigation (System)
LV	Low Voltage
MCS	Mains communicating system
MID	Measuring Instruments Directive
M/490	Mandate issued by the European Commission to European Standardization Organizations (ESOs) to support European Smart Grid deployment
NC	National Committee
NCE	Non-mains-communicating equipment
NELS	Northwest European LORAN-C System
NIE	Non-intentional emissions
NIST	National Institute of Standards and Technology, Boulder, CO, USA
NPL	National Physical Laboratory, England
NTSC	National Time Service Center, China
OJ	Official Journal (EU)
PC	Personal Computer
PCC	Point of Common Coupling
PDS	Power Drive System
PLC	Powerline Communication
PLC	Power-Line Carrier
PLT	Powerline Telecommunication
PSU	Power Supply Unit
PTB	Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

PV	Photovoltaic
PWM	Pulse Width Modulation
RF	Radio Frequency
RPM	Revolutions per minute
RR	Radio Regulation (ITU)
SC	Sub-Committee
S-FSK	Spread Frequency Shift Keying
SGCG	Smart Grids Coordination Group (CEN/CENELEC/ETSI)
SGIP	Smart Grid Interoperability Panel (NIST)
SM	Smart meter
SMB	Standardization Management Board (IEC)
SPS	Saudi Positioning System
SWEDAC	Swedish Board for Accreditation and Conformity Assessment
TC	Technical Committee
TDL	Touch-Dimmer Lamp
TF	Task Force
TR	Technical Report
TS	Technical Specification
TUT	Tampere University of Technology
UPS	Uninterruptible Power Supply
VSD	Variable Speed Drive
VFD	Variable Frequency Drive
WAN	Wide Area Network
WELMEC	(Western) European Cooperation in Legal Metrology
WG	Working Group
WRC	World Radiocommunication Conference

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