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TECHNICAL REPORT

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INTERNATIONAL SPECIAL COMMITTEE ON RADIO INTERFERENCE

AMENDMENT 2

Specification for radio disturbance and immunity measuring apparatus and methods –
Part 4-4: Uncertainties, statistics and limit modelling – Statistics of complaints and a model for the calculation of limits for the protection of radio services

CISPR TR 16-4-4:2007-07/AMD2:2020-04(en)

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FOREWORD

This amendment has been prepared by CISPR subcommittee H: Limits for the protection of radio services.

The text of this amendment is based on the following documents:

Draft TR	Report on voting
CIS/H/402/DTR	CIS/H/407A/RVDTR

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

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

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- withdrawn,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

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2 Normative references

Replace the references to IEC 60050(161) and CISPR 11 with the following:

IEC 60050-161, *International Electrotechnical Vocabulary (IEV) – Part 161: Electromagnetic compatibility* (available at http://www.electropedia.org)

CISPR 11, *Industrial, scientific and medical equipment – Radio-frequency disturbance characteristics – Limits and methods of measurement*

Add the following new reference:

CISPR 15:2018, *Limits and methods of measurement of radio disturbance characteristics of electrical lighting and similar equipment*

3 Terms and definitions

Replace Clause 3 with the following new Clause 3:

3 Terms, definitions, symbols and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-161 and the following apply.

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

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

3.1.1
complaint
request for assistance made to the RFI investigation service by the user of a radio receiving equipment who complains that reception is degraded by radio frequency interference (RFI)

3.1.2
RFI investigation service
institution having the task of investigating reported cases of radio frequency interference and which operates at the national basis

EXAMPLE Radio service provider, CATV network provider, administration, regulatory authority.

3.1.3
source
any type of electric or electronic equipment, system, or (part of) installation emanating disturbances in the radio frequency (RF) range which can cause radio frequency interference to a certain kind of radio receiving equipment

3.2 Symbols and abbreviated terms

E_{ir}	permissible interference field strength at the point A in space where the antenna of the victim receiver is located – without consideration of probability factors
E_{Limit}	permissible interference field strength at the point A in space where the antenna of the victim receiver is located – with consideration of probability factors
R_P	protection ratio
C_{PV}	coupling factor describing the proportionality of the field strength E with the square root of the power P injected as common mode into the radiating structure by the apparatus (GCPC)
Group A	defined PV generator group for single-family detached houses
Group B	defined PV generator group for multi-storey buildings with flat roof tops
Group C	defined PV generator group for sun tracking supports (“trees”)
Group D	defined PV generator group for large barns in the countryside
ρ_i	probability of an individual PV generator being a member of Group i
$\bar{C}_{PV}$	group-independent mean value for the coupling factor

P_S	disturbance power emitted by a GCPC with the complex source impedance Z_S
P_L	power injected into the PV generator eventually radiated via that installation
P_{TC}	disturbance power determined at the DC-AN on a standardized test site according to CISPR 11 with fixed impedance Z_{TC} = 150 Ω
U_{Limit}	permitted disturbance voltage limit
P_7	probability for time coincidence (μ_{P7} in dB)
P_8	probability for location coincidence (μ_{P8} in dB)
P_4	probability for frequency coincidence inclusive harmonics(μ_{P4} in dB)
m_L	mismatch loss in use case (between the GCPC with complex source impedance Z_S and the PV generator with complex load impedance Z_L)
m_{TC}	mismatch loss in test case (between the GCPC with complex source impedance Z_S and the DC-AN according to CISPR 11 with measurement impedance fixed to Z_{TC} = 150 Ω)
AMN	artificial mains network
CM	common mode
DC-AN	DC artificial network
DM	differential mode
GCPC	grid connected power converter
S/N	noise power/signal power

5.6.5.2.10.2 Estimation for the possible range of μ_{P10}

Add, at the end of 5.6.5.2.10.2, added by Amendment 1, the following new Subclauses 5.6.5.3 and 5.6.5.4:

5.6.5.3 Rationale for determination of CISPR limits for photovoltaic (PV) power generating systems

For a model for the derivation of limits for photovoltaic (PV) power generating systems see Annex C.

5.6.5.4 Rationale for determination of CISPR limits for in-house extra low voltage (ELV) lighting installations

For a model for the estimation of radiation from in-house extra low voltage (ELV) lighting installations see Annex D.

Add, after the existing Annex B, the following new Annex C and Annex D:

Annex C
(informative)

Model for estimation of radiation from photovoltaic (PV) power generating systems

C.1 Overview

This annex presents a model for the estimation of radiation from photovoltaic (PV) power generating systems in the radio frequency range. The model is based on theoretical assumptions, measurement and simulation results as well as on a database with the statistical values of relevant parameters together with appropriate model factors. The simulation results were validated by measurement.

The model was developed for verification of the limits for the LV DC power port of power converters (GCPCs) intended for assembly into PV power generating systems specified in CISPR 11.

The subject of interest was the frequency range below 30 MHz and PV generators with a nominal power throughput in the range up to 20 kVA. Of the two known modes of conducted disturbances, radiation caused by conducted common mode (CM) disturbances was found to be dominant. Therefore the model exclusively considers radiation caused by common mode RF currents (i.e. antenna mode currents).

The structure of this annex is divided into two main parts.

Clause C.2 describes the general model approach mainly consisting of physical rationale, formulae and procedural methods needed for the characterization of the interrelation of the relevant influence factors.

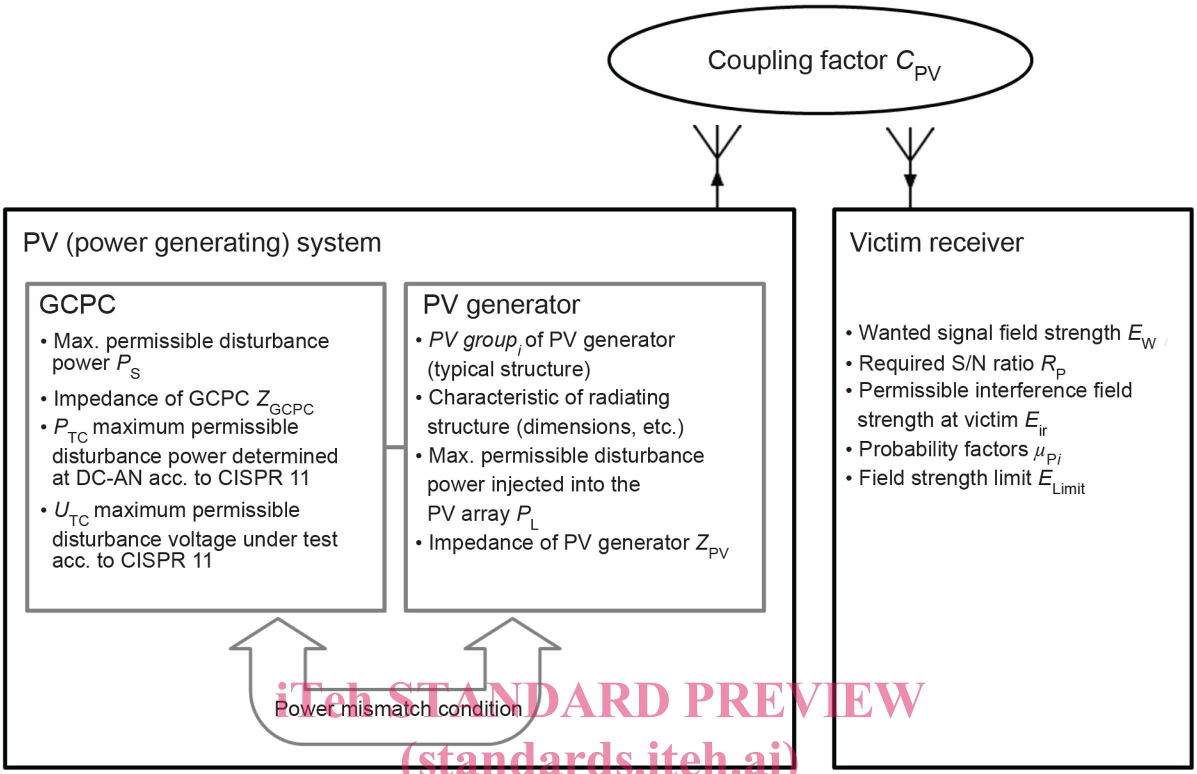
The approach is based on the application of practical data for the various model input parameters gained from measurement, simulation and statistics. Clause C.3 provides the calculation of a resulting limit which serves the primary task of verification of the limits for the LV DC power port of power converters specified in CISPR 11.

C.2 Description of the basic model

C.2.1 Overview

To provide a model suitable for an estimation of radiation from photovoltaic (PV) power generating systems, various influence factors have to be considered.

Figure C.1 gives a schematic overview of the determined influence parameters considered in the model and their interrelation.



NOTE: For the considerations of the model victim receiver R and measuring receiver M (Figure 2) are identical.

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Figure C.1 – Schematic overview of the considered model influence factors

Initially, the permissible value for the disturbance field strength limit E_{Limit} was determined, at a given point A in space where the antenna of the victim receiver is located, with help of the given formula for the mathematical interrelation of relevant parameters in a remote coupling situation (see C.2.2).

In a second step a model for the PV power generating system was introduced to determine the RFI potential. Subsequently, typical classes of PV power generating systems were selected. Sets of appropriate input parameters for modelling the radiation characteristics were determined (see C.2.3). Those input parameters comprise all the mechanical and electrical data of the solar generator used during its simulation, including electrical permittivity and conductivity of the surrounding ground.

Based on these conventions and assumptions, the coupling between the electromagnetic field at the victim receiver location and the PV generator was characterized by a parameter (introduced as coupling factor C_{PV}). By means of the field strength limit E_{Limit} and this coupling factor C_{PV} the maximum permissible disturbance power P_L injected into the PV generator was estimated. Thereby the basic model for the PV power generating system was completed (see C.2.4).

In addition, the effects of power mismatch losses in test site conditions and at the place of operation of PV power generating systems were used to refine the model (see C.2.5).

C.2.2 Conditions at the location of the antenna of the victim receiver

Considering the technical parameters for reliable transmission and reception of the radio service or application to be protected, the permissible interference field strength E_{ir} (without consideration of probability factors) at the point A in space where the antenna of the victim receiver is located can be determined by subtracting the necessary protection ratio R_{P} from the minimum wanted field strength E_{w} needed for this radio reception (see Equation (C.1), all quantities expressed in logarithmic units).

$$E_{\mathrm{ir}} = E_{\mathrm{w}} - R_{\mathrm{P}} \tag{C.1}$$

The permissible interference field strength is based on the measurement bandwidth of 9 kHz for the frequency range in question used together with the limit. If the radio service evaluated uses the same bandwidths, as in the case of broadcast radio, no change is necessary. If however the bandwidth of the victim radio service is lower than the measurement bandwidth, a correction shall be applied according to 5.6.6.2 (see Equation (C.2)).

$$E_{\mathrm{ir,corr}} = E_{\mathrm{ir}} + 10 \times \log\left(\frac{b_{\mathrm{victim}}}{b_{\mathrm{measurement}}}\right) \tag{C.2}$$

When the calculation of limits for the DC power port of a power converter (GCPC) intended for assembly into a PV power generating system is considered, then only the radiation coupling path to the victim radio receiver needs to be considered. The conductive coupling via the LV AC mains lines is considered to be highly unlikely due to heavy filtering of the AC mains power port of the GCPC.

Equation (37) of this document is the basic calculation rule to gain the permissible disturbance field strength limit E_{Limit} for use with type tests on standardized test sites. The comprehensive formula also includes the various probability factors $\mu_{\mathrm{P}i}$ and their corresponding standard deviations $\sigma_{\mathrm{P}i}$, reflecting the likelihood of occurrence of a real disturbance in the field, as well as the term $t_{\beta}\sigma_i$ describing the predefined statistical significance of CISPR limits for type-approved appliances. Combining Equation (37), Equation (C.1) and Equation (C.2) leads to Equation (C.3):

$$E_{\mathrm{Limit}} = E_{\mathrm{ir,corr}} + \mu_{\mathrm{P1}} + \ldots + \mu_{\mathrm{P10}} + t_{\beta}\sigma_i - t_{\alpha}\sqrt{\sigma_{\mathrm{P1}}^2 + \ldots + \sigma_{\mathrm{P10}}^2} \tag{C.3}$$

NOTE 1 Suitable probability factors for PV power generating systems are defined depending on the context of application (see C.3.3).

NOTE 2 This document is based on the assumption that the signal characteristics of disturbances caused by PV systems in its worst case are continuous, leading to equivalent outputs of all CISPR detectors.

Once the field strength limit E_{Limit} is found, a coupling factor C_{PV} comprising the coupling characteristics between the electromagnetic field at the victim receiver location and the PV power generating system can be applied to estimate the maximum permissible disturbance power P_{L} that can be injected into a given PV generator (see C.2.4).

C.2.3 Characteristics of PV generators

C.2.3.1 General

In this Subclause C.2.3 a model for the PV power generating system is introduced to determine the permissible RFI potential. Subsequently, typical classes of PV power generating systems are selected. Sets of appropriate input parameters for modelling of their radiation characteristics are determined.

C.2.3.2 Characteristic parameters of a PV generator seen as radiator of RF disturbances

In a simplified approach, a typical PV power generator can be regarded as an ideal vertical rod antenna with capacitive top loading. The DC power string wires are treated as antenna, while the PV panels or modules make up its capacitive loading. This approach is applicable for common mode radiation only, but several investigations indicated this radiation to be predominant in the considered case.

For the specified power range (i.e. up to 20 kVA) typical PV generator configurations can be found in large numbers. On a single-family detached house some PV panels are mounted on the inclined roof. For multiple-family houses very often a flat top roof can be found carrying rows of PV panels on its top. A sun tracker, which is made up by a singular steel support carrying some PV panels that always present their broad side to the sun, and fairly large generators on barns in the countryside, are also fairly common.

As consideration of every individual PV generator configuration is not feasible, group representatives of PV generator types are introduced (see C.2.3.3).

Subclause C.3.4 reveals the technical parameters that were assumed and used in the simulation for calculation of the RF characteristics of the respective group of PV generators.

C.2.3.3 Grouping of PV generators

For every individual photovoltaic power generating system or installation, the individual coupling property C_{PV_i} may assume a different value, but it can be expected that PV generators with about the same geometric structure and size, will show a typical property C_{PV_i} allocated somewhere in a given (predictable standard deviation) range.

As PV generators occur in various different configurations in the field, it was decided to define group representatives of PV generator types and to create a model for each group leading to different coupling factors $C_{\mathrm{PV\ Group}\ i}$ (see C.3.4), describing the interrelation between the victim receiver and the respective assumed group or category of PV generators.

The defined PV generator groups are:

- Group A – Single-family detached houses;
- Group B – Multi-storey buildings with flat roof tops;
- Group C – Sun tracking supports (“trees”);
- Group D – Large barns in the countryside.

Assuming the properties of all photovoltaic power generators in the world are known and that every individual one of those can be put into one of the predefined groups which is represented by its model or type (and thus has C_{PV_i} as a describing constant) it can be defined that

$$\rho_i = \frac{\text{Nb of PV generators in group } i}{\text{Nb of PV generators in the world}} \tag{C.4}$$

where ρ_i represents the probability of an individual PV generator being a member of group i, while the respective coupling factor C_{PV_i} describes the typical RF characteristics of this group (see Figure C.2).

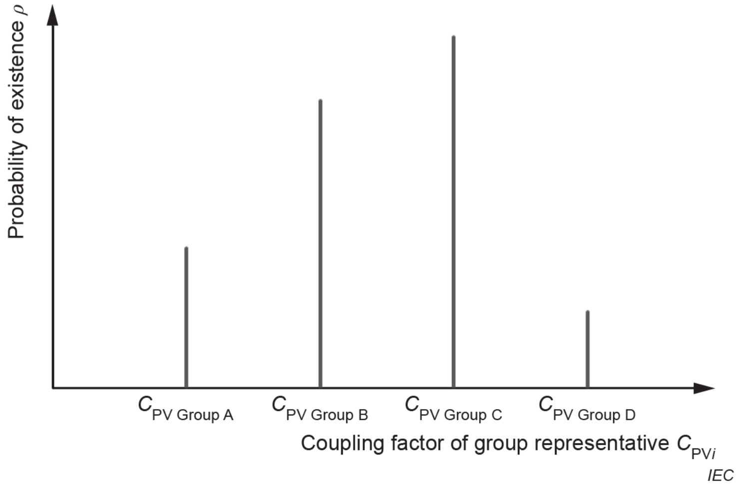

Figure C.2 – Schematic representation of probability of existence of PV generator groups in the field

Statistical data on the population density of the PV generators in the field is given in C.3.4.3.2.

From this data, a group-independent mean value for the coupling factor $\overline{C}_{PV}$ and its variance $\overline{\sigma}_{PV}$, which is valid and typical for any PV generator configuration, can be deduced (see Figure C.3).

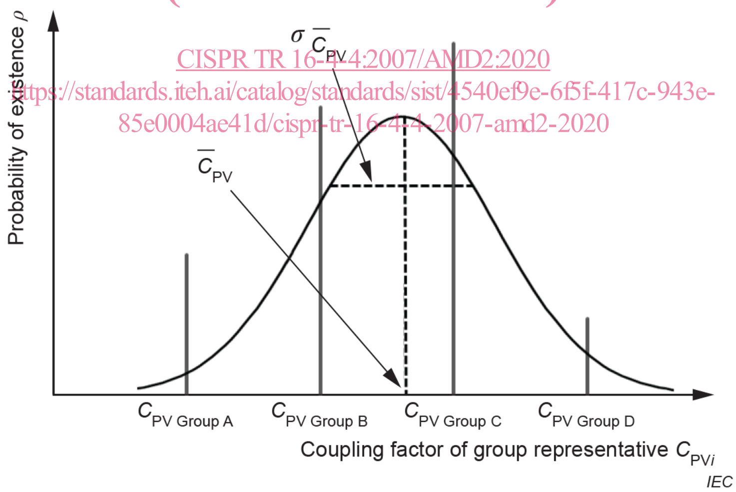

Figure C.3 – Schematic representation of mean value $\overline{C}_{PV}$ and variance σ_{CPV}

The global (or mean) value $\overline{C}_{PV}$ can be calculated by Equation (C.5):

$$\overline{C}_{PV} = \sum_{\text{all groups}} C_{PV} \times \rho_i \tag{C.5}$$

This simplified value $\overline{C}_{PV}$ for the global coupling factor is needed to select the type-independent limit $U_{TC\ Limit}$ for the LV DC power port of power converters (GCPCs) specified in CISPR 11 (see Clause C.3 of this document).

C.2.3.4 Electrical input parameters of the PV generator

One intermediate step of the approach is the determination of the maximum permissible disturbance power P_L that may be injected into the PV generator. In power matching conditions, this P_L is identical with the permissible disturbance power P_S provided by the GCPC.

For thorough estimation of the RFI potential, the typical power mismatch loss between the GCPC and the DC power interface of the respective PV generator has to be taken into account which requires knowledge of the complex impedances of GCPCs and PV generators (see C.2.5).

C.2.4 Coupling between the electromagnetic field at the victim receiver location and PV power generating system

C.2.4.1 General

When assessing the disturbance potential of any given apparatus with any attached structure, the relationship between the disturbance field strength E_{Limit} at a given point A in space and the RF power P_L fed into the radiating structure by the given apparatus has to be determined. The relevant technical parameter or characteristic of a given PV generator is its frequency dependent coupling factor C_{PV}.

For this task, the disturbance source, i.e. the grid connected power converter (GCPC) can be modelled as a common mode power generator that injects a certain power P into a radiating structure through its DC power port. The AC power port connects directly or via the PE conductor in the AC mains cable local ground as the counterpoise of the radiating structure. A block scheme covering this situation is shown in Figure C.4.

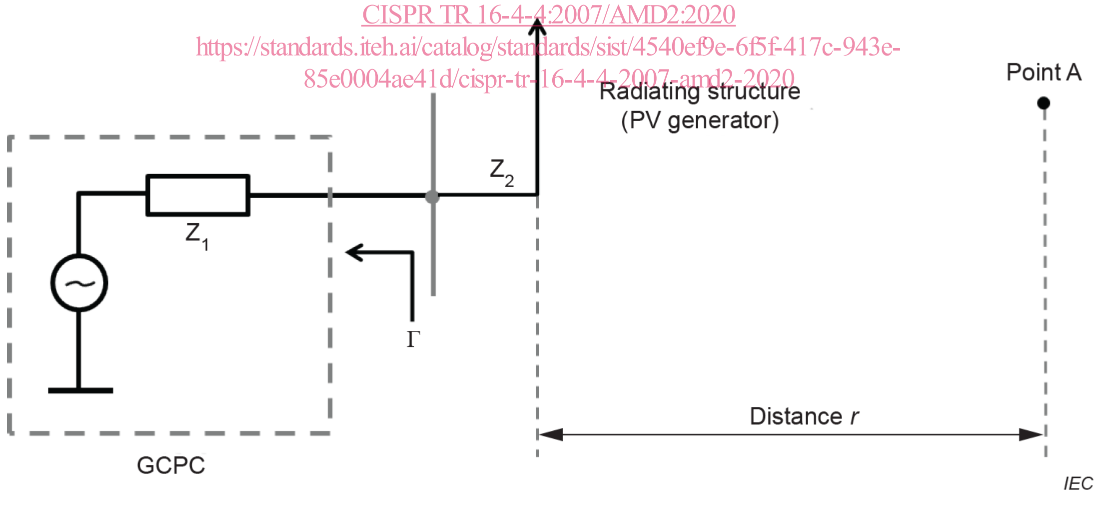

Figure C.4 – General model for coupling of CM disturbances of a GCPC to an attached photovoltaic power generating system (PV generator)

In a first approach the observation point A in space is assumed to be located at a fixed distance r from the PV generator. The electrical (disturbance) field strength E of the electromagnetic field emanating from the radiating structure is proportional to the square root of the real power P fed into the PV generator, due to the linearity of Maxwell's equations.

For a single point in space, a fixed function $C_{PV} = C_{PV}(f)$ (coupling factor) describes the proportionality of the field strength E with the square root of the power P injected into the radiating structure by the apparatus (GCPC), as given in Equation (C.6).

$$E = C_{\mathrm{PV}} \times \sqrt{P} \tag{C.6}$$

For EMC considerations the situation at a fixed distance (e.g. the CISPR protection distance of 10 m or 30 m) is needed. For real objects many points in space with the property of having a given distance to the EUT exist, for example in different azimuth directions and at different heights. This applies to simulation and measurement equally. Therefore the field strength used in Equation (C.6) shall undergo some kind of maximization procedure before being used for the calculation of the coupling factor. Henceforward this parameter C_{PV} covers the worst case radiation properties/characteristics of the model for the fixed installation and is explicitly valid for one given fixed distance r and one specific group (A, B, C or D) of PV generators. By means of Equation (C.7) the maximum permissible disturbance power that may be injected into the PV generator P_{L} can be calculated to:

$$P_{\mathrm{L}} = \frac{E_{\mathrm{Limit}}{}^{2}}{C_{\mathrm{PV}}{}^{2}} \tag{C.7}$$

Basically, it does not matter whether a victim receiver's antenna picks up either the electric or the magnetic portion of the radiated disturbance and which of the two coupling mechanisms is predominant for the respective distance. They differ, because for most frequencies the victim receiver is in the near field zone of the radiating structure.

Using the coupling factor for the electric field strength and the magnetic field strength to calculate the resulting field strengths appearing at the point in question, it can be seen, that the two coupling factors can be compared to each other in the same unit (Equation (C.8)). The disturbance field strengths, which are compared to each other and to the field strength of the radio service, are in the far field of the transmitter.

$$\left.\begin{array}{l} E = C_{\mathrm{PV\ elec}} \cdot \sqrt{P} \\ H = C_{\mathrm{PV\ mag}} \cdot \sqrt{P} \end{array}\right\} \rightarrow \frac{E}{H} = \frac{C_{\mathrm{PV\ elec}}}{C_{\mathrm{PV\ mag}}} \tag{C.8}$$

By multiplying the coupling factor for the magnetic field $C_{\mathrm{PV\ mag}}$ with the free space impedance Z_0, the results can be compared in the same units. Note that the coupling factor for the magnetic fields will also be given in the unit $\sqrt{\Omega}/\mathrm{m}$ (see Equation (C.9)).

$$C_{\mathrm{PV elec}}\left[\frac{\sqrt{\Omega}}{\mathrm{m}}\right] = C_{\mathrm{PVmag}} \cdot Z_0 \left[\frac{1}{\mathrm{m} \cdot \sqrt{\Omega}}\right]. \tag{C.9}$$

NOTE Generally electric and magnetic fields are not interrelated by the free space impedance Z_0 in the near field.

By convention, the coupling factor for the required protection distance is defined as the mean value of all field strengths determined for a number of points in the xy-plane at the required distance. When only four spatial directions are assessed, the final values of the coupling factor can be calculated by

$$\begin{array}{l} C_{\mathrm{PV\ elec}} = \mathrm{mean}(C_{\mathrm{PV\ elec\ 0°}}, C_{\mathrm{PV\ elec\ 90°}}, C_{\mathrm{PV\ elec\ 180°}}, C_{\mathrm{PV\ elec\ 270°}}) \\ C_{\mathrm{PV\ mag}} = \mathrm{mean}(C_{\mathrm{PV\ mag\ 0°}}, C_{\mathrm{PV\ mag\ 90°}}, C_{\mathrm{PV\ mag\ 180°}}, C_{\mathrm{PV\ mag\ 270°}}) \end{array} \tag{C.10}$$

In a last step the predominant coupling (electric or magnetic) is found by maximization.

$$C_{PV} = \max(C_{PV\ elec}, C_{PV\ mag}) \times Z_0 \tag{C.11}$$

C.2.4.2 Determination of coupling factor by simulation $C_{PV\ sim}$

One approach to determine the coupling factor is to carry out simulations with a Maxwell equation solver (i.e. NEC2, FEKO, Concept).

Taking a defined representative geometrical configuration for each PV generator group as basis, a relationship between the injected disturbance power and the resulting radiated disturbance field strength in a point A in space at a defined distance from the PV generator can be found.

The main input for the simulation is the geometry of the photovoltaic generator. This mechanical structure needs to be programmed into the simulating engine. An example is shown in Figure C.5.

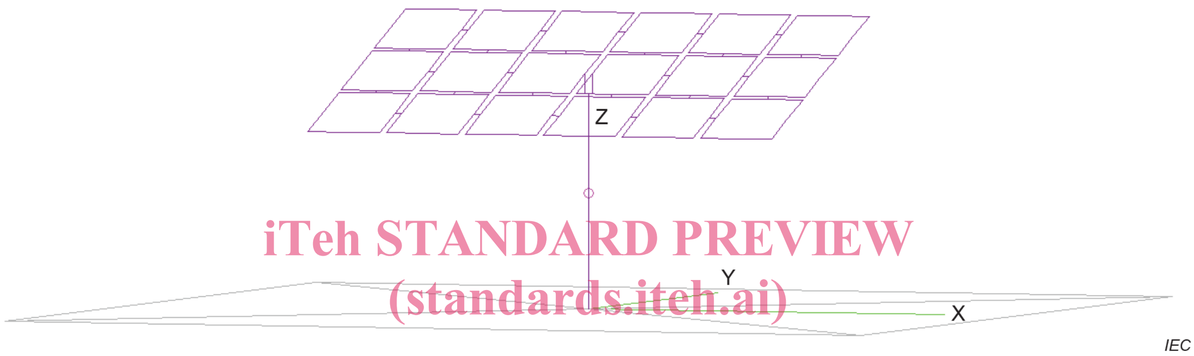

Figure C.5 – Geometric representation of a PV generator with 18 modules

In the defined structure, common mode power is injected at the feed point (indicated by a purple circle in the middle of the feed line) and the field strength is calculated in a cuboid around the structure. The distance from the structure at which the coupling factor C_{PV} shall be calculated determines the size of the cuboid in x and y directions. The protection distance in CISPR standards is often 3 m, 10 m or 30 m. For a large structure like a photovoltaic array, calculations for the protection distance of 3 m are not used for the example presented in this document. The size of the cuboid in vertical z direction shall be twice the height of the structure itself.

The output of the simulation is the field strength on the surface of the pre-programmed cuboid. Choosing a point on the xy-plane at a distance corresponding to the required protection distance defines a vertical line (see Figure C.6).

Dimensions in metres

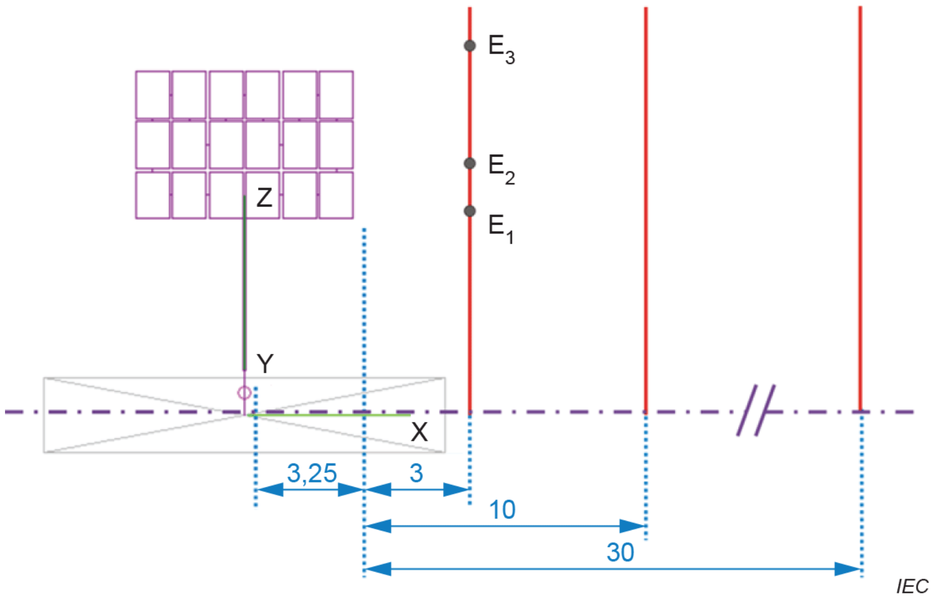

Figure C.6 – Field strength determination by maximization (height scan) along a red line

The maximum of all field strengths in the cross-section between this line and the cuboid represents the final field strength for the distance. Ideally this procedure would be repeated for each angular direction, however it suffices to consider only the four different orthogonal directions in space. The coupling factor $C_{PV\ sim}$ is then derived according to Equations (C.10) and (C.11).

C.2.4.3 Determination of coupling factor by measurement $C_{PV\ meas}$

The coupling factor introduced by Equation (C.6) can also be determined by measurement. However, as the coupling factor is defined in transmission mode, it is difficult to measure the field strength distribution around a typical setup for a PV generator, since the setup is too large for accurate measurement in most available shielded rooms. On the other hand it is not possible to actually transmit a potential test signal on any frequency at the installation site of a PV generator, because of national restrictions. However, under specific operating conditions (e.g. limitation of transmission to suitable single test frequencies) a measurement on real installations is feasible.

For these measurements, the DC wires of the PV generator shall be disconnected from the GCPC, shorted and connected to a typical antenna tuner. The tuner should be grounded the same way an installed GCPC would be grounded. The tuner shall be able to tune the feed point impedance of this “antenna” to the 50 Ω output of the transmitter at all test frequencies, such that only very little RF reflection occurs. The actual forward and reflected power shall be measured and monitored during the procedure with a power meter.

The field strength shall then be measured at a pre-defined fixed distance from the outer boundary of the PV installation (e.g. at 10 m or 30 m). The measurement should be made in the four dominant perpendicular directions at heights starting from 1 m above ground level up to twice the installation height. If this cannot be achieved, the measurement can be simplified to fewer directions and lower and fewer heights.

A comprehensive result table of this suite of measurements shall provide the following information:

1) frequencies used for testing;