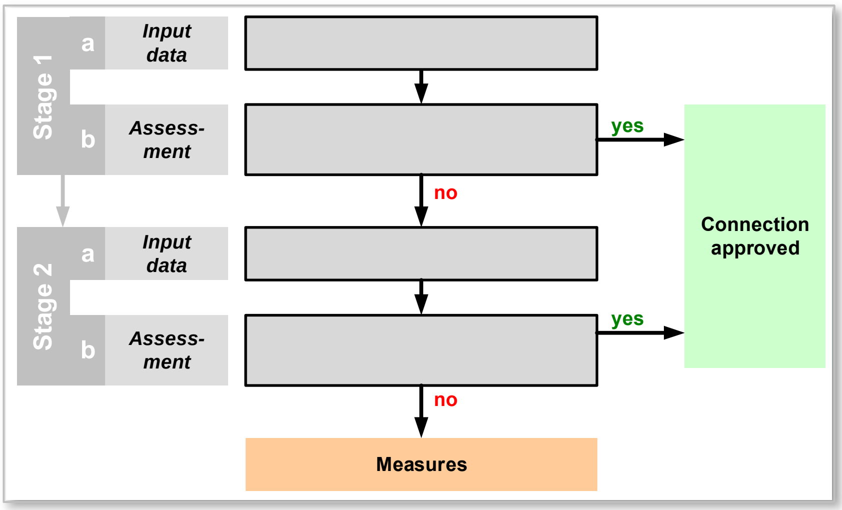
Technical Rules for the assessment of network disturbances

(Technische Regeln für die Beurteilung von Netzrückwirkungen)

Part B: Requirements and assessment

Section I: Low voltage



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Publisher:

Österreichs E-Wirtschaft
Brahmsplatz 3
A-1040 Wien
akademie@oesterreichsenergie.at

VSE Verband Schweizerischer Elektrizitätsunternehmen
Hintere Bahnhofstrasse 10
CH-5000 Aarau
www.strom.ch

CSRES – Ceske sdruzeni regulovanych elektroenergetickych spolecnosti
Na hroude 19/2149
10000 Praha 10 – Strasnice
www.csres.cz

Forum Netztechnik/Netzbetrieb im VDE (VDE FNN)
VDE Verband der Elektrotechnik Elektronik Informationstechnik e. V.
Bismarckstr. 33
10625 Berlin

Content

Foreword

This document outlines the assessment procedures and the calculation of emission limits for customer installations for connection to the public low voltage network. It is the first of three sections in Part B of the 3rd edition of the D-A-CH-CZ Technical Rules for the assessment of network disturbances.

Though the three sections are applicable individually for assessments in low-voltage, medium-voltage and high-voltage networks, general knowledge and specifications from Part A (Fundamentals) are required for the application of this document. All relevant passages in the document are referenced accordingly.

This document can be used by DSOs as well as planners and installers to properly assess network disturbances of a customer installation as part of the planning process and to specify appropriate emission limits. This allows an early assessment of whether additional mitigation measures may be required to reduce emissions.

1. Voltage changes and flicker

1.1 Voltage changes

1.1.1 Supply voltage variations

Relative supply voltage variations are assessed as voltage deviation Δu.

Compatibility levels for supply voltage variations in public LV networks are not specified. The voltage deviation should not exceed ±10 % under normal operating conditions excluding interruptions.

Requirements:

- During the normal network operation, the absolute value of the change of supply voltage caused by **all generating and/or storage installations** shall not exceed a value of 3 % as compared to the voltage without generating and/or storage installations, at any of the PCCs in this network.

The DSO can specify other limit values for the change of supply voltage if this is permitted or required for the network type and operation.

Note:
For consuming installations, the permitted change of supply voltage is determined based on the individual planning guidelines of the DSO.

1.1.2 Rapid voltage changes

Compatibility levels for rapid voltage changes in public LV networks are not specified.

Requirements:

- The maximum rapid voltage change caused by a single customer installation shall not exceed 3 % for frequent events (repetition rate $r \geq 0.01\ \text{min}^{-1}$). For repetition rates $r \geq 0.1\ \text{min}^{-1}$, an assessment of flicker shall also be performed.
- For infrequent rapid voltage changes (several times per day with repetition rates $r < 0.01\ \text{min}^{-1}$), up to 6 % are acceptable after consultation with the DSO.

Rapid voltage changes of several customer installations do not usually occur simultaneously, unless the rapid voltage changes are synchronized.

If the voltage drops during a voltage change characteristic, the resulting d value is positive; if the voltage rises during a voltage change characteristic, the resulting d value is negative [EN 61000-4-15].

1.2 Flicker

If the relative voltage change characteristic $d(t)$ is known, the P_{st} value can be determined by a computer simulation or by calculation using the analytical approach (see Part A "Fundamentals"). Non-repetitive voltage changes can only be assessed by measurement or special simulations.

With increasing short-circuit power of the network, the permitted P_{st} and P_{lt} values in public networks should decrease, since in most cases, according to the principle of flicker propagation, a higher number of customer installations is affected.

1.2.1 Compatibility levels

According to [EN 61000-2-2], the following compatibility levels apply:

$$C_{\text{Pst LV}} = 1.0$$

$$C_{\text{Plt LV}} = 0.8$$

The DSOs specify planning levels for the MV network level in order to be able to coordinate emissions between network levels. Reference values are:

$$C_{\text{Pst MV}} = 0.8$$

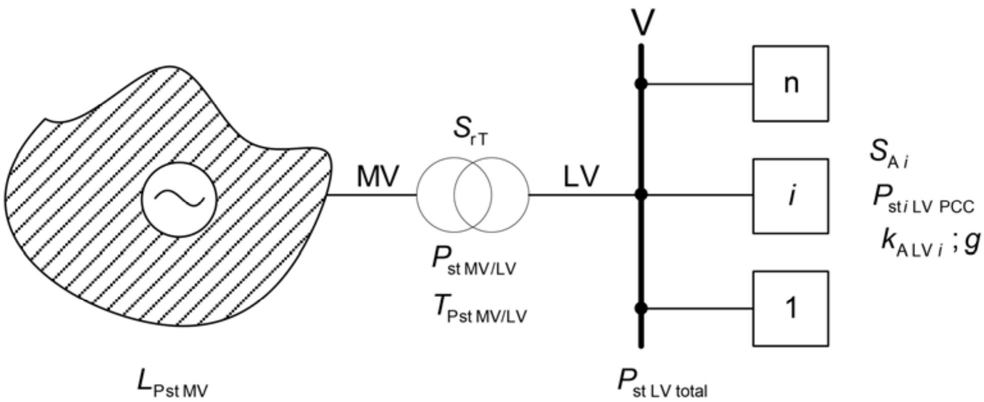
$$C_{\text{Plt MV}} = 0.6$$

The maximum flicker level transferred from the MV network to the LV network is:

$$P_{\text{st MV/LV}} = T_{\text{Pst MV/LV}} \cdot L_{\text{Pst MV}} \quad (1\text{-}1)$$

The global contribution of all customer installations in an LV network can then be calculated by the following equation:

$$\begin{aligned} P_{\text{st LV total}} &= \sqrt[3]{C_{\text{Pst LV}}^3 - P_{\text{st MV/LV}}^3} \\ &= \sqrt[3]{C_{\text{Pst LV}}^3 - \left(T_{\text{Pst MV/LV}} \cdot L_{\text{Pst MV}}\right)^3} \end{aligned} \quad (1\text{-}2)$$



where

$k_{A\ LV\ i}$	*is the connection type factor of the customer installation i,*
g	*is the simultaneity factor of the flicker-generating customer appliances or installations in the same line section,*
$C_{Pst\ LV}$	*is the compatibility level in the LV network,*
$P_{st\ LV\ total}$	*is the total permitted short-term flicker emission of loads directly connected to the LV network (global contribution),*
$P_{st\ MV/LV}$	*is the flicker level transferred from the MV network to the LV network,*
$T_{Pst\ MV/LV}$	*is the transfer coefficient from the MV network to the LV network,*
$L_{Pst\ MV}$	*is the planning level in the MV network,*
$S_{A\ i}$	*is the agreed power of customer installation i,*
$P_{st\ i\ LV\ PCC}$	*is the maximum permitted short-term flicker emission of customer installation i.*

Fig. 1-1: Transfer/allocation of flicker levels in the network

Taking into account a typical transfer coefficient $T_{\text{Pst MV/LV}} = 1.0$, the total permitted short-term flicker emission by all customer installations in an LV network (global contribution) can be determined. Thus, the global contribution for an LV network is:

$$P_{\text{st LV total}} = 0.8$$

$$P_{\text{lt LV total}} = 0.6$$

Using equation (1-2) as well as the corresponding equations for the upstream network levels, the network operators can individually coordinate the flicker emission through all network levels. In this way, the available resources can be used optimally from both a technical and an economic point of view. If different network operators are responsible for the network levels, coordination shall be agreed between all network operators involved.

1.2.2 Emission limits

The total permitted short-term flicker emission (global contribution) allowed for a network level is allocated to the individual customers according to a specific allocation parameter.

The connection type factor k_{A} is generally accepted as a possible allocation parameter. In addition, a simultaneity factor g, which is provided by the DSO based on studies, shall be considered together with already existing flicker sources.

The permitted short-term flicker emission of a customer installation shall be considered as reference value which can be customised by the DSO according to design calculations under its own responsibility.

$$P_{\text{st LV PCC}} = P_{\text{st LV total}} \cdot \sqrt{k_{\text{A LV}}} \cdot \sqrt{\frac{1}{g}} \tag{1-3}$$

For LV networks, the following connection type factor is used:

$$k_{\text{A LV}} = \frac{S_{\text{A}}}{S_{\text{N}}} \tag{1-4}$$

The permitted emission of an individual customer installation in LV networks is:

$$P_{\text{st LV PCC}} = P_{\text{st LV total}} \cdot \sqrt{\frac{S_{\text{A}}}{S_{\text{N}}}} \cdot \sqrt{\frac{1}{g}} \tag{1-5}$$

$$P_{\text{lt LV PCC}} = 0.65 \cdot P_{\text{st LV PCC}} \tag{1-6}$$

The reference power of the network S_N is determined by the DSO. Based on the factors k_C, k_G and k_S, it can be approximated from the rated power S_{rT} of the supply transformer. The sum of $k_C + k_G + k_S$ may be greater than 1.

$$S_N = (k_C + k_G + k_S)\, S_{rT} \tag{1-7}$$

where

$P_{st\ LV\ total}$	*is the total permitted short-term flicker emission of loads directly connected to the LV network (global contribution),*
$P_{st\ LV\ PCC}$	*is the maximum permitted short-term flicker emission of the customer installation,*
$P_{lt\ LV\ PCC}$	*is the maximum permitted long-term flicker emission of the customer installation,*
S_A	*is the agreed power of the customer installation,*
S_{rT}	*is the rated power of the MV/LV transformer,*
g	*is the simultaneity factor of adjacent flicker sources in the same network,*
k_C	*is the consumption capacity factor,*
k_G	*is the generation capacity factor,*
k_S	*is the storage capacity factor.*

Note 1:
The simultaneity factor represents the probability of temporal overlapping of the flicker generated by multiple appliances/installations. It is provided by the DSO depending on the network configuration and the operating times (morning, midday, evening, all-day) of the appliances/installations in the respective network area. If no reliable knowledge is available, use $g = 1$.

Note 2:
k_C, k_G and k_S are specified independent of the considered disturbance phenomenon.

Note 3:
If k_C, k_G and k_S are not known, $k_C + k_G + k_S = 1$ can be assumed for networks where no connection of generating and storage installations is expected. Otherwise, it is recommended to use $k_C + k_G + k_S = 1.35$.

Note 4:
In public networks, two-winding transformers are usually used as distribution transformers. Three-winding transformers are a special case, e.g. used for distribution to different subnetworks. Provided that there are no interferences between the subnetworks, the respective partial powers of the transformers can be used for the assessment.

A low agreed power of a customer installation can result in very low emission limits. Therefore, minimum emission limits of $P_{st\ LV\ PCC} = 0.30$ and $P_{lt\ LV\ PCC} = 0.25$ are recommended for any customer installation.

If the calculations according to equations (1-5) and (1-6) result in emission limits $P_{st\ LV\ PCC} > 0.75$ or $P_{lt\ LV\ PCC} > 0.5$, the maximum permitted emissions of a customer installation shall be limited to $P_{st\ LV\ PCC\ max} = 0.75$ or $P_{lt\ LV\ PCC\ max} = 0.50$, respectively.

1.3 Assessment

In LV networks, the phase-to-neutral voltage will be assessed.

Appliances that meet the requirements according to [EN 61000-3-3] may generally be connected without further testing. For appliances that meet the special connection conditions according to [EN 61000-3-11], it shall be ensured that the installation impedance is less than the minimum required installation impedance specified by the manufacturer. In any case, it shall be ensured that in an accumulation of flicker-generating appliances at a high simultaneity factor in the customer installation, the emission limits of the installation are complied with.

In general, compliance with the connection conditions for appliances/installations determined in the stages 1 and 2 does not yet mean that these appliances/installations may be operated without further constraints. In fact, the cumulative effects associated with appliances and installations of other customers shall be taken into account.

1.3.1 Simplified assessment (Stage 1)

If the $S_{\mathrm{sc\ PCC}}/S_{\mathrm{r}}$ ratio for an appliance or installation is higher than the value given in Tab. 1-1, it can be assumed that no disturbing voltage changes or flicker occur at this PCC. The values in Tab.1-1 are empirical values for the various appliance types and provide an initial indicator for the assessment. If the $S_{\mathrm{sc\ PCC}}/S_{\mathrm{r}}$ ratio according to Tab. 1-1 is not satisfied, an assessment according to stage 2 is required.

If other appliances are connected to this PCC, which generate voltage changes and/or flicker, these shall be taken into account by applying the summation law.

Tab. 1-1 Simplified assessment of voltage changes and flicker in networks

Type of appliance/installation	Example	Required $S_{sc\,PCC}/S_r$ ratio when connected to			
		1p: 230 V (2p: 400 V)		3p: 400 V	
Electric heat with low switching rate	Heating systems	>120		>30	
	Welding machines[2]	>600 (>400)		>150[1] >250	
with high switching rate	Spot-welding machines[2]	>1,000 (>500)		>500	
	Copy machines, laser printers, devices with multicycle control (e.g. continuous-flow heaters)	>1,000			
Power electronics	Fast-charging stations for electric vehicles			>175	
Motors		Direct-on-line starting	Starting aid	Direct-on-line starting	Starting aid
without inrush current limitation and low switching rates	Cooling units, heat pumps, lifts in residential areas	>600	>300	>150	>75
without inrush current limitation and high switching rates	Lifts in commercial areas, construction cranes	>1,000	>500	>250	>125
with inrush current limitation or connection via converter	Pumps	>250		>70	
	Frame saws Shredders			>500 (up to 1,500) >250 (up to 750)	

1) DC welding machines

2) S_r = 50 % duty cycle – Power usually indicated on the nameplate

Note:
PV systems can also cause flicker. In a future edition of these Technical Rules, additional recommendations for a simplified assessment will be provided.

1.3.2 Detailed assessment (Stage 2)

The detailed assessment is based on repetitive voltage changes. It shall be noted that the worst-case flicker-related apparent power change ΔS_A (e.g. maximum AC power or starting power) is used. Customer installations with low power changes can thus be permitted without further testing.

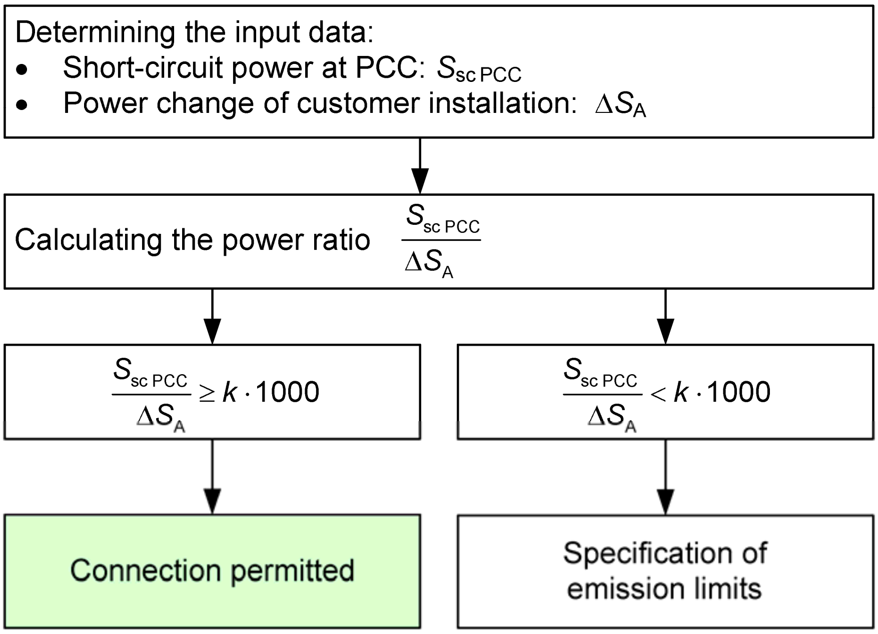


Fig. 1-2: Flowchart of the detailed assessment of voltage changes and flicker

The factor *k* shall be selected from Tab. 1-2.

Tab. 1-2: Factor k

Type of connection	***k***
three-phase	1
two-phase (without neutral conductor)	$\sqrt{3}$
single-phase	6

If the worst-case repetition rate to be expected from the customer installation is known, the power ratio given in Fig. 1-2 can be selected for the assessment according Tab. 1-3.

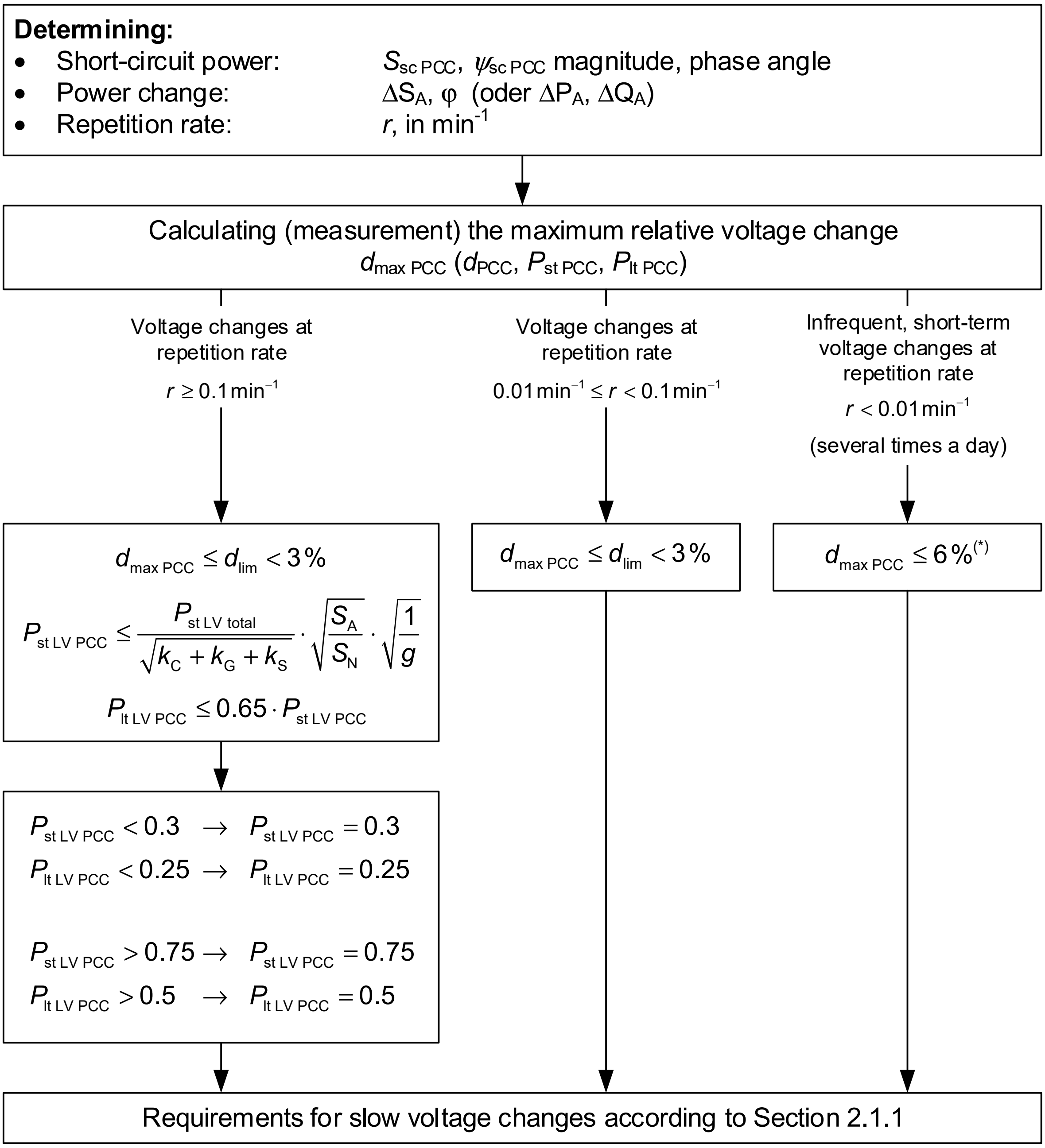
Tab. 1-3: Power ratio limits at different repetition rates

Repetition rate r / min^{-1}	**Power ratio $S_{sc\,PCC}/\Delta S_{A\,i}$**
$r > 500$	$k \cdot 1{,}000$
$10 \leq r \leq 500$	$135 \cdot k \cdot \sqrt[3]{r/\text{min}^{-1}}$
$r < 10$	$k \cdot 500$

1.3.3 Flowchart for determining the emission limits

For any customer installation that does not meet the preconditions for the simplified or detailed assessment, an individual specification of emission limits is required. This is necessary because high-power customer installations can affect a larger network area.

Fig. 1-3 shows the procedure for calculating the emission limits. Additionally, compliance with the requirements for slow voltage changes is required.



(*) After consultation with the DSO

Fig. 1-3: Flowchart for determining the emission limits for voltage changes and flicker

1.3.4 Additional guidance for the assessment

The customer installation shall be assessed according to the following criteria:

- When determining the long-term flicker severity of a customer installation, it shall be taken into account that due to to the superposition with the contribution from other customer installations and the upstream network, the overall level complies with the selected planning level. In no case, the compatibility level for the long-term flicker severity P_{lt} = 0,8 [EN 61000-2-2] may be exceeded.
- The decisive parameter for the behaviour of an installation is the short-circuit power at the POC. The values for Δu, d, P_{st} and P_{lt} determined at the POC shall be converted to the PCC.
- The short-circuit power at the PCC $S_{sc\,PCC}$ or at the POC $S_{sc\,POC}$ is calculated according to Part A "Fundamentals", Section 3. To determine the relative voltage change, the load change indicated as apparent power change ΔS_A of the customer installation or the appliance to be assessed shall also be known.
- The repetition rate r_i shall be taken into account when assessing the voltage change. The maximum voltage change d_{max} caused by the operation of a customer installation is calculated from that power change which induces the highest voltage change or the highest flicker level.
- The phase conductor in which the highest voltage changes occur shall be selected. Non flicker-related transient voltage changes are not to be taken into account when determining d_{max}.
- The emission of a customer installation represents the voltage change d or the flicker severity P_{st}, which is caused solely by the load change of this installation at the PCC.
- In particular, the observation time shall include that part of the total operating time during which the worst-case sequence of voltage changes is induced.
- The flicker level P_{st} in the network or the resulting voltage change characteristic $d(t)$ is the outcome of the cumulative effect of all customer installations in the network and is therefore always higher than the corresponding values (contribution) of the individual customer installation.
- When assessing existing customer installations, the maximum values of d as well as of P_{st} and P_{lt} are to be determined by measurement. In particular, for stochastic voltage changes of irregular amplitude and shape, a reliable assessment is only possible by measurement.
- For load changes occurring only a few times a day (e.g. switching on high-power loads in the customer installation), the flicker limits are not to be applied. For infrequent load changes with r < 0.01 min^{-1}, higher voltage changes are permitted (see flowchart).

1.3.5 Distribution transformers with onload tap changer (OLTC transformers)

Distribution transformers with on load tap changer cause voltage changes due to their control response which can result in flicker. Therefore, it is necessary to specify technical requirements.

The following limit values are recommended:

- For self-regulating operation:
  - maximum voltage change d_{max} = 3 %,
  - $P_{st\ PCC}$ = 0.35, $P_{lt\ PCC}$ = 0.25.
- For tap changing:
  - maximum voltage change d_{max} = 6 %,
  - for repetition rates r < 0.01 min^{-1} (several times per day) no flicker limits have to be considered.

Note:
With two voltage changes within a 10-min interval, P_{st} = 0.35 is satisfied with d = 1.5 %.

1.3.6 Measurement

To check the permitted emissions of individual customer installations or the total emission of all customer installations, the 95 % quantile of the probability distribution of a one-week period shall be analysed.

- $P_{lt\ 95\%}$ and $P_{st\ 95\%}$ shall not exceed the permitted values of P_{lt} and P_{st} at any PCC in the network.
  In addition, no single value of short-term flicker severity shall exceed 1.3 · P_{st}.
- $P_{lt\ total\ 95\%}$ and $P_{st\ total\ 95\%}$ shall not exceed the permitted values of $P_{lt\ total}$ and $P_{st\ total}$ at any PCC in the network.
  In addition, no single value of short-term flicker severity shall exceed 1.3 · $P_{st\ total}$.

Note:
For the measurement-based compliance verification, the background level has to be taken into account, if applicable.

2. Unbalance

The determination of emission limits of customer installations is based on the allocation of permitted contributions to the negative-sequence voltage unbalance. For a simplified assessment, these limits are usually expressed to negative-sequence currents.

High-power generating units, storage units and consuming appliances shall always be connected with a balanced three-phase connection.

If the customer installation consists of unbalanced installed generating and/or storage units and/or consuming appliances, these are to be allocated to the phase conductors in such a way that the unbalanced power of the customer installation is as low as possible during operation.

2.1 Compatibility level

The compatibility level of the (negative-sequence) voltage unbalance is C_{U2} = 2 % according to [EN 61000-2-2].

2.2 Emission limits

The equation for calculating the emission limit of a customer installation at the PCC is based on the general approach according to [IEC 61000-3-14]. Simplifying assumptions and suitable combining or conversion processes result in the following equation:

$$I_{2\,\mathrm{PCC}} = \frac{s}{1000} \cdot \frac{1}{\sqrt{k_\mathrm{G} + k_\mathrm{C} + k_\mathrm{S}}} \cdot \sqrt{\frac{S_\mathrm{sc\,PCC}}{S_\mathrm{A}}} \cdot I_\mathrm{A} \tag{2-1}$$

where

S_A	*is the agreed power of the customer installation,*
$S_{sc\,PCC}$	*is the short-circuit power,*
k_G	*is the generation capacity factor,*
k_C	*is the consumption capacity factor,*
k_S	*is the storage capacity factor,*
$I_{2\,PCC}$	*is the permitted negative-sequence current of the customer installation,*
I_A	*is the installation current,*
s	*is the proportionality factor of the unbalance.*

Equation (2-1) was derived following the same methodology like for harmonic limits. The proportionality factor s is significantly dominated by the characteristics of the LV network and depends, for example, on the length of the feeders, on the differences of the length between feeders and on the distribution of the customer installations along the feeders. The characteristic of an LV network is represented by the minimum short-circuit power of all network nodes within the related LV network and the rated power of the MV/LV supply transformer. Tab. 2-1 provides reference values for the proportionality factor as a function of the rated transformer power S_{rT} and the minimum short-circuit power in the respective network.

Tab. 2-1: Reference values for the proportionality factor s as a function of the rated transformer power and the minimum short-circuit power in LV networks

S_{rT}	Proportionality factor *s*					
	30	**25**	**20**	**15**	**10**	
100 kVA	>0.7 MVA	0.7 .. 0.5 MVA	0.5 .. 0.3 MVA	0.3 .. 0.2 MVA	<0.2 MVA	Minimum short-circuit power
250 kVA	>1.7 MVA	1.7 .. 1.1 MVA	1.1 .. 0.8 MVA	0.8 .. 0.5 MVA	<0.5 MVA	
400 kVA	>2.1 MVA	2.1 .. 1.7 MVA	1.7 .. 1.4 MVA	1.4 .. 1.2 MVA	<1.2 MVA	
630 kVA	>3.2 MVA	3.2 .. 2.5 MVA	2.5 .. 2.0 MVA	2.0 .. 1.5 MVA	<1.5 MVA	
1 000 kVA	>4.1 MVA	4.1 .. 3.1 MVA	3.1 .. 2.4 MVA	2.4 .. 1.8 MVA	<1.8 MVA	

For rated transformer powers not indicated in the table, the next higher or the highest rated power shall be selected.

If no further details of the network configuration are known, the proportionality factor *s* = 15 is recommended.

Instead of the permitted negative-sequence current, the permitted unbalanced power can be calculated and provided as a limit value:

$$S_{\text{A un}} = \frac{s}{1000} \cdot \frac{1}{\sqrt{k_{\text{G}} + k_{\text{C}} + k_{\text{S}}}} \cdot \sqrt{\frac{S_{\text{sc PCC}}}{S_{\text{A}}}} \cdot S_{\text{A}} \qquad (2\text{-}2)$$

where

s — *is the proportionality factor of the unbalance.*
$S_{A\,un}$ — *is the permitted unbalanced power of the customer installation,*
S_A — *is the agreed power of the customer installation,*
$S_{sc\,PCC}$ — *is the short-circuit power,*
k_G — *is the generation capacity factor,*
k_C — *is the consumption capacity factor,*
k_S — *is the storage capacity factor.*

Note:
If k_C, k_G and k_S are not known, $k_C + k_G + k_S = 1$ can be assumed for networks where no connection of generating and storage installations is expected. Otherwise, it is recommended to use $k_C + k_G + k_S = 1.35$.

If required, the agreed power of the customer installation S_A can be calculated either from the nominal fuse current or from the agreed powers of the individual appliances or units and their allocation to the phase conductors. If the nominal fuse current of the customer installation is known, the agreed power of the customer installation S_A is calculated using the following equation:

$$S_{\text{A}} = \sqrt{3} \cdot U_{\text{n}} \cdot I_{\text{n}} \qquad (2\text{-}3)$$

where

S_A — *is the agreed power of the customer installation,*
U_n — *is the nominal network voltage,*
I_n — *is the nominal fuse current.*

For a given combination of individual appliances and units, the agreed power of the customer installation S_A corresponds to three times the maximum absolute value of the phase power, which can occur under worst-case operating condition. Tab. 2-2 includes calculation examples for the agreed power of customer installations when individual single-phase appliances and units are connected.

Tab. 2-2: Calculation examples for the agreed power of customer installations

Example	S_{L1}	S_{L2}	S_{L3}	S_A
Generating unit (3.7 kVA) in L1, Storage unit (3.0 kVA, discharging) in L2	3.7 kVA	3.0 kVA	0 kVA	3 · 3.7 kVA = 11.1 kVA
Generating unit (3.7 kVA) in L1, Consumer unit (3.0 kVA) in L1	3.7 kVA	0 kVA	0 kVA	3 · 3.7 kVA = 11.1 kVA
Generating unit (3.7 kVA) in L1, Storage unit (3.0 kVA, discharging) in L1	3.7 kVA + 3.0 kVA	0 kVA	0 kVA	3 · 6.7 kVA = 20.1 kVA
Consumer installation (3.0 kVA) in L1, Storage installation (3.0 kVA, charging) in L1	3.0 kVA + 3.0 kVA	0 kVA	0 kVA	3 · 6.0 kVA = 18.0 kVA

Knowing the related parameters, a specific proportionality factor s can be determined using the following equation:

$$s = \frac{k_{\mathrm{u\,BB}} \cdot G_{\mathrm{un\,LV}}}{\sqrt{u_{\mathrm{sc}}}} \cdot 1000 \tag{2-4}$$

where

s	*is the proportionality factor of the unbalance.*
$k_{u\,BB}$	*is the reduction factor, depending on the characteristic of the network,*
$G_{un\,LV}$	*is the global contribution in the LV network,*
u_{sc}	*is the short-circuit voltage of the MV/LV transformer.*

The range of values for the global contribution in the LV network is obtained by assuming the planning level for the unbalance factor of the voltage in MV networks according to [EN 61000-3-13], the compatibility level for the unbalance factor of the voltage in LV networks according to [EN 61000-2-2] as well as ranges of realistic values for the summation exponent α (1.4 .. 2.0) and the transfer coefficient $T_{MV\text{-}LV}$ between the MV and the LV network (0.8 .. 0.9).

The reduction factor $k_{u\,BB}$ can be approximated using the following equation:

$$k_{\mathrm{u\,BB}} = a + b \cdot \ln\left(\frac{S_{\mathrm{sc\,min}}}{\mathrm{MVA}}\right) \tag{2-5}$$

where

$S_{sc\,min}$	*is the minimum short-circuit power on all POCs throughout the network,*
$k_{u\,BB}$	*is the reduction factor, depending on the characteristics of the network,*
a, b	*are the parameters according to Tab. 2-3.*

The parameters for equation (2-5) are indicated in Tab. 2-3.

Tab. 2-3: Parameters for estimating the reduction factor $k_{u\,BB}$ in LV networks

S_{rT} in kVA	a	b
100	0.78	0.25
250	0.43	0.25
400	0.26	0.40
630	0.11	0.40
1 000	0.08	0.35

If the $k_{u\,BB}$ value is to be determined with higher accuracy, the procedure described in [IEC 61000-3-14] can be used to calculate $k_{u\,BB}$ directly. According to this procedure, a new $k_{u\,BB}$ value shall be determined each time another customer installation is connected or in case the network configuration has been changed.

2.3 Assessment

2.3.1 Marginal criterion

Marginal criterion for individual appliances and units

For individual appliances and units with long-term operation (e.g. PV inverters, storage installations, charging units for electric vehicles), the rated power shall not exceed the values according to Tab. 2-4, depending on the type of connection and operating conditions.

Tab. 2-4: Maximum rated power of individual appliances and units in LV networks

Type of connection of the individual appliance/unit	$S_{r\,perm}$
single-phase	3.7 kVA
two-phase without neutral conductor	3.7 kVA
two-phase with neutral conductor	2 · 3.7 kVA

For individual appliances and units with operating times of less than 10 min (e.g. continuous-flow heaters), a maximum rated power $S_{r\,perm}$ = 4.6 kVA ($I_{r\,perm}$ = 20 A) is permitted.

If several individual appliances or units are installed unbalanced in a customer installation, an assessment of the unbalanced power is mandatory.

Marginal criterion for installations

For a customer installation, which comprises several individual appliances or units, an unbalanced power of 3.7 kVA is always permitted, regardless of the POC. With the reference impedance according to [IEC 60725], this results in a contribution to the unbalance factor of the voltage of:

$$k_{U2} = \frac{S_{A\,un}}{S_{sc\,PCC}} \leq \frac{3.7\,\text{kVA}}{565\,\text{kVA}} \leq 0.65\,\% \tag{2-6}$$

where

$S_{A\,un}$ *is the permitted unbalanced power of the customer installation,*

$S_{sc\,PCC}$ *is the short-circuit power,*

k_{U2} *is the contribution to the unbalance factor of the voltage.*

If the marginal criterion is not satisfied, an assessment according to stage 1 is required.

2.3.2 Simplified assessment (Stage 1)

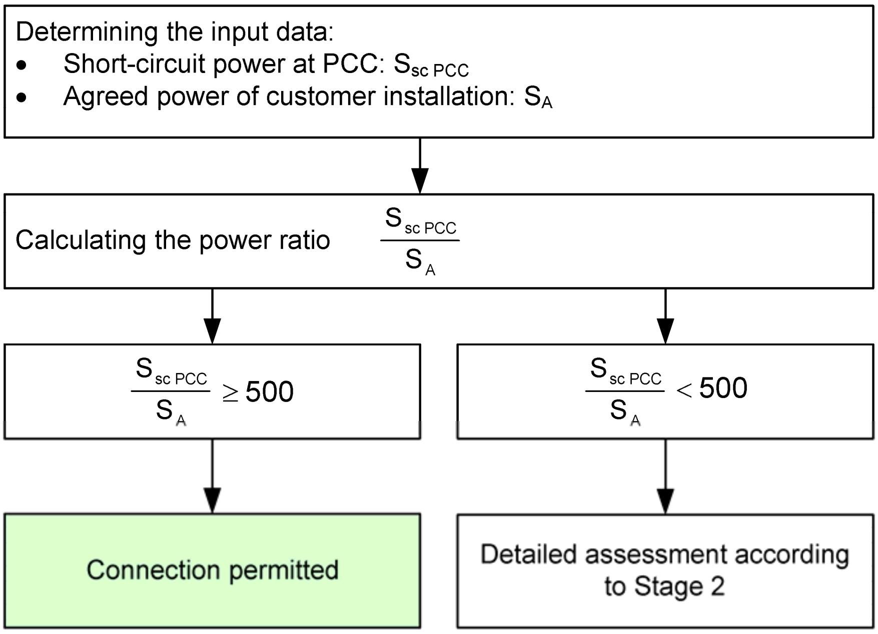


Fig. 2-1: Flowchart of the simplified assessment of the unbalance in LV networks

Note:
Assuming that in certain situations the unbalanced power of a customer installation might also conform to the agreed power of this customer installation, the contribution to the unbalance factor of the voltage for the ratio $S_{sc\ PCC}/S_A = 500$ is $k_{U2} \approx 0{,}2$ %.

2.3.3 Detailed assessment (Stage 2)

If the share of individual balanced appliances or units within the customer installation is known, a limiting ratio $S_{A\ unbal}/S_A$ can be specified using the following equations, where all powers are to be applied with positive signs:

$$\frac{S_{A\ unbal}}{S_A} = \frac{1}{\sqrt{500}} \cdot \sqrt{\frac{S_{sc\ PCC}}{S_A}} \tag{2-7}$$

$$S_{A\ unbal} = \left(S_{A\ G} - S_{A\ G\ bal}\right) + \left(S_{A\ C} - S_{A\ C\ bal}\right) + \left(S_{A\ S} - S_{A\ S\ bal}\right) \tag{2-8}$$

where

$S_{A\ unbal}$	*is the unbalanced part of the agreed power of the customer installation,*
$S_{A\ G}$	*is the total power of all generating units of the customer installation,*
$S_{A\ G\ bal}$	*is the balanced part of the power of all generating units of the customer installation,*
$S_{A\ C}$	*is the total power of all consuming units of the customer installation,*
$S_{A\ C\ bal}$	*is the balanced part of the power of all consuming units of the customer installation,*
$S_{A\ S}$	*is the total power of all storage units of the customer installation,*
$S_{A\ S\ bal}$	*is the balanced part of the power of all storage units of the customer installation,*
S_A	*is the agreed power of the customer installation,*
$S_{sc\ PCC}$	*is the short-circuit power.*

Note:
The unbalanced part of the agreed power of the customer installation $S_{A\ unbal}$ is not related to the unbalanced power $S_{A\ un}$. If $S_{A\ unbal}$ exceeds the absolute value of S_A, $S_{A\ unbal}$ should be equal to *S_A.*

Alternatively, the diagram below (Fig. 2-2) can be used for assessment. The connection of the customer installation is permitted if the pair of values [$S_{A\ unbal}/S_A$; $S_{sc\ PCC}/S_A$] in the diagram is below the curve.

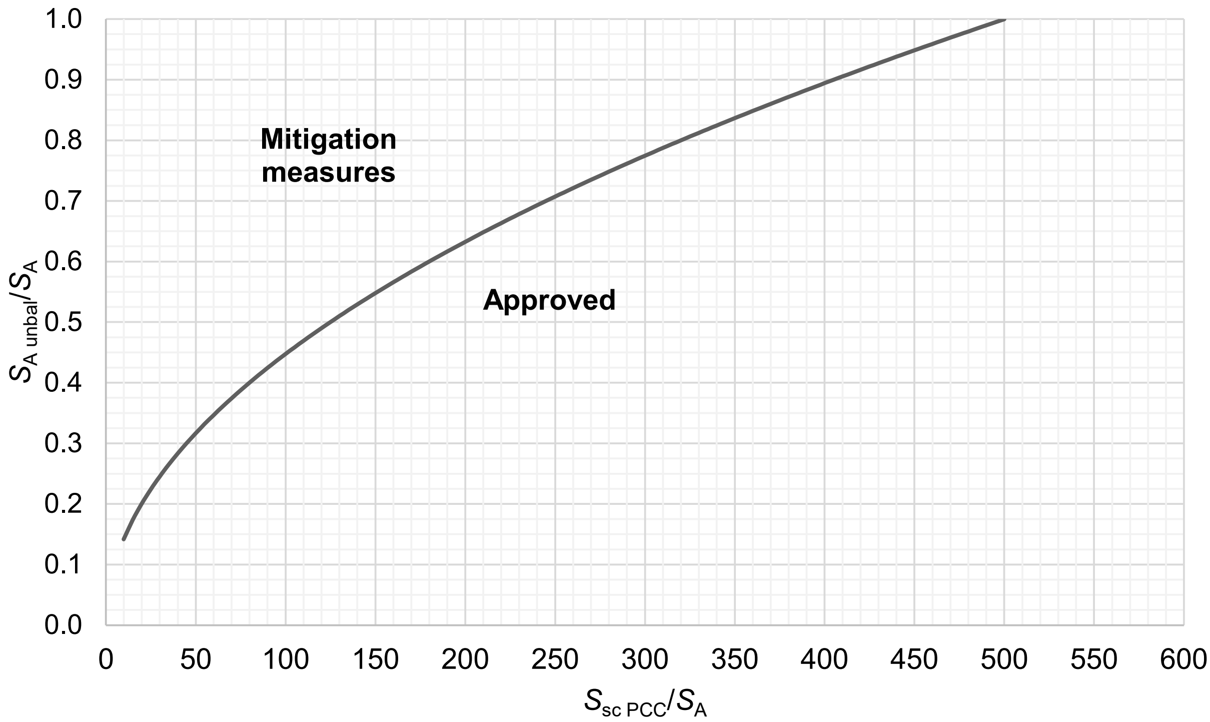


Fig. 2-2: Diagram for the detailed assessment

In case the pair of values [$S_{A\ unbal}/S_A$; $S_{sc\ PCC}/S_A$] is in the range above the curve, an emission limit shall be calculated using Equation (2-1), which shall be met by the customer installation.

It is recommended to specify an emission limit (absolute value of the negative-sequence current $I_{2\ PCC}$ or the unbalanced power $S_{A\ un}$) for the customer installation even if it is in the permitted range.

Note:
If a customer installation with an agreed power of 50 kVA is connected to a POC with a short-circuit power of 10 MVA, the contribution of balanced agreed power shall be at least 36.8 % (18.4 kVA).

Equation (2-1) can result in impractically low values. Therefore, a contribution to the unbalance factor of the voltage of k_{U2} = 0.2 % is allowed for each customer installation, irrespective of its size. The permitted negative-sequence current $I_{2\ PCC}$ can then be calculated according the following equation:

$$I_{2\ PCC} = \frac{1}{500} \cdot \frac{S_{sc\ PCC}}{\sqrt{3} \cdot U_{PCC}} \quad (2\text{-}9)$$

where
$S_{sc\ PCC}$ *is the short-circuit power,*
$I_{2\ PCC}$ *is the permitted negative-sequence current of the customer installation,*
U_{PCC} *is the phase-to-phase voltage.*

The related unbalanced power can be calculated using the following equation:

$$S_{\text{A un}} = \frac{1}{500} \cdot S_{\text{sc PCC}} \tag{2-10}$$

where

$S_{sc\ PCC}$ *is the short-circuit power,*

$S_{A\ un}$ *is the unbalanced power of the customer installation.*

3. Harmonics, interharmonics and supraharmonics

The determination of emission limits of customer installations is based on the allocation of its permitted contributions to the voltage distortion. For a simplified assessment, these voltage emission limits are expressed as harmonic or interharmonic or supraharmonic currents of the customer installation.

Where LV and MV networks are typically operated as single-fed, radial networks (or as single-fed, open ring networks), an HV network is usually meshed and supplied from multiple EHV infeeds. Therefore, the equations for calculating emission limits are different for LV/MV networks and HV networks.

3.1 Harmonic components

3.1.1 Compatibility levels

The compatibility levels for harmonic voltages in public LV networks are specified in [EN 61000-2-2].

Tab. 3-1: Compatibility levels for harmonic components of the voltage in public LV networks

Odd-order harmonics				**Even-order harmonics**	
No multiples of 3		**Multiples of 3** [a)]			
ν	**Harmonic voltage in %**	ν	**Harmonic voltage in %**	ν	**Harmonic voltage in %**
5	6.0	3	5.0	2	2.0
7	5.0	9	1.5	4	1.0
11	3.5	15	0.4	6	0.5
13	3.0	21	0.3	8	0.5
$17 \leq \nu \leq 37$	$2.27 \cdot \left(\frac{17}{\nu}\right) - 0.27$	$27 \leq \nu \leq 39$	0.2	$10 \leq \nu \leq 40$	$0.25 \cdot \left(\frac{10}{\nu}\right) + 0.25$

a) The levels given for odd-order harmonics which are multiples of 3 apply for zero-sequence harmonics. In addition, the values for 3rd and 9th order harmonics in a three-phase system without a neutral conductor or a load connected between phase and earth can be much lower than the compatibility levels, depending on the unbalance of the network.

3.1.2 Emission limits

All limits for harmonic orders ν are defined for harmonic subgroups according to [EN 61000-4-7].

The general equation for calculating the emission limit of a harmonic current of the order ν of a customer installation at the PCC is:

$$I_{\nu\ \mathrm{perm\ PCC}} = \frac{p_\nu}{1000} \cdot \frac{1}{k_\nu} \cdot \frac{1}{k_{XR}} \cdot \frac{1}{\sqrt{k_C + k_G + k_S}} \cdot \sqrt{\frac{S_{\mathrm{sc\ PCC}}}{S_A}} \cdot I_A \qquad (3\text{-}1)$$

where

p_ν	*is the proportionality factor for the harmonic order ν,*
$I_{\nu\ perm\ PCC}$	*is the permitted harmonic current of the customer installation,*
I_A	*is the installation current of the customer installation,*
$S_{sc\ PCC}$	*is the short-circuit power,*
S_A	*is the agreed power of the customer installation,*
k_ν	*is the resonance factor for the harmonic order ν,*
k_{XR}	*is the impedance angle factor,*
k_C	*is the consumption capacity factor,*
k_G	*is the generation capacity factor,*
k_S	*is the storage capacity factor.*

Further guidance and details on the individual factors can be found in Part A “Fundamentals”, Section 6.

Tab. 3-2 provides reference values for the proportionality factor p_ν.

Tab. 3-2: Reference values for the proportionality factor p_ν for calculating permitted harmonic currents

ν	p_ν	ν	p_ν	ν	p_ν
2	4.5	15	0.3	28	0.4
3	5.7	16	0.9	29	1.0
4	2.9	17	2.6	30	0.3
5	13.1	18	0.5	31	0.9
6	1.1	19	2.1	32	0.4
7	7.8	20	0.7	33	0.1
8	1.2	21	0.2	34	0.4
9	1.2	22	0.6	35	0.7
10	1.6	23	1.6	36	0.2
11	5.1	24	0.4	37	0.7
12	0.8	25	1.4	38	0.3
13	3.7	26	0.5	39	0.1
14	1.0	27	0.1	40	0.3

Note:
Harmonics which are multiples of 3 primarily form zero-sequence systems, which add up in the neutral conductor. Therefore, appropriately lower proportionality factors are defined. If it is known for a customer installation that it cannot emit zero-sequence systems (e.g. without neutral conductor) or the installation is connected directly to the transformer busbar, higher values for the proportionality factors of the harmonics which are multiples of 3 can be applied in agreement with the DSO.

It is recommended to determine the k factors in equation (3-1) individually for the related network. Guidance and reference values can be found in Part A "Fundamentals", Sections 6.2 and 6.3.

If no detailed information is available, the following can be assumed for simplification:

- If k_C, k_G and k_S are not known, $k_C + k_G + k_S = 1$ can be assumed for networks where no connection of generating and storage installations is expected. Otherwise, it is recommended to use $k_C + k_G + k_S = 1.35$.
- The short-circuit impedance at the POC is considered to be dominated by its inductive component. In this case $k_{XR} = 1$ can be assumed for the impedance angle factor.
- For all harmonics from the 7th to 25th order, the resonance factor $k_\nu = 1.15$ is recommended. This assumption is based on the fact that particularly in networks with a high density of power electronic devices, due to their capacitive behaviour, the first parallel resonance are to be expected at lower harmonic orders. These reference values are based on extensive measurements and apply to approximately 90 % of the measurement points.

Taking these assumptions into account, the following simplified equation can be used to calculate the harmonic emission limits:

$$\nu = 7\,..\,25: \qquad I_{\nu\ \mathrm{perm}} = \frac{p_\nu}{1150} \cdot \sqrt{\frac{S_{\mathrm{sc\ PCC}}}{S_A}} \cdot I_A \tag{3-2}$$

$$\nu \neq 7\,..\,25: \qquad I_{\nu\ \mathrm{perm}} = \frac{p_\nu}{1000} \cdot \sqrt{\frac{S_{\mathrm{sc\ PCC}}}{S_A}} \cdot I_A \tag{3-3}$$

For harmonic currents of the orders $\nu = 16\,..\,40$, exceeding the limits is permitted up to 1 % of I_A ($\nu = 16\,..\,30$) or 0.8 % of I_A ($\nu = 31\,..\,40$). In this case, the weighted global distortion (PWHIDI) of all emitted harmonic and interharmonic currents

$$\mathrm{PWHIDI} = \frac{1}{I_A} \cdot \sqrt{\sum_{\nu=16}^{40} \nu \cdot I_\nu^2 + \sum_{\mu=16}^{39} \mu \cdot I_\mu^2} \tag{3-4}$$

shall not exceed the PWHIDI of the limit values or 17 % (whichever is higher) (see Section 3.2.2).

3.1.3 Assessment

Appliances that meet the requirements of [EN 61000-3-2] may generally be connected without further testing. For appliances that meet the special connection conditions according to [EN 61000-3-12], it shall be ensured that the installation impedance is less than the specified installation impedance. In any case, it shall be ensured that in an accumulation of harmonics-generating appliances at a high simultaneity factor in the customer installation, the emission limits of the installation are complied with.

3.1.3.1 Simplified assessment (Stage 1)

The simplified assessment is performed according to the flowchart in Fig. 3-1.

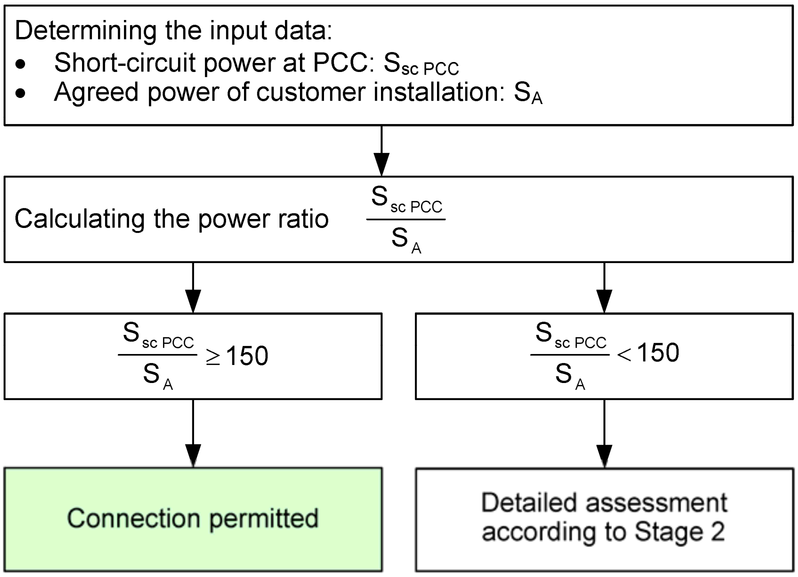


Fig. 3-1: Flowchart of the simplified assessment

3.1.3.2 Detailed assessment (Stage 2)

If the contributions of individual harmonics-generating appliances or units within the customer installation are known, a ratio S_{HG}/S_A can be calculated using the following equation:

$$\frac{S_{HG}}{S_A} = \frac{1}{\sqrt{150}} \cdot \sqrt{\frac{S_{sc\ PCC}}{S_A}} \qquad (3\text{-}5)$$

where

S_{HG}	*is the weighted distorted power of the customer installation,*
S_A	*is the agreed power of the customer installation,*
$S_{sc\ PCC}$	*is the short-circuit power.*

The detailed assessment is based on the fact that all significant harmonics-generating appliances in the customer installation are combined to a resulting weighted distorted power S_{HG}.

In order to determine the weighted distorted power of the customer installation, all harmonics-generating appliances are divided into three classes according to Part A “Fundamentals”, Section 6.7, taking into account any existing simultaneities. The weighted distorted power is determined according to the following equation:

$$S_{HG} = \frac{1}{2} \cdot S_{Cl\ 1} + S_{Cl\ 2} + 2 \cdot S_{Cl\ 3} \qquad (3\text{-}6)$$

where

S_{HG}	*is the weighted distorted power of the customer installation,*
$S_{Cl\ 1}$	*is the total power of all class 1 appliances (THDi $\leq$ 25 %),*
$S_{Cl\ 2}$	*is the total power of all class 2 appliances (25 %< THDi $\leq$ 50 %),*
$S_{Cl\ 3}$	*is the total power of all class 3 appliances (THDi > 50 %).*

If S_{HG} exceeds S_A, then S_{HG} has to be set equal to S_A. The rated powers are used in the summation. If a customer installation contains harmonics-generating consumer appliances as well as harmonics-generating generating and/or storage installations, their rated powers are added without signs.

The detailed assessment is performed according to the flowchart in Fig. 3-2.

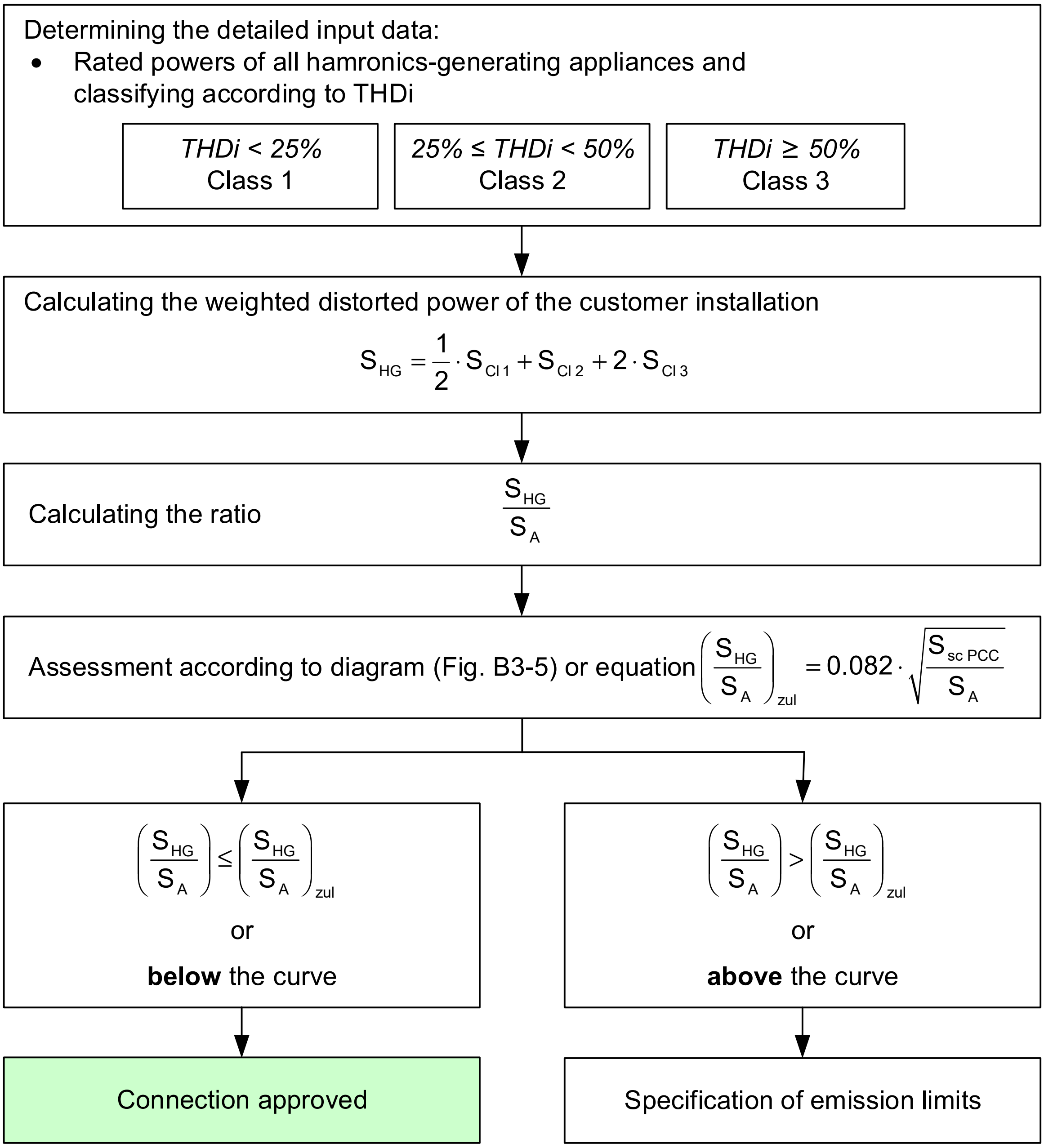


Fig. 3-2: Flowchart of the detailed assessment

The connection of the customer installation is permitted if the pair of values [S_{HG}/S_A; $S_{sc\ PCC}/S_A$] in the diagram in Fig. 3-3 is below the curve.

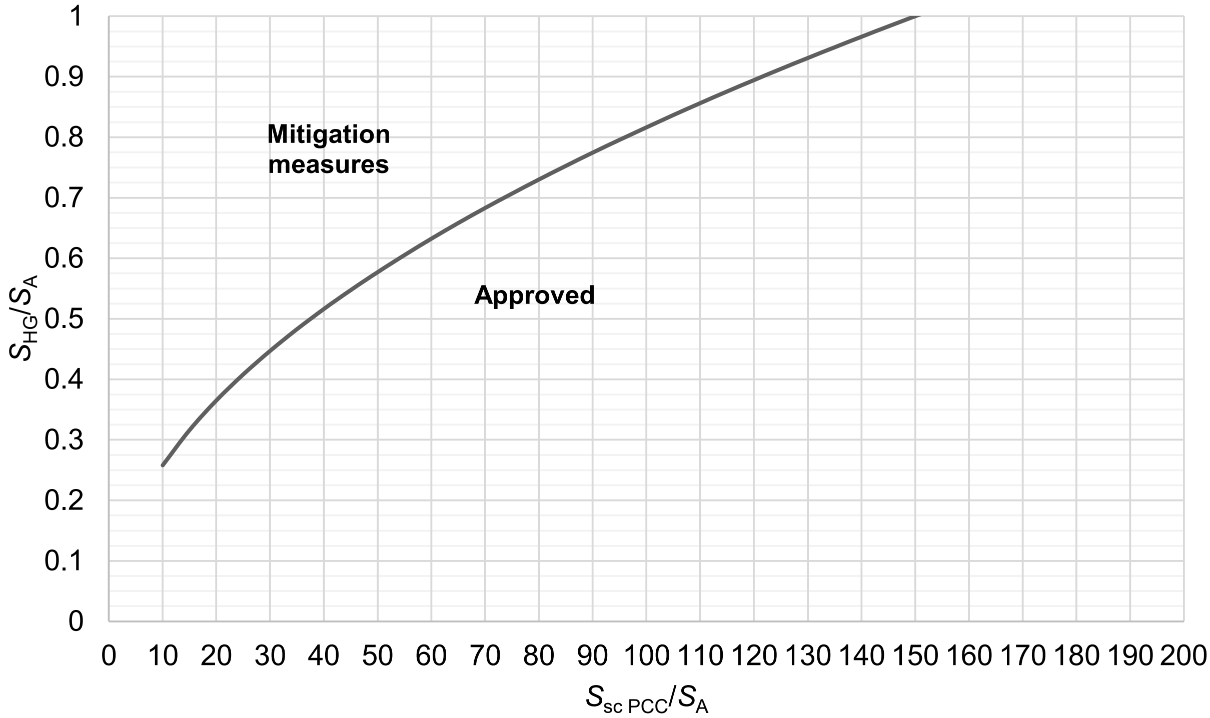


Fig. 3-3: Diagram for the assessment when detailed knowledge of the harmonics-generating appliances in the customer installation is available

3.2 Interharmonics

3.2.1 Compatibility levels

The compatibility levels (Tab. 3-3) are based on the informative details in [EN 61000-2-2].

Tab. 3-3: Compatibility levels for interharmonic voltages in public LV networks

Order μ	**Compatibility level**
1, 2	0.15%
μ > 2 at ripple-control frequency	0.1%
μ > 2 out of ripple-control frequency	0.3%

3.2.2 Emission limits

All limits for interharmonic orders μ are defined as harmonic subgroups according to [EN 61000-4-7].

The emission limits are calculated using the following equation:

$$I_{\mu\ \mathrm{perm\ PCC}} = \frac{1}{k_\mu} \cdot \frac{g_\mu}{100} \cdot \frac{S_{\mathrm{sc\ PCC}}}{S_\mathrm{A}} \cdot I_\mathrm{A} \quad (3\text{-}7)$$

where

g_μ *is the proportionality factor for interharmonics of the order μ,*
$I_{\mu\ perm\ PCC}$ *is the permitted interharmonic current,*
I_A *is the installation current of the customer installation,*
$S_{sc\ PCC}$ *is the short-circuit power,*
S_A *is the agreed power of the customer installation,*
k_μ *is the resonance factor for interharmonics of the order μ.*

For the interharmonic component μ of a customer installation, the proportionality factors g_μ according to Tab. 3-4 apply.

Tab. 3-4: Proportionality factors for the simplified calculation of the permitted interharmonic currents

μ	g_μ
1 .. 30	0.2/(μ + 0.5)
31 .. 39	0.3/(μ + 0.5)
3 .. 39[1)]	0.1/(μ + 0.5)

1) Applies to the interharmonic component at or near the ripple-control frequency (see also Section 5.3).

For interharmonic currents of the orders μ = 16 .. 39, exceeding the limits is permitted up to 1 % of I_A (μ = 16 .. 29) or 0.8 % of I_A (μ = 30 .. 39) provided they are not close to the ripple-control frequency. In this case, the partially weighted harmonic and interharmonic distortion (PWHIDI) of all relevant harmonic and interharmonic currents

$$\mathrm{PWHIDI} = \frac{1}{I_\mathrm{A}} \cdot \sqrt{\sum_{\nu=16}^{40} \nu \cdot I_\nu^2 + \sum_{\mu=16}^{39} \mu \cdot I_\mu^2} \quad (3\text{-}8)$$

shall not exceed the PWHIDI calculated from the limit values or 17 % (whichever is higher) (see also Section 3.1.2).

3.2.3 Assessment

An assessment based on power ratios is not intended for interharmonic components.

3.3 Supraharmonics

3.3.1 Compatibility levels

Tab. 3-5 shows the compatibility levels in the frequency range from 2 kHz to 9 kHz for nonintentional, differential mode emissions according to [EN 61000-2-2]. They apply to frequency bands of 200 Hz with the centre frequency *b* according to [EN 61000-4-7].

Tab. 3-5: Compatibility levels for supraharmonic voltages in public LV networks in the frequency range from 2 kHz to 9 kHz

Frequency range (kHz)	**Compatibility level (%)**
2 to 3	1.4%
3 to 9	$u_\mathrm{b} = 3.2\,\% \cdot \frac{b}{\mathrm{kHz}}^{-0.7}$

3.3.2 Emission limits

Supraharmonic limits in the frequency range from 2 kHz to 9 kHz are defined based on 200 Hz bands with centre frequency *b* according to [EN 61000-4-7].

For calculating the maximum permitted supraharmonic currents of a customer installation, the following equation shall be used:

$$I_{\mathrm{b\ perm\ PCC}} = \frac{1}{k_\mathrm{b}} \cdot \frac{3.3 \cdot \left(\frac{b}{\mathrm{kHz}}\right)^{-0.52} \cdot 1\,\mathrm{A}}{\left(10.25 - \frac{9\,\mathrm{kHz} - b}{\mathrm{kHz}}\right) \cdot \left(r + (1-r) \cdot \frac{0.57\,\mathrm{MVA}}{S_{\mathrm{sc\ PCC}}}\right)} \tag{3-9}$$

where

$I_{b\ perm\ PCC}$ *is the permitted supraharmonic current,*
k_b *is the resonance factor for the supraharmonic with the centre frequency b,*
$S_{sc\ PCC}$ *is the short-circuit power,*
b *is the centre frequency of the frequency band b,*
r *is the splitting factor.*

Note:
This equation applies for a nominal network voltage U_n = 400 V. For other nominal network voltages, linear extrapolation can be applied.

The values in the table below are to be used for the splitting factor *r*.

Tab. 3-6: Splitting factor for calculating the permitted supraharmonic currents

Short-circuit power $S_{sc\ PCC}$ (MVA)	**Splitting factor *r***
< 2	0.45
≥ 2	0.1

Note:
The permitted supraharmonic currents calculated using Equation (3-9) apply for customer installations equipped with a neutral conductor. For three-phase connected customer installations without a neutral conductor, the permitted emission limits may be higher by a factor of 1.8.

3.3.3 Assessment

An assessment based on power ratios is not intended for supraharmonic components.

4. Commutation notches

4.1 Compatibility levels

Compatibility levels for commutation notches are not specified.

4.2 Emission limits

The relative depth of commutation notches d_{Com} due to line-commutated converters in consuming, generating or storage installations shall not exceed $d_{\mathrm{Com}} = 10\ \%$ at the PCC during worst-case operating conditions.

4.3 Assessment

An assessment of connected installations with regard to commutation notches is only necessary for (thyristor) controlled line-commutated converters.

Such converter installations operated in LV networks usually exhibit pronounced commutation notches, the depth of which can be calculated with sufficient accuracy according to equation (4-1). In the assessment, the worst-case firing angle during operation shall always be assumed. Start-up processes shall also be taken into account.

$$d_{\mathrm{Com}} = K \cdot \sin\alpha \cdot \frac{6}{p} \cdot \left(u_{\mathrm{sc\,Com}} \cdot \frac{S_{\mathrm{sc\,PCC}}}{S_{\mathrm{Conv}}} + 1 \right)^{-1} \qquad (4\text{-}1)$$

where

d_{Com}	*is the relative depth of a commutation notch (repetitive transient voltage dips),*
K	*is the connection type factor according to the type of connection and the transformer connection symbol,*
$u_{sc\ Com}$	*is the relative short-circuit voltage of the commutation reactance,*
$S_{sc\ PCC}$	*is the short-circuit power at the PCC,*
S_{Conv}	*is the agreed power of the converter installation,*
p	*is the pulse number of the converter*
α	*is the firing angle of the converter.*

For direct connection without transformer or when using a three-phase transformer with the uncommon connection symbols Dd5 or Yy0 (star-star), $K = \sqrt{3}/2$ applies. In case of connection using the standard connection symbol Dy5 or Yd5 (star-delta), $K = 1$ is to be used.

If the converter on the LV side is connected via a commutation reactor and a separate converter transformer with the transformation ratio $k_{\mathrm{T}} = 1$, the resulting relative short-circuit voltage of the commutation reactance is determined using the following equation:

$$u_{\mathrm{sc\,Com}} = u_{\mathrm{sc\,T}} + u_{\mathrm{sc\,R}} \qquad (4\text{-}2)$$

where

$u_{sc\ T}$	*is the relative short-circuit voltage of the converter transformer,*
$u_{sc\ R}$	*is the relative short-circuit voltage of the commutation reactor.*

Using the simplified assumptions (K = 1, α = 90°, p = 6), the worst-case condition is:

$$d_{\text{Com}} = \left(u_{\text{sc Com}} \cdot \frac{S_{\text{sc PCC}}}{S_{\text{Conv}}} + 1 \right)^{-1} \tag{4-3}$$

where

d_{Com}	*is the relative depth of a commutation notch (repetitive transient voltage dip),*
$u_{sc\ Com}$	*is the relative short-circuit voltage of the commutation reactance (reactance of transformer and/or commutation reactor),*
$S_{sc\ PCC}$	*is the short-circuit power at the PCC,*
S_{Conv}	*is the agreed power of the converter installation.*

In general, it is sufficient to consider each converter separately, since the probability of overlapping commutation notches is low. If, on the other hand, several converters are operated synchronously, care shall be taken to ensure that the cumulative effect remains below the emission limit.

4.3.1 Stage 1 – Simplified assessment

The simplified assessment is performed according to the flowchart in Fig. 4-1.

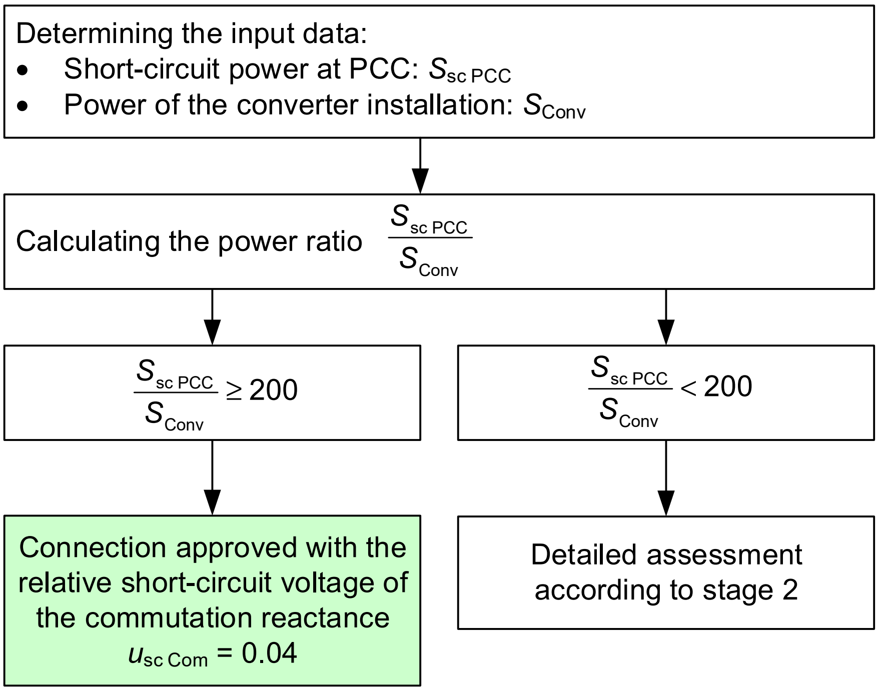


Fig. 4-1: Flowchart of the simplified assessment of commutation notches

If the installation contains only a single converter with a known rated power $S_{\text{r C}}$, this is used instead of the power S_{Conv} of the converter installation in the simplified assessment.

4.3.2 Stage 2 – Detailed assessment

The detailed assessment is performed according to the flowchart in Fig. 4-2.

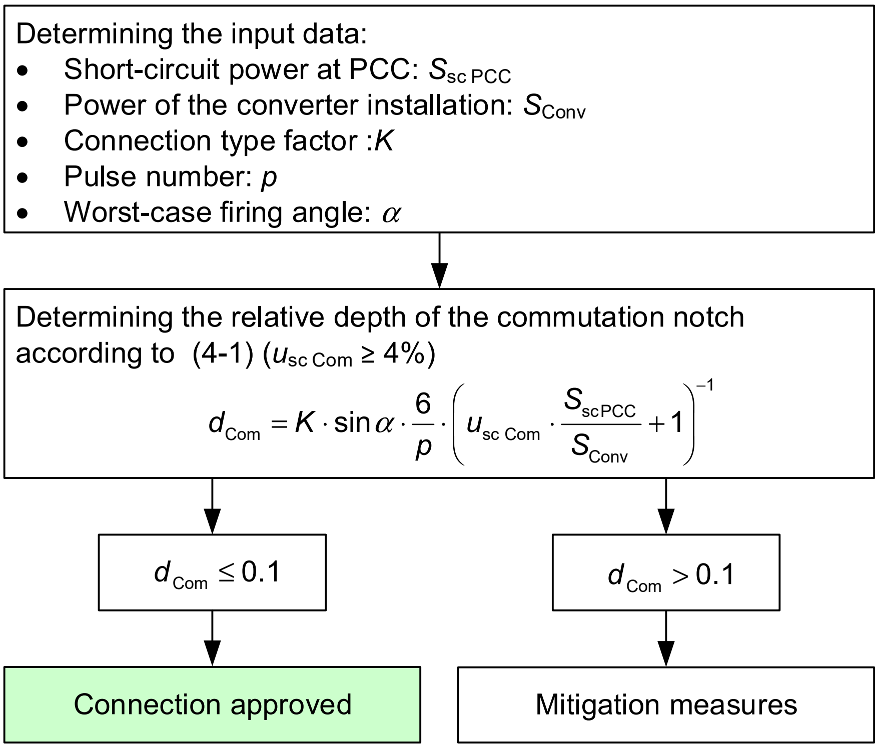


Fig. 4-2: Flowchart of the detailed assessment of commutation notches

5. Mains signalling voltages

5.1 Signal levels

To ensure that the ripple-control receivers in the distribution network respond reliably, the minimum signal level for all receivers shall be above their operating value with a sufficient margin.

Unacceptable high signal levels can result in interferences of customer appliances or installations. Compatibility levels for the network communication are specified in [EN 61000-2-2] (Tab. 5-1) and should not be exceeded by the DSO.

Tab. 5-1 Compatibility levels (differential mode) for the network communication according to [EN 61000-2-2]

	Frequency range	Signal level
AFRC	0.11 kHz to 0.5 kHz	9 % U_n
	0.5 kHz to 3 kHz	9 % to 1.5 % (logarithmically decreasing with the logarithm of the frequency)
PLC	3 kHz to 9 kHz	140 dBμV
	9 kHz to 95 kHz	140 dBμV to 128 dBμV (linearly decreasing with the logarithm of the frequency)
	95 kHz to 150 kHz	128 dBμV

5.2 Assessment

In the assessment, the effect of the frequency-dependent impedance of the customer installations or power-factor correction systems on the AFRC as well as the impact of nonintentional emissions of customer installations near the AFRC frequency have to be considered.

5.2.1 Interferences of the signal level by customer installations

The customer installations connected in an LV network shall not unacceptably decrease or increase the signal level in the LV network. The maximum permitted level reduction depends on the existing margin of the AFRC level in the MV network to the operating voltage of the ripple-control receivers. The following diagram (Fig. 5-1) shows the available margin *σ* (safety factor), with the following equations applying:

$$\sigma = \frac{u_{\mathrm{c\,MV}}}{u_{\mathrm{f}}} \tag{5-1}$$

$$\Delta u_{\mathrm{ARFC}} = \frac{u_{\mathrm{c\,MV}} - u_{\mathrm{c\,R}}}{u_{\mathrm{c\,MV}}} = \frac{\sigma \cdot u_{\mathrm{f}} - 1{,}5 \cdot u_{\mathrm{f}}}{\sigma \cdot u_{\mathrm{f}}} = 1 - \frac{1{,}5}{\sigma} \tag{5-2}$$

where

$u_{c\,MV}$ *is the control signal level in the MV network,*

$u_{c\,R}$ *is the control signal level at the ripple-control receiver,*

u_f *is the operating level of the AFRC,*

σ *is the safety factor,*

Δu_{AFRC} *is the maximum permissible level reduction.*

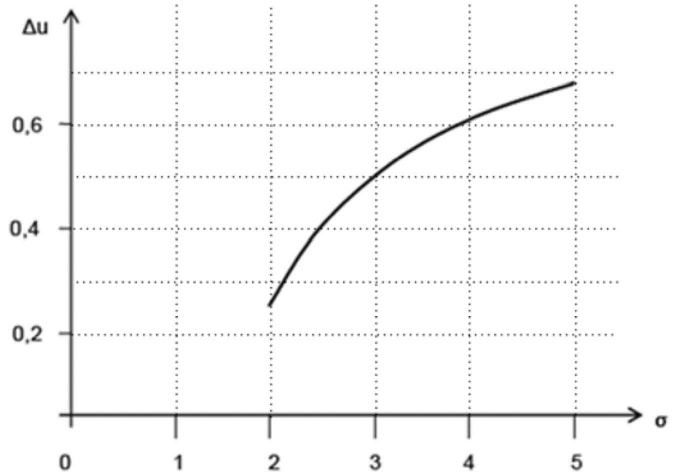


Fig. 5-1: Maximum permissible reduction of the control signal level versus σ [1]

For ripple-control frequencies $f_{AFRC} \leq 250$ Hz, the safety factor σ is 2, and thus the maximum permissible voltage reduction Δu_{ARFC} is 0.25. For ripple-control frequencies $f_{AFRC} > 250$ Hz, the safety factor $\sigma > 2$ is used.

The increase of the ripple-control signal shall not exceed 50 %, irrespective of the ripple-control frequency.

Direct connection of rotating machines (static converters excluded) is permitted up to a rated power of 5 kVA at a PCC or up to 10 kVA in the entire LV network without any specific provisions.

To ensure that the maximum permitted decrease or increase of the ripple-control level in the LV network resulting from the cumulative effect of all customer installations is complied with, a lower limit value has to be specified for an individual customer installation. The decrease or increase of the AFRC level by the customer installation shall not exceed $\Delta u_{AFRC} = 5$ %.

The decreased AFRC level shall always exceed the operating voltage of the ripple-control receivers with a sufficient margin. Otherwise, the customer shall install audio-frequency blocking devices or take another effective measure. The required margin will be specified by the DSO.

The DSO can tolerate higher level changes due to a customer installation as long as the level at all points in the LV network has a sufficient margin to the operating value.

5.2.2 Interference of the signal level by power-factor correction systems

As seen from the MV network, the capacitance of power-factor correction capacitors at the LV side form a series resonant circuit with the inductance of the MV/LV transformer. As the capacitance increases, its resonance frequency decreases. If power-factor correction systems contain several capacitors that can be switched in stages, this results in changing resonance frequencies.

De-tuning means that an inductance is connected upstream of the capacitors. This inductance is designed so that the resonance frequency of the resonant circuit is below the AFRC frequency, so that the resonant circuit has a high impedance at the AFRC frequency.

All power-factor correction systems with a power $S_{Comp} \leq 25$ kvar and AFRC frequencies $f > 350$ Hz shall be de-tuned. Power-factor correction systems with a power $S_{Comp} > 25$ kvar shall always be de-tuned, irrespective of the ripple-control frequency used.

The degree of de-tuning is expressed by the de-tuning ratio *p*, for which the following equation applies:

$$p = \left(\frac{f_N}{f_{res}} \right)^2 \qquad (5\text{-}3)$$

where

p *is the de-tuning ratio,*

f_N *is the power frequency,*

f_{res} *is the series resonance frequency of the de-tuned power-factor correction system.*

For the de-tuning ratio, the following values are recommended.

Tab. 5-2: Recommended de-tuning ratio p

Ripple-control frequency	**De-tuning ratio *p***
< 250 Hz	≥ 14 %
250 .. 350 Hz	≥ 7 %
> 350 Hz	≥ 5 %

Note:
The de-tuning ratio is the ratio of the 50 Hz power of the de-tuning reactor to the 50 Hz power of the power-factor correction capacitance.

For a power-factor correction system de-tuned with *p* = 7 %, the resonance frequency is 189 Hz according to the equation.

5.3 Emissions of customer installations

If the customer installation causes emissions with a frequency equal to the AFRC frequency or near this frequency in the LV network, these emissions shall not exceed 0.1 % U_n.

If the customer installation causes emissions with a frequency equal to or near the spurious frequencies of the AFRC frequency $f_{ARFC} \pm 100$ Hz, this emission shall not exceed 0.3 % U_n.

List of standards

IEC/TR 60725 Ed. 3.0:2012-06
Consideration of reference impedances and public supply network impedances for use in determining the disturbance characteristics of electrical equipment having a rated current ≤ 75 A per phase

EN 61000-2-2:2020
Electromagnetic compatibility (EMC) – Part 2-2: Environment – Compatibility levels for low-frequency conducted disturbances and signalling in public low-voltage power supply systems (IEC 61000-2-2:2002 + A1:2017 + A2:2018); German version EN 61000-2-2:2002 + A1:2017 + A2:2019

EN 61000-3-2:2014
Electromagnetic compatibility (EMC) – Part 3-2: Limits – Limits for harmonic current emissions (equipment input current ≤16 A per phase)

EN 61000-3-3:2013
Electromagnetic compatibility (EMC) – Part 3-3: Limits – Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current ≤16 A per phase

EN 61000-3-11:2000
Electromagnetic compatibility; (EMC) Part 3-11: Limits – Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current ≤ 75 A per phase

EN 61000-3-12:2011
Electromagnetic compatibility (EMC) – Part 3-12: Limits – Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current > 16 A and ≤ 75 A per phase

IEC/TR 61000-3-13 Ed. 1.0:2008-02
Electromagnetic compatibility (EMC) – Part 3-13: Limits – Assessment of emission limits for the connection of unbalanced installations to MV, HV and EHV power systems

IEC/TR 61000-3-14 Ed. 1.0:2011-10
Electromagnetic compatibility (EMC) – Part 3-14: Assessment of emission limits for harmonics, interharmonics, voltage fluctuations and unbalance for the connection of disturbing installations to LV power systems

EN 61000-4-7:2002+A1:2009
Electromagnetic compatibility (EMC) – Part 4-7: Testing and measurement techniques – General guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto

EN 61000-4-15:2011
Electromagnetic compatibility (EMC) – Part 4-15: Testing and measurement techniques – Flickermeter – Functional and design specifications

Bibliography

[1] E-Control TOR D3: Tonfrequenz-Rundsteuerung; Empfehlung zur Vermeidung unzulässiger Rückwirkungen