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# Assessment of the Dutch Grid-Code requirements on harmonics

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# 1 Introduction

Among the requirements set out in the Dutch Electrical Grid-Code, "Dutch NE' (NE) [1] on the power quality of new connections of Power Generating Modules (PGM), this paper focuses on those applicable when assessing flicker.

The objective is to highlight issues arising during the application of these requirements either because of inconsistencies between regulations or because of lack of established detailed methodology when applying the requirements. This would assist both Relevant System Operators (RSO) to remain effective in managing power quality levels in their networks and also PGM Developers to review such requirements from the angle of the RSOs' interest.

For the purpose of conducting the analysis, DigSilent Powerfactory software suite [2] was used.

# 2 What is flicker

Flicker phenomenon is among the main characteristics of power (or voltage) quality. According to IEC 61000-3-7:2008, flicker is the impression of unsteadiness of visual sensation induced by a light stimulus whose luminance or spectral distribution fluctuates with time. In other words, flicker is the visible change in brightness of an incandescent lamp.

The electromagnetic phenomenon causing flicker is referred as voltage fluctuations, which are systematic variations of the voltage waveform envelope, or a series of random voltage changes in the voltage of the power supply caused by the voltage drop generated over the source impedance of the grid by the changing load current of fluctuating equipment.

Flicker effects on human can range from disturbance to more severe impact on photosensitive persons. It can affect the production environment by causing personnel fatigue and lower work concentration levels. In addition, voltage fluctuations may subject electrical and electronic equipment to detrimental effects that may disrupt production processes with considerable financial costs. Other effects of voltage fluctuation include the following:

- Nuisance tripping due to misoperation of relays and contactors.
- Unwanted triggering of UPS units to switch to battery mode.
- Problems with some sensitive electronic equipment, which require a constant voltage (i.e. medical laboratories).

The international flickermeter (IEC 61000-4-15 [3]) provides two quantities to characterize the flicker severity: Pst ("st" referring to "short term": one value is obtained for each 10 min period) and Plt ("lt" referring to "long term": one value is obtained for each 2 h period). The flicker related voltage quality criteria are generally expressed in terms of Pst and/or Plt, with Plt typically being derived from groups of 12 consecutive Pst values as per Equation 1.

$$P_{lt} = \sqrt[3]{\frac{1}{12} \cdot \sum_{j=1}^{12} P_{st\,j}^{\,3}}$$

(Equation 1)

# 3 Requirements according to Dutch NE

In accordance with the PGM compliance verification document [4] from Netbeheer Nederland, the following references are included in the Dutch NE regarding power quality requirements on new connections of distributed generation plants:

From Dutch NE, article 2.14:

1. Without prejudice to the provisions in or pursuant to this code, all equipment and appliances in or connected to the electrical installations shall comply with the standards applicable to these operating assets and equipment.

2. The machines, appliances, materials and parts included in an electrical installation comply with the legal requirements established for the trade or use thereof.

3. The electrical installation is resistant to the short-circuit power expected by the grid operator on site.

From Dutch NE, article 2.15:

1. Electrical installations and connected devices do not cause inadmissible interference/disturbances via the Relevant System Operator's (RSO) network.

2. The RSO may request the connected party to make provisions such that the inadmissible nuisance ceases or, for a number of hours determined by the RSO, prohibit the connected party from using equipment and engines to be designated by the RSO.

From Dutch NE, article 2.28:

1. The connected party demonstrates that in the case of machines, devices, materials and components in electrical installations or connected to electrical installations whose electromagnetic compatibility is not laid down in a legal regulation, at the network connection point the requirements for electromagnetic compatibility, imposed by the network operator, are met.

2. For equipment with a capacity greater than 11 kVA, the "Richtlijnen voor toelaatbare harmonische stromen geproduceerd door apparatuur met een vermogen groter dan 11 kVA" of June 1997 issued by EnergieNed apply.

<u>From Dutch NE Article 2.40:</u>

1. In addition to Article 2.14, paragraph 2, the electrical installation and the machines, appliances, materials and parts included therein comply with NPR-IEC/TR 61000-3-7:2008 en (Electromagnetic compatibility – Part 3-7: Limits – Assessment of emission limits for the connection of fluctuating installations to Medium Voltage (MV), High Voltage (HV) and Extra High Voltage (EHV) power systems) [5].

2. In the case of a connection to a high voltage network [a grid with a voltage level higher than 35 kV], the connected party shall demonstrate by calculation that his electrical installation complies with the first paragraph.

3. In the case of a connection to a medium voltage network [a grid with a voltage level higher than 1 kV and lower than or equal to 35 kV], where the power to be connected at the connection point exceeds the values listed in table 3 of the NPR-IEC/TR 61000-3-7:2008, the connected party shall show by means of calculation that his electrical installation complies with the first paragraph.

4. If one of the paragraphs two or three of this article applies, the manner of application of the NPR-IEC/TR 61000-3-7:2008 is laid down in an implementation instruction and is added as an appendix to the connection agreement (ATO).

5. In addition to article 2.28, the "Richtlijn voor harmonische stromen en netspanningsasymmetrie bij éénfasige 25 kV-voedingen" from March 1999, issued by EnergieNed, applies to the connection of single-phase traction power supplies to high-voltage networks.

Concerning flicker emission on the Connection Point, the following limits are proposed in Netcode elektriciteit article 7.3:

1. $P_{LT} \leq 1$ in 95% of all 10 minutes moving average values during one week

2. $P_{LT} \leq 5$ in all 10 minutes moving average values during one week

Regarding the simulation procedure, Flicker $P_{ST}$ and $P_{LT}$ shall be determined at the Connection Point. This should be done at least according to procedure described in NEN-EN-IEC 61400-21-1: 2019 [6] or latest version.

Regarding the evaluation criteria, PGM compliance verification document from Netbeheer Nederland suggest as applicable:

- Evaluation will be performed based on national legislation, standards, rules and best practices;
- Netcode elektriciteit;
- Nederlandse praktijkrichtlijn NPR-IEC/TR 61000-3-7 (en) Electromagnetic compatibility (EMC) – Part 3-7: Limits – Assessment of emission limits for the connection of fluctuating installations to MV, HV and EHV power systems;
- The Emission levels shall be lower than the emission limits: EPsti = 0,35 and EPlti = 0,25;

- Measurements results according to: NEN-EN-IEC 61400-21-1:2019 Wind energy generation systems – Part 21-1: Measurement and assessment of electrical characteristics – Wind turbines, paragraph 8.2: Power quality aspects (or later version).

# 4 Flicker assessment according to IEC 61000-3-7:2008

## 4.1 Review of the general principles and methodologies

IEC 61000-3-7:2008 provides guidance on principles which can be used as the basis for determining the requirements for the connection of fluctuating installations to MV, HV and EHV public power systems (LV installations are covered in other IEC documents). For the purposes of the standard, a fluctuating installation means an installation (which may be a load or a generator) that produces voltage flicker and / or rapid voltage changes. The primary objective of the standard is to provide guidance to system operators or owners on engineering practices which will facilitate the provision of adequate service quality for all connected customers. In addressing installations, the standard does not intend to replace equipment standards for emission limits.

IEC 61000-3-7:2008 addresses the allocation of the capacity of the system to absorb disturbances. It does not address how to mitigate disturbances, nor does it address how the capacity of the system can be increased.

Since the guidelines outlined in the standard are necessarily based on certain simplifying assumptions, there is no guarantee that this approach will always provide the optimum solution for all flicker situations. The recommended approach should be used with flexibility and engineering judgment as far as engineering is concerned, when applying the given assessment procedures in full or in part.

The system operator or owner is responsible for specifying requirements for the connection of fluctuating installations to the system. The fluctuating installation is to be understood as the customer's complete installation (i.e. including fluctuating and non-fluctuating parts).

Problems related to voltage fluctuations fall into two basic categories:

• Flicker effect from light sources as a result of voltage fluctuations;

• Rapid voltage changes even within the normal operational voltage tolerances are considered as a disturbing phenomenon.

Regarding the evaluation of flicker effect, IEC 61000-3-7:2008 suggests Stage 1 as a simplified evaluation of disturbance emission. In Stage 1, the connection of small installations with only a limited amount of fluctuating power can be accepted without detailed evaluation of the emission characteristics or the supply system response.

This paper focuses on issues arising during application of IEC 61000-3-7:2008 on the pre-connection assessment of flicker for distributed generation plants in the medium voltage (MV) which typically fall under the provisions of Stage 2 approach. According to Stage 2 approach, the specific characteristics of the flicker generating equipment within the customer's installation should be evaluated together with the absorption capacity of the system. The absorption capacity of the system is derived from the planning levels and is apportioned to individual customers according to their demand with respect to the total system supply capacity. The disturbance level transferred from upstream voltage systems should also be considered when apportioning the planning levels to individual customers. The principle of this approach is that, if the system is fully utilised to its designed capacity and all customers are injecting up to their individual limits, the total disturbance levels will be equal to the planning levels taking into account transfer factors between different voltage levels and the summation effect of various flicker producing equipment. IEC 61000-3-7:2008 provides indicative values of planning levels for flicker presented in Table 1.

| | **Planning levels** (see NOTE 2) | |
|---|---|---|
| | MV | HV-EHV |
| $P_{st}$ | 0,9 | 0,8 |
| $P_{lt}$ | 0,7 | 0,6 |

**Table 1 – Indicative values of planning levels for flicker in MV, HV and EHV power systems**

Planning levels are voltage flicker levels that can be used for the purpose of determining emission limits, taking into consideration all fluctuating installations. Planning levels are specified by the system operator or owner for all system voltage levels and can be considered as internal quality objectives of the system operator or owner and may be made available to individual customers on request.

Finally, IEC 61000-3-7:2008 suggests Stage 3 approach according to which, under some circumstances, the system operator or owner may accept a fluctuating installation to emit disturbances beyond the basic limits allowed in Stage 2. This is especially the case when Stage 2 limits are generic limits derived using typical but conservative system characteristics.

## 4.2 Flicker emission limits according to Stage 2 approach

According to Stage 2 approach, the allowable global contribution to the overall level of disturbance is apportioned to each individual installation in accordance with its share of the total capacity of the supply system (St) to which this installation is connected. This ensures that the disturbance level due to the emissions of all customers connected to the system will not exceed the planning level. The approach assumes that propagation of flicker disturbances in a radial power system follows quite simple laws:

– The general summation law provided by the standard as a general combination relationship for short-term flicker severity caused by various installations

– The flicker values present at a given voltage level will be transferred downstream with some attenuation (transfer coefficient somewhat lower than 1, e.g. 0.8)

– Due to the increase of short circuit power with that of voltage level and to the low coincidence of voltage changes, flicker contributions from lower to higher voltage systems can be considered practically negligible in most situations

## 4.2.1 Global emission to be shared between the customers

In order to define Power Park Module (PPM) flicker emission limits $E_{Psti}$, $E_{Plti}$ according to Stage 2 approach it is necessary to determine the global contribution of all flicker sources present in a particular system. Indeed, the actual flicker level in a MV system results from the combination of the flicker level coming from the upstream with the flicker level produced by all fluctuating installations connected to the considered MV system, including LV fluctuating installations. A typical representation of such a system would be as in Figure 1.

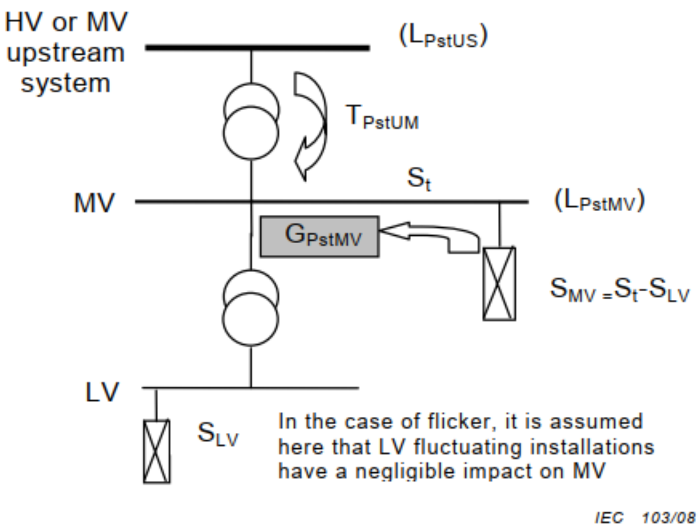


**Figure 1 – Example of a system for sharing global contributions at MV**

However, as already mentioned, it can generally be assumed that LV fluctuating installations only have a negligible impact on MV systems flicker levels. The global contribution for MV fluctuating installations can be determined for $P_{st}$ or similarly for $P_{lt}$ from Equation 2:

$$G_{PstMV} = \sqrt[\alpha]{L_{PstMV}^{\alpha} - T_{PstUM}^{\alpha} \cdot L_{PstUS}^{\alpha}} \qquad \text{(Equation 2)}$$

where:

$G_{PstMV}$ is the maximum global contribution to the flicker level of all the MV fluctuating installations that can be connected to the considered system (expressed in terms of $P_{st}$ or $P_{lt}$);

$L_{PstMV}$ is the planning level for flicker (indices $P_{st}$ or $P_{lt}$) in the MV system;

$L_{PstUS}$ is the planning level for flicker in the upstream system;

$T_{PstUM}$ is the transfer coefficient of flicker ($P_{st}$ or $P_{lt}$) from the upstream system to the MV system;

α is the summation law exponent, commonly equal to 3.

### 4.2.2 Individual flicker emission limits for a PPM

For each customer, only a fraction of the global emission limit $G_{PstMV}$ will be allowed. The individual emission limits ($E_{Psti}$ and $E_{Plti}$) are given by Equation 3 and 4, where α = 3 is commonly used:

$$E_{Psti} = G_{PstMV} \cdot \sqrt[\alpha]{\frac{S_i}{(S_t - S_{LV})}} \qquad \text{(Equation 3)}$$

$$E_{Plti} = G_{PltMV} \cdot \sqrt[\alpha]{\frac{S_i}{(S_t - S_{LV})}} \qquad \text{(Equation 4)}$$

Where:

$E_{Psti}$, $E_{Plti}$ are the flicker emission limits for the customer's installation i directly supplied at MV,

$G_{PstMV}$, $G_{PltMV}$ are the maximum global contributions to the flicker levels of all the MV fluctuating installations that can be connected to the considered system

$S_i = (P_i / \cos \varphi_i)$ is the agreed power of the customer's installation i, or the MVA rating of the considered fluctuating installation,

$S_t$ is the total supply capacity of the considered system including provision for future load growth

$S_{LV}$ is the total power of the installations supplied directly at LV in the considered system including provision for future load growth,

α is the summation law exponent.

However, IEC 61000-3-7:2008 suggests that for customers having a low agreed power, this approach may yield impractically low limitations. Emission limits shall then be set at values given in Table 2. These limits are also recommended in PGM compliance verification document from Netbeheer Nederland as already mentioned in Part 2 of this paper.

| $E_{Psti}$ | $E_{Plti}$ |
|---|---|
| 0,35 | 0,25 |

**Table 2 – Minimum flicker emission limits at MV**

### 4.2.3 Individual flicker emission limits for a PPM – Solar-PV case study

In this paragraph the recommended Stage 2 methodology on calculating individual flicker emission limits is applied on the case of a Solar-PV farm with an agreed power $S_i$ = 15.87 MVA connected at 10 KV level. The farm is connected on a distribution substation with a busbar rated at 3150 A, equalling a total supply capacity of 54.56 MVA. A transfer coefficient of the disturbance from the upstream system $T_{PstUM}$ = 0.9 is considered. The IEC 61000-3-7:2008 recommended emission planning levels in the MV and HV level are also considered. Table 3 provides the calculated flicker emission limits for the PPM of this case.

| $E_{Psti}$ | $E_{Plti}$ |
|---|---|
| 0.2357 | 0.1229 |

**Table 3 – Individual flicker emission limits for the considered PPM**

### 4.2.4 The effect of the transfer coefficient $T_{PstUM}$ from the upstream system

Flicker values present at a given voltage level will be transferred downstream with some attenuation (transfer coefficient somewhat lower than 1, e.g. 0.8). Typically transfer coefficients can be assessed by simulation or measurement. IEC 61000-3-7:2008 provides an example of coefficients between different voltage levels calculated from measurements which are presented in Table 4.

| Voltage level | $T_{PstAB}$ |
|---|---|
| 220 kV towards 70 kV | 0,82 |
| 70 kV towards 15 kV | 0,91 |
| 15 kV towards 230 V | 0,98 – 1,0 |

**Table 4 – Example of flicker transfer coefficients**

It is observed that the transfer coefficient reduces as the voltage steps into consideration become higher. It should also be mentioned that an overall transfer coefficient from EHV to LV is a product of the transfer coefficients of the intermediate voltage steps, so generally it may depend among others on factors such as structure and characteristics of the electrical network in total (EHV voltage level, degree of meshing, fault levels), the intermediate voltage steps before distribution level and, also planning strategy on the transmission level.

As an example of the sensitivity of the transfer coefficient $T_{PstUM}$ on the calculation of individual PPM emission limits, a calculation is conducted on the emission limits of the Solar-PV farm example of Paragraph 3.2.3 for different values of transfer coefficient within a typically expected range. Table 5 tabulates the results. The percentage values correspond to the reduction in the limits as $T_{PstUM}$ increases.

| $T_{PstUM}$ | $E_{Psti}$ | $E_{Plti}$ |
|---|---|---|
| 0.7 | 0.3666 (100%) | 0.1781 (100%) |
| 0.8 | 0.3093 (-15.6%) | 0.1539 (-13.6%) |
| 0.9 | 0.2357 (-35.7%) | 0.1229 (-31%) |

**Table 5 – Example of flicker transfer coefficients**

## 4.3 Flicker emission levels for a PPM – Solar-PV case study

In this paragraph, the calculated results of flicker emission levels for the Solar-PV farm example of Paragraph 3.2.3 are presented. The simulation was conducted with DigSilent Powerfactory software. The point of evaluation is the 10 KV Point-of-Interconnection (POI) of this installation with the electricity network. The calculation of the flicker emission severity factors is conducted according to IEC-61400-21. The 10 KV POI is capable of providing a minimum of 106.18 MVA at a bolted short-circuit condition and presents R/X = 0.161. Figure 1 shows the electrical model of Losser Solar-PV plant developed in PowerFactory software.

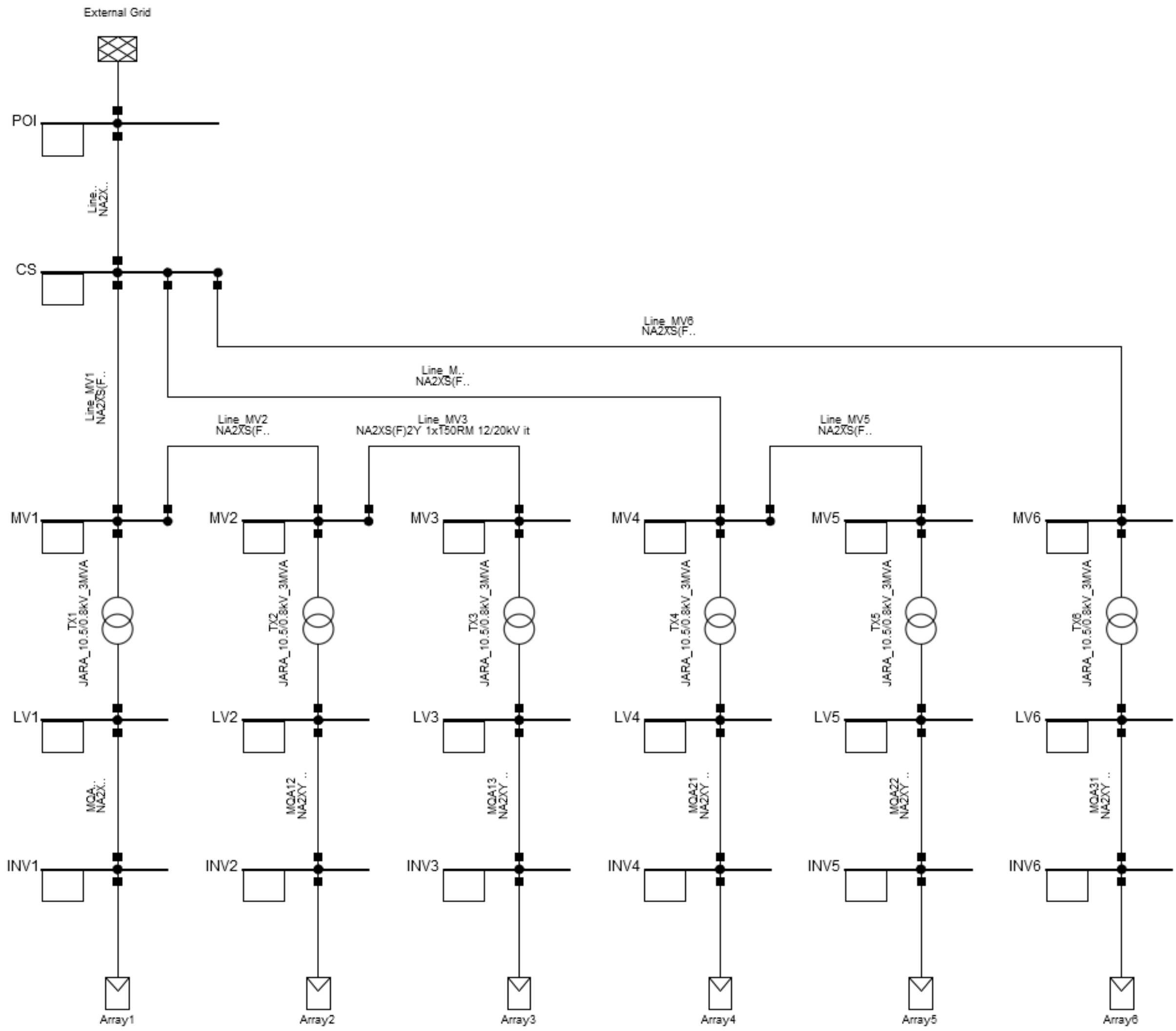


**Figure 2 – Solar-PV plant Powerfatcory model**

Solar-PV inverters can cause flicker disturbance both during continuous and switching operation. In the example of this Paragraph, the Solar-PV inverters are arranged in 6 arrays, while each array comprises 12 inverters. The flicker emission coefficients of a single inverter unit for continuous and switching operation are presented in Table 6 and Table 7 respectively. The software calculates the aggregated disturbance at the POI.

Table 8 and Table 9 provides the calculated results for continuous and switching operation respectively of the Solar-PV farm at 100% output.

| Network impedance phase angle, Ψk | 30º | 50º | 70º | 85º |
|---|---|---|---|---|
| **Average active power, P(%Pn)** | Flicker coefficient, C (Ψk, $P_{bin}$) | | | |
| 0 | 0.33 | 0.27 | 0.21 | 0.17 |
| 10 | 0.18 | 0.18 | 0.17 | 0.17 |
| 20 | 0.23 | 0.21 | 0.18 | 0.17 |
| 30 | 0.25 | 0.22 | 0.19 | 0.17 |
| 40 | 0.23 | 0.21 | 0.18 | 0.18 |
| 50 | 0.22 | 0.20 | 0.18 | 0.18 |
| 60 | 0.21 | 0.20 | 0.19 | 0.18 |
| 70 | 0.22 | 0.21 | 0.20 | 0.19 |
| 80 | 0.21 | 0.20 | 0.19 | 0.19 |
| 90 | 0.21 | 0.21 | 0.20 | 0.20 |
| 100 | 0.26 | 0.24 | 0.22 | 0.22 |

Table 6 – Flicker emission coefficients for continuous operation of a single inverter unit

| Case of switching operation | Switch-on at $P_{available}$ < 10 %$P_n$ | | | |
|---|---|---|---|---|
| **Max, number of switching operations, $N_{10}$** | 20 | | | |
| **Max, number of switching operations, $N_{120}$** | 240 | | | |
| **Grid impedance angle** | 30º | 50º | 70º | 85º |
| **Flicker step factor, $k_f$ ($\Psi_k$)** | 0.07 | 0.05 | 0.04 | 0.04 |
| **Voltage change factor, $k_u$ ($\Psi_k$)** | 0.03 | 0.03 | 0.03 | 0.03 |

| Case of switching operation | Switch-on at $P_{available}$ P = 100 %Pn | | | |
|---|---|---|---|---|
| **Max, number of switching operations, $N_{10}$** | 20 | | | |
| **Max, number of switching operations, $N_{120}$** | 240 | | | |
| **Grid impedance angle** | 30º | 50º | 70º | 85º |
| **Flicker step factor, $k_f$ ($\Psi_k$)** | 0.78 | 0.59 | 0.33 | 0.14 |
| **Voltage change factor, $k_u$ ($\Psi_k$)** | 0.08 | 0.06 | 0.04 | 0.03 |

Table 7 – Flicker emission coefficients for switching operations of a single inverter unit

| $P_{st\_cont}$ | $P_{lt\_cont}$ |
|---|---|
| 0.00418 | 0.00418 |

Table 8 – Flicker emission levels of the PPM for continuous operation

| $P_{st\_sw}$ | $P_{lt\_sw}$ |
|---|---|
| 0.07576 | 0.07275 |

Table 9 – Flicker emission levels of the PPM for switching operations

# 5 Summary & Conclusions

- A review of the requirements on flicker emissions of new installations arising from the Dutch grid code (NE), is presented in Part 2 of this paper. Relevant System Operators (RSO) reserve the right to apply specific requirements on the methodology, limits and evaluation criteria arising from local network constraints and/or planning strategies. In the absence of RSO specific regulations, the pre-connection assessment of flicker severity indices should be conducted according to IEC/TR 61000-3-7:2008 standard, as per NE.

- Part 3 of this document deals with possible issues arising during application of the relevant methodologies provided in IEC/TR 61000-3-7:2008. Paragraph 3.1 provides a review of the general principles and methodologies of IEC/TR 61000-3-7:2008. It is noted that Stage 2 approach is the methodology that the pre-connection assessment of flicker for the majority of distributed generation plants would fall under. However, IEC/TR 61000-3-7:2008 provides Stage 1 approach which is a simplified assessment that very small installation could follow. Stage 3 approach would be applied on a conditional basis for projects that do not comply under Stage 2 approach, according to IEC/TR 61000-3-7:2008.

- Paragraph 3.2 provides guidance on the application of Stage 2 approach and more specifically on the calculation of individual emission limits of a single installation against which the actual emission levels of this installation would be evaluated. The idea behind the calculation of individual limits is that, if the system is fully utilised to its designed capacity and all customers are injecting up to their individual limits, the total disturbance levels will be equal to the planning levels taking into account transfer factors between different voltage levels and the summation effect of various flicker producing equipment. The sensitivities of the calculation of those limits are reviewed and more specifically the contribution of the transfer coefficient of the disturbance from the upstream system is analysed. An example is presented based on a Solar-PV installation with agreed power $S_i$ = 15.87 MVA connected at 10 KV level, and the individual flicker emission limits are calculated for different transfer coefficients within a typically expected range of its value. The results show the importance of the value of the transfer coefficients on the calculation of the limits. It is interesting to note that even if the agreed power of the Solar-PV farm of the example comprises a substantial portion of the total supply capacity of the MV system that is connected on (~29%), the calculated individual limits are below the minimum individual emission limits provided in IEC/TR 61000-3-7:2008 in order to be applied on relatively small installations/customers. Only for low values of the transfer coefficient these limits would approach the minimums.

- Paragraph 3.3 provides the results of the calculation of flicker emission levels for the Solar-PV farm example presented earlier. The calculated levels are well below the individual emission limits calculated for this installation, even at conservative consideration of the transfer coefficient of the upstream flicker levels.

# 6 References

[1] – Netcode elektriciteit, valid from 30-04-2021 to present

[2] – DIgSILENT PowerFactory 2021

[3] – IEC 61000-4-15 – Electromagnetic compatibility (EMC) – Part 4-15: Testing and measurement techniques – Flickermeter – Functional and design specifications

[4] – Power-Generating Modules compliance verification – Power-Generating Modules type B,C and D according to NC RfG and Netcode elektriciteit – Version 1.2.1 – Netbeheer Nederland

[5] – IEC/TR 61000-3-7:2008-2 – Electromagnetic compatibility (EMC) – Part 3-7: Limits – Assessment of emission limits for the connection of fluctuating installations to MV, HV and EHV power systems

[6] IEC 61400-21-1:2019 – Wind energy generation systems - Part 21-1: Measurement and assessment of electrical characteristics - Wind turbines

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