Derivation of limits for radiated emissions from power drive systems

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1 Introduction

Limits for the unwanted radiation from power drive systems (PDS) are specified in the international standard IEC 61800-3 [1]. The standard contains various sets of limits in the frequency range from 30 MHz to 1 GHz applicable to the different categories C1, C2 or C3 of power drive systems. There is a particular set of limits for the category C3 PDS which exceed those used in the generic emission standard IEC 61000-6-4 [2]. Though PDS configurations assigned to this category C3, which means that they are intended for sole use in an industrial location and not intended for use in a residential, commercial or light industrial location, there is a general understanding that emission limits for all types of products shall use those of the applicable generic standards which approach is expressed in the IEC Guide 107 [3]. However, according deviations are allowed for cases where those limits are seemed not to be appropriate. But for those cases a justification for the deviations needs to be provided according to IEC Guide 107. Usually, this justification is expected to be done based on the procedures described in the document CISPR TR 16-4-4 [4].

2 Basic model for the derivation of limits

Basically, the derivation of a limit which applies to the unintended radiated emissions of an item of equipment under consideration, with the goal to protect radio services can be done by means of a very simple equation [4]:

$$E_{ir} = E_w - R_p \tag{1}$$

With E_{ir} as the maximum tolerable disturbance level (at the location of a receiver), E_w as the wanted field strength to ensure radio reception and R_p as the signal-to-noise ratio, specified for a receiver. The value for E_{ir} represents the worst-case limit and might depend on the frequency.

Deriving of limits by that simple approach has the benefit that radio reception is not disturbed at all but has the big disadvantage that the resulting limits are that severe that in some cases it is technically not possible to meet them, in most cases extensive attenuation measures are necessary on equipment level which are difficult and expensive to achieve. Hence, the question of the economic impact of such severe limits with respect to its relevance for the society should be considered.

3 Usage of a probabilistic approach

In real situations the above worst-case limit is actually not needed (hence allowing products to use more realistic limits) as in most cases the worst-case conditions do not apply, for example: there is a certain probability that

(1) disturbing equipment is not always installed at or in the vicinity of a receiver's location, or
(2) disturbing equipment does not always operate at a period when reception is wanted, or
(3) the radiation from a disturbing source does propagate into the direction of the receiver in a certain extent only.

Hence, in a practical approach the probability of several factors needs to be considered in the constellation between potentially disturbing equipment and radio reception systems, resulting in a slightly modified equation to (1):

$$E_{ir} = E_w - R_p + \boldsymbol{P} \tag{2}$$

With ***P*** representing a value which can lead to a relaxation of limits, and which results from the probability that the worst-case conditions do not occur.

4 Probability factors

The procedure for the derivation of limits, described in CISPR TR 16-4-4, proposes the consideration of ten probability factors in total which have been identified to determine the probability of interference to radio reception equipment. Some of them are related to the disturbance source, some of them to the reception equipment and some consider general aspects. In this paper, only the first ones are considered as they are specific to power drive systems (using the numbering of the probability factor as described in [4]), being:

- P_1 : probability that the major lobe of radiation from a disturbing source is in the direction of the receiving radio equipment;
- P_4 : probability of the disturbing source generating a spectral disturbance component on a critical frequency
- P_5 : probability that the spectral disturbance component on the critical frequency is below a limit value
- P_7 : probability of coincident (i.e. simultaneous) operation of the disturbing source and the receiving radio equipment
- P_8 : probability of the disturbing source being operated within the distance at which interference at a receiving radio equipment is likely to occur;

Applying equation (2) in conjunction with the ten probabilities is intended to finally lead to a proposal for limits for C3 PDS. As all those ten probabilities are independent from each other and have the same practical relevance (i.e. are not weighted), the entire probability ***P*** is a product of the individual ones, being described by:

$$P = P_1 \times P_2 \times P_3 \times P_4 \times P_5 \times P_6 \times P_7 \times P_8 \times P_9 \times P_{10} \tag{3}$$

As probabilities are mostly expressed in units of percentage and as the values for the above probabilities are in most cases not concrete numbers rather than figures which themselves are described by probability functions the approach used in [4] introduces probability factors μ_{Pi} which are expressed in logarithm units and mathematically derived from the above probabilities. The full description of the probability factors considers the mean values as well the standard deviations derived from a statistical description of the probabilities. It should be noted that at the time of this publication the above approach is being reconsidered and a future edition of CISPR TR 16-4-4 might contain an amended procedure.

5 Discussion of some probability factors

5.1 Probability factor P_1: Directivity of the disturbance source

The probability P_1 considers the fact that the radiation from a C3 PDS configuration is not necessarily isotropic. Depending for example of the position of converter and motor and the physical arrangement of the cabling there might be a certain directivity of the radiation and consequently there is a probability that receivers are not positioned in the major lobe(s) of the radiation patterns. This effect is the more distinct the more the radiation deviates from the isotropy. To assess the impact of this factor, information about a wide range of PDS configurations is needed, specifically information about typical cable lengths, or about typical arrangements of cables with respect to ground, to a ceiling, or a straight laying versus laying with multiple changes in the direction. As such information should reflect realistic conditions, a site survey has been performed in this regard, involving manufacturers and installers of C3 PDS [5]. One of the results concerning typical cable lengths is summarized in Table 1.

Table 1: PDS configurations having certain cable lengths

Case	**Relative amount of PDS configurations**	
	With cable lengths [a]	***Mean*** [b]
1-A	less than 3 m	9,6 %
1-B	between 3 m and 10 m	28,4 %
1-C	between 10 m and 30 m	36,3 %
1-D	between 30 m and 100 m	14,8 %
1-E	between 100 m and 300 m	9,4 %
1-F	longer than 300 m	1,4 %

[a] Length of cable between converter unit and motor
[b] Average of PDS configurations across all participants to the site survey

The radiation from the PDS configurations was calculated by means of numerical simulations using a computer program based on the method of moments [6]. A simplified model was used which basically consists of a cable between the converter unit and the motor. It should be noted that for the statistical investigations not the absolute amplitudes of the calculated field strengths are needed, rather the horizontal radiation pattern. This characteristic is of special interest as it gives information whether radiation from PDS configurations can be considered as isotropic or directional.

An example for the radiation pattern in the horizontal plane for a configuration where the cable with a length of 10 m is arranged 0,1 m above the ground plane is shown in Figure 1.

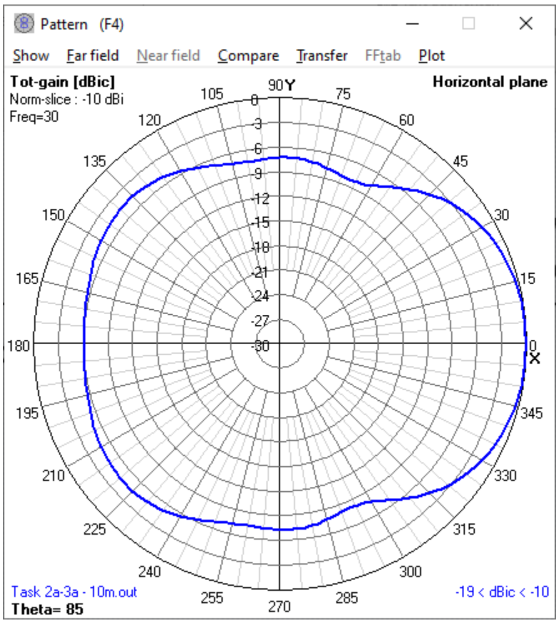

Figure 1: Horizontal radiation pattern of a power drive system at a frequency of 30 MHz with a load cable of length 10 m

The radiation pattern shown in Figure 1 represents the situation for a frequency of 30 MHz and indicates a certain degree of directivity. This means there are directions from the PDS configuration in which the radiation is less intense (for example at 180-degree 6 dB less than compared to 0 degree) than in other ones and hence a potential impact on a receiving equipment is less probable. The extent of directivity, or expressed in terms of an antenna gain, depends on the frequency under consideration and the various cable parameters. An example for the variety of antenna gains is shown in Figure 2 for various cable lengths and a cable height of 0,1 m above ground.

The dotted curve in Figure 2 shows the average (unweighted, i.e. not considering the relative distribution of cable lengths according to Table 1) antenna gain for the various lengths considered here. This antenna gain represents the mean value of the probability factor μ_{P1} and allows a probability factor of about 2 to 11 dB to be considered when deriving limits.

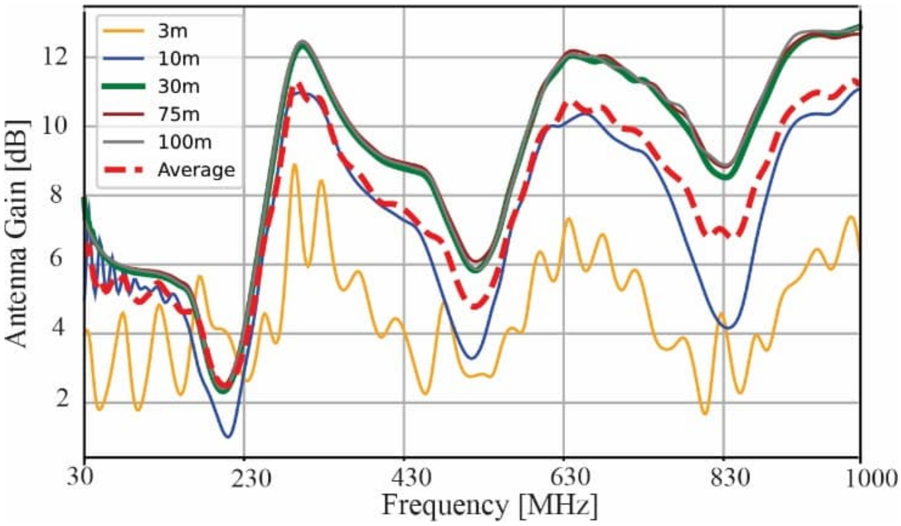

Figure 2: Antenna gain for PDS configurations with various cable lengths and cable height 0,1 m above ground plane in the frequency range from 30 MHz to 1 GHz

5.2 Probability factor P_4: Critical frequencies

Though PDS configurations produce radiated emissions it can be assumed that these emissions mostly occur at some frequencies or in some frequency bands, and not in the entire range from 30 MHz to 1000 MHz, at least not with relevant amplitudes. Such emissions are partly due to broad band effects of the switching semiconductor devices and partly due to the operation of distinct high frequency components such as microprocessors. As it is not realistic to model and simulate PDS in that accuracy to get precise results, in terms of precise amplitudes of radiated emissions, an approach will be used where emission spectra of actually measured PDS configurations are assessed.

For that purpose, a survey was performed which aimed at the assessment of emission spectra from various types of PDS produced from various manufacturers. An example of a spectrum provided by those manufacturers who took part at the site survey is shown in Figure 3.

However, it turned out that in general radiated emission spectra from C3 PDS are not that comparable to allow a straightforward evaluation which could result in some common quantitatively describable characteristics. This is not astonishing as different manufacturers use different designs, devices or topologies. But what they have for example in common is that they meet the limits for C3 PDS and that in the frequency range below about 230 MHz some parts of the spectrum exceed the limits lines for industrial equipment as specified in the generic emission standard IEC 61000-6-4. In the frequency range above 230 MHz no relevant spectral lines could be identified (which could be specific for the spectra assessed, there might other ones where some spectral lines occur also in that frequency range). Hence the assessment of the spectra and the resulting values for the probability factor μ_{P4} was split into two frequency ranges.

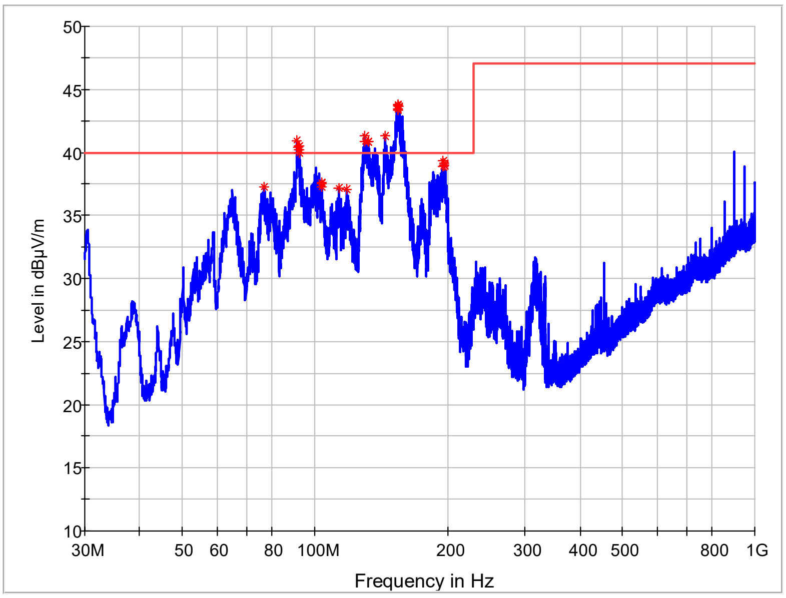

Figure 3: Example for the radiated emissions from a C3 PDS, measured at 10 m distance (Limits indicated according to IEC 61000-6-4 [2])

Frequency range 30 MHz to 230 GHz:

In this frequency range spectral lines or portions of the spectrum could be identified which have significant amplitudes. As such those are considered as significant where the amplitudes are closer than 10 dB to the applied limits. The assessment of the spectra showed that for the evaluated spectra a total portion of between 6 MHz to 20 MHz (not necessarily within one frequency band) has amplitudes closer than 10 dB to the limit line.

For the determination of the probability factor a worst-case approach was applied which assumes a rectangular distribution for possible portions with the boundaries between 6 MHz and 20 MHz, hence resulting in a mean value of 13 MHz (out of the total frequency range of 200 MHz) which leads to

$$\mu_{P4} = -10 \log (13/200) \text{ dB} = 11{,}9 \text{ dB}$$

The standard deviation of a rectangular distribution [7] is calculated for the above values as

$$\sigma_{P4\text{-}rectangular} = (20 \text{ MHz} – 6 \text{ MHz})/(2 \cdot 1{,}73) = 4{,}046 \text{ MHz}$$

This leads to a value of σ_{P4} which can be calculated as:

$$\sigma_{P4} = 10 \log(7 \text{ MHz}/14 \text{ MHz}) - 10 \log((7 \text{ MHz} + 4{,}046 \text{ MHz})/14 \text{ MHz}) = 1{,}98 \text{ dB}$$

Frequency range 230 MHz to 1 GHz:

In this frequency range, no spectral lines could be identified which exceed the limit lines of the generic standard IEC 61000-6-4 (values for 10 m measurement distance, values applicable to emissions in the residential environment), hence no spectrum shows spectral components closer than 10 dB with respect to the limits of IEC 61800-3 for C3 PDS. Here, a worst-case estimation is applied where only 1 % of the whole spectrum in that frequency range can be considered as critical (in case one or the other C3 PDS not considered in this report might have some relevant spectral lines).

This estimation leads to values for

$$\mu_{P4} = -10 \log (0.01) \text{ dB} = 20 \text{ dB, and}$$

$$\sigma_{P4} = 0 \text{ dB.}$$

5.3 Probability factor P_7: Coincidence in operation

Interference caused by a source can occur only when both: interference source and receiving equipment are simultaneously in operation. For example, for a very short operation of a PDS per day, the probability to cause interference is relatively low. That situation is covered by the probability factor μ_{P7} which is the expected mean value when the operation of the disturbance source is coincident with the operation of a receiving system.

It is assumed that receivers are operated on a 24/7 basis (24/7: 24 hours, 7 days); this does not necessarily mean that a user listens for example to broadcast for 24 hours per day. But as it is not known when a user does actually use a receiver the situation has to be assumed that it could by any time of a day.

C3 PDS are used in a broad range of applications. There could be installations where they operate for a few minutes only (for example cranes) or where they operate the whole day (for example pumps or ventilation). A natural probability distribution used for cases where no information is available about the distribution which means where it is assumed that every state can occur with the same probability, is the uniform (or rectangular) probability density (see for example [7]). Its usage shows the largest value for the standard deviation (of a probability function), hence can be considered as a conservative approach in limit setting.

The mean value T_{mean} of a rectangular distribution can be calculated by

$$T_{mean} = (T_{max} – T_{min})/2 = (24 \text{ h} – 0 \text{ h})/2 = 12 \text{ h}$$

resulting in the probability factor

$$\mu_{P7} = 10 \log(12 \text{ h}/24 \text{ h}) = 3 \text{ dB.}$$

The standard deviation σ_{P7} of a rectangular distribution is calculated for the above values as

$$\sigma_{P7} = (T_{max} – T_{min})/(2 \cdot 1{,}73) = 6{,}93 \text{ h}$$

leading to a value for σ_{P7} which can be calculated as:

$$\sigma_{P7} = 10 \log(12 \text{ h}/24 \text{ h}) - 10 \log(18{,}93 \text{ h}/24 \text{ h}) = 1{,}97 \text{ dB.}$$

5.4 Probability factor P_8: Distance between source and receiver/Density of disturbance sources

The probability $\boldsymbol{P_8}$ considers the fact that a disturbing source is operated within the distance at which interference at a receiving radio equipment is likely to occur. Basis for that assessment is the protection distance which has been considered when establishing limits and which is typically 30 m for equipment used in industrial premises.

Similar to the site survey as used for the assessment of $\boldsymbol{P_1}$, a further one has been performed in order to get information where C3 PDS configurations are typically used and which are the distances typically to be expected between a PDS configuration and a potential radio user. C3 PDS are strictly limited for usage in industrial premises and hence models which are mostly used for the determination of typical distances when both, interference source and receiver are located in the same electromagnetic environment [8], basically in the residential environment, cannot be applied. Also, the term industrial premise might be used in a different meaning in different countries or regions and therefore the focus was given to the parameter: typical size of an industrial premise. This parameter would allow to conclude on distances between a C3 PDS towards a receiver location. The results of the site survey are given in Table 2.

Table 2: PDS configurations installed in industrial premises of a certain size

Case	**Relative amount of PDS configurations**	
	in industrial premises of the size	***Percentage [a]***
2-A	less than 2 500 m^2	4 %
2-B	between 2 500 m^2 and 10 000 m^2	17 %
2-C	between 10 000 m^2 and 100 000 m^2	22 %
2-D	larger than 100 000 m^2	57 %

In a first approach, a relatively simple model can be used which is schematically shown in Figure 4 and which shows an industrial premises with a square shape, a length of about 316 m of each side, resulting in an area of 100 000 m^2.

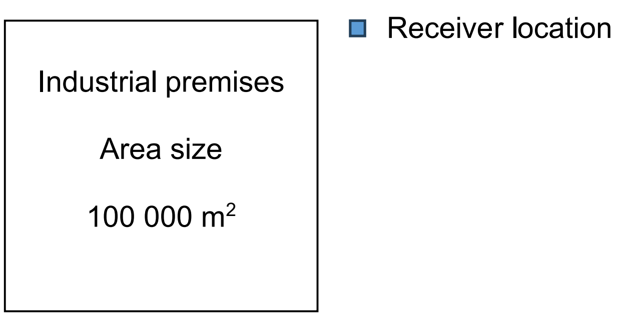

Figure 4: Simplified model for calculation of the average distance between a C3 PDS and a radio receiver

With the assumption that there is radio receiver placed at the corner of that industrial area separated from it for example by a road with the width of 10 m, and with the further assumption that a C3 PDS can be operated at any location inside the industrial area having a distance of 10 m to the border with the same probability, the average distance $r_{average}$ between the PDS and the receiver can be calculated as follows:

$$r_{average} = \frac{1}{297 \cdot 297} \cdot \sum_{y=0}^{296} \sum_{x=0}^{296} \sqrt{(20+x)^2 + (10+y)^2}$$

For this example, an average distance of $r_{average}$ = 246 m can be calculated. This results according to [4] in a probability factor

$$\mu_{P8} = 20 \log \left(\frac{246}{10}\right) = 27{,}8\ dB$$

assuming a distance of 10 m when measuring the emissions according to the standard and using a conservative wave propagation coefficient of 1.

6 Conclusion

The first results obtained for the above probability factors demonstrate that less severe limits than in the generic standards can be justified using the values currently published in the IEC Radio Services Database [8]. Further investigations are currently being performed to consider a bigger variety of configurations which is at least considerable for the probabilities P_1 and P_8. In addition to the probability factors covered in this paper, the other factors (P_2, P_3, P_6, P_9, and P_{10}) would need to be considered in order to conclude on limits. These factors are not considered here as they are not specific to C3 PDS configurations, but relevant information about these can be taken from the examples given in [4] and all factors then can be used for the derivation.

Literature

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