Including a best practice on the pre-connection assessment of new distributed generation plants

WHITE PAPER

Understanding the Dutch Grid Code harmonic emission requirements

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1 Introduction

This paper was created with two objectives in mind. First, to review the requirements set out in the Dutch Electrical Grid-Code, “Dutch NE’ (NE) [1] regarding the emission of harmonic distortion from grid-connected Power Generating Modules (PGM). Second, to highlight issues arising during the application of these requirements, either because of inconsistencies between regulations or because of lack of established methodology when applying the requirements.

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

2 Requirements according to Dutch NE

In accordance with the PGM compliance verification document [3] from Netbeheer Nederland, the following references are included in the Dutch NE regarding requirements on harmonic emissions of grid-connected electrical installations:

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.

From Dutch NE Article 2.40:

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).

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 en, 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 en 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.

Moreover, with regards to the evaluation criteria of harmonic emissions assessment, Netbeheer Nederland PGM compliance verification document stipulates that evaluation will be performed based on national legislation, standards, rules and best practices and according to:

· Netcode elektriciteit;

· Nederlandse praktijkrichtlijn NPR-IEC/TR 61000-3-6: 2008 (en) Electromagnetic compatibility (EMC) – Part 3-6: Limits – Assessment of emission limits for the connection of distorting installations to MV, HV and EHV power systems (or later version);

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

· NPR-IEC/TR 61400-21-3:2019 (en) Wind energy generation systems - Measurement and assessment of electrical characteristics - Wind turbine harmonic model and its application (or later version);

· NEN-EN-IEC 61000-4-30 EMC: Testing and measurement techniques – Power quality measurement methods;

· Given harmonic, inter, sub, and THD harmonic limits by the relevant system operator: harmonic emission within emission limits specified by RSOIt is evident from the above that Dutch NE includes two references of documents to further consider during a harmonic assessment of a new installation:

- IEC/TR 61000-3-6:2008 [4]
- Richtlijnen voor toelaatbare harmonische stromen geproduceerd door apparatuur met een vermogen groter dan 11 kVA [5]

3 Inconsistency of requirements referenced in Dutch NE

Both documents mentioned in the previous section provide compatibility limits on the harmonic voltage emissions. These are reference values for coordinating the emission and immunity of equipment, which is part of, or supplied by, a supply system in order to ensure the Electromagnetic Compatibility (EMC) in the whole system (including system and connected equipment). Compatibility levels are generally based on the 95 % probability levels of entire systems, using statistical distributions which represent both time and space variations of disturbances. There is allowance for the fact that the system operator or owner cannot control all points of a system at all times. Therefore, evaluation with respect to compatibility levels should be made on a system-wide basis and no assessment method is provided for evaluation at a specific location.

Table 1 provides the compatibility limits for medium voltage as provided in EnergieNed document and Table 2 those provided in IEC/TR 61000-3-6:2008.

Odd harmonics non-multiple of 3		Odd harmonics multiple of 3		Even harmonics	
harmonic order n	harmonic voltage %	harmonic order n	harmonic voltage %	harmonic order n	harmonic voltage %
5	6	3	5 (1)	2	2
7	5	9	1,5 (1)	4	1
11	3,5	15	0,3	6	0,5
13	3	21	0,2	8	0,5
17	2	> 21	0,2	10	0,5
19	1,5			12	0,2
23	1,5			> 12	0,2
25	1,5				
> 25	0,2+1,3.25/n (2)				

(1) Values given for 3rd and 9th harmonics relate to single-phase networks. The levels in three-phase three-wire networks are about 1/3 of the levels given above.

(2) This formula of compatibility level takes account of possible resonance conditions in the supply network. For the connection of large loads, subject to agreement between the supply authority and the customer, target levels are set to limit the current emissions which may depend on the network impedance. These target levels may be expressed by the formula 0.2 + 0.5 x 25/n and are lower than the compatibility level.

Table 1 – Compatibility limits of harmonic voltages in medium voltage – EnergieNed document

Odd harmonics non-multiple of 3		Odd harmonics multiple of 3		Even harmonics	
Harmonic order h	Harmonic voltage %	Harmonic order h	Harmonic voltage %	Harmonic order h	Harmonic voltage %
5	6	3	5	2	2
7	5	9	1,5	4	1
11	3,5	15	0,4	6	0,5
13	3	21	0,3	8	0,5
$17 \leq h \leq 49$	$2{,}27 \cdot \frac{17}{h} - 0{,}27$	$21 < h \leq 45$	0,2	$10 \leq h \leq 50$	$0{,}25 \cdot \frac{10}{h} + 0{,}25$
NOTE The compatibility level for the total harmonic distortion is THD = 8 %.					

Table 2 – Compatibility limits of harmonic voltages in medium voltage – IEC61000-3-6:2008

EnergieNed document is based on IEC 1000-2-12, which has been replaced by IEC 61000-2-12:2003 [6]. The compatibility limits provided in EnergieNed document have been updated and are no longer valid. Figure 1 presents the relative increase or decrease introduced by IEC/TR 61000-3-6:2008 in the compatibility limits for medium voltage provided in the EnergieNed document.

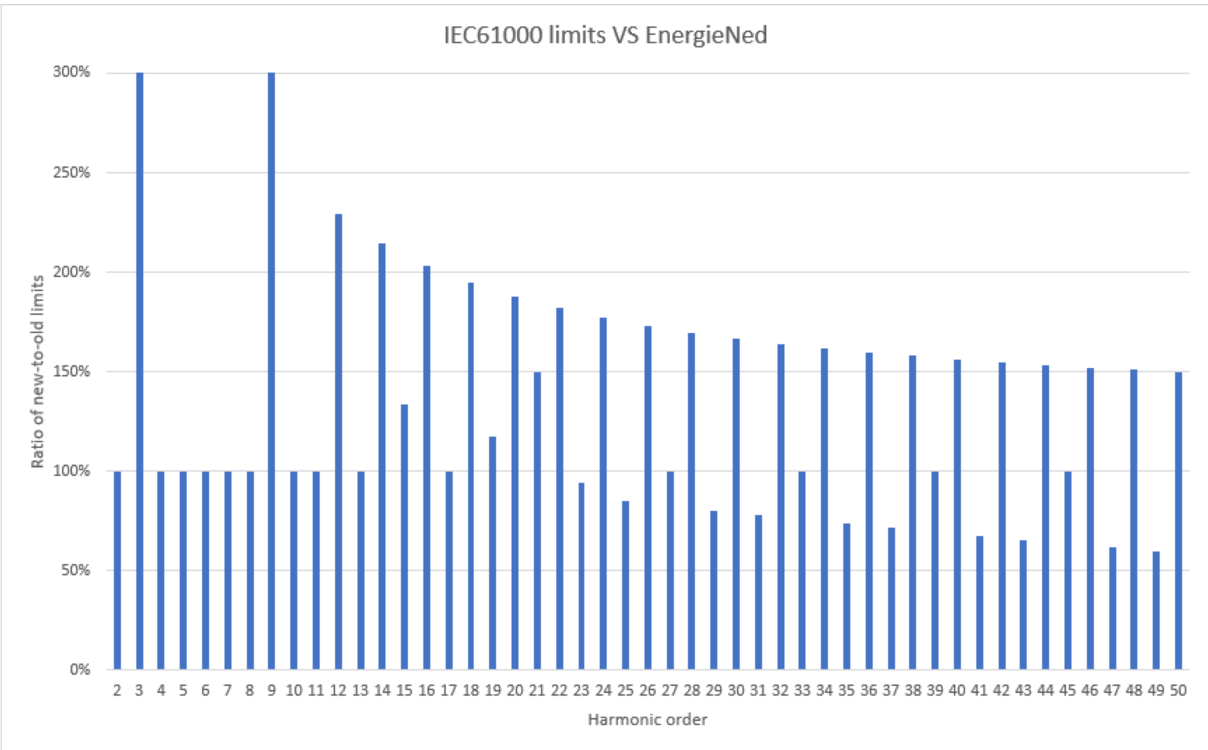

Figure 1 – IEC61000 limits as % of EnergieNed limits

4 Application of IEC 61000-3-6:2008

4.1 Review of the general principles and methodologies

As per Dutch NE, new connections should comply with IEC61000-3-6:2008. Essentially IEC61000-3-6:2008 provides the methodologies to be followed when assessing the compatibility of new installations. However, our concern is that certain requirements in the methodologies are prone to be applied improperly or even disregarded, resulting in either too optimistic or too conservative assessment of the distortion. Such cases in new connections could result in either a power-plant at which the emitted distortion during operation may exceed the assessed values or impede and slow down the compliance demonstration, respectively.

The lack of a published supportive guideline on the application of the standard may also be a reason for the misinterpretations of the methodologies. The aim is to raise concern among the relevant stakeholders, especially RSOs, with the purpose of ensuring that there is a uniform and consistent application of the standard when assessing the compliance of new Distributed Generation plants. Such an initiative can promote equality and fairness in the way that new Distributed Generation plants under development are treated, and furthermore assist RSOs in controlling and managing the level of harmonic distortion across the distribution network, which is essentially the main objective of a harmonic assessment being required under Dutch NE. Therefore, beneficiaries of such an initiative can be in principle all the stakeholders involved in the industry of renewable energy generation and electricity distribution.

IEC61000-3-6:2008 suggests that a 3-stage approach is applied in the assessment of the compatibility of new distorting installations.

Stage 1 approach is a simplified evaluation of disturbance emission according to which the connection of small installation or installations with only a limited amount of distorting equipment can be accepted without detailed evaluation of the emission characteristics or the supply system response. The criterion that enables the application of Stage 1 approach is the agreed power of the installation and more specifically the following equation:

$$\frac{S_i}{S_{sc}} \leq 0,2\%$$

S_i = agreed power of the installation

S_{sc} = system short-circuit power at the POI

As the above equation suggests, Stage 1 can be typically applied to installations with maximum power of few hundreds of kVA.

If an installation does not meet Stage 1 criteria, the specific characteristics of the harmonic generating equipment within the customer's installation should be evaluated during Stage 2 approach together with the absorption capacity of the system. The latter is derived from the planning levels and is apportioned to individual customers according to their demand with respect

to the total system capacity.

The disturbance level transferred from upstream voltage levels of the supply system to lower voltage levels should also be considered when apportioning the planning levels to individual customers. The principle of this approach is that, if the system is fully utilized 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 of various harmonic producing installations.

Finally, Stage 3 approach is applied when the acceptance of higher emission levels should be considered on a conditional basis. Under some circumstances, a customer may require acceptance to emit disturbances beyond the basic limits allowed in Stage 2. In such a situation, the customer and the system operator or owner may agree on special conditions that facilitate connection of the distorting installation. A careful study of the actual and future system characteristics will need to be carried out in order to determine these special conditions.

Focusing on the main field of our application which are PGMs connected on the medium or high voltage, it becomes evident that Stage 2 approach is the most typical methodology in the evaluation of the distortion emissions. The main points that require a more attentive consideration are mainly involved in IEC61000-3-6:2008 Stage 2 evaluation methodology and are presented hereafter.

4.2 The sensitivities of Stage 2 approach

4.2.1 Global emission to be shared among customers limits vs planning levels

In Stage 2 approach, Power Park Module (PPM) emission limits E_{Uhi} relative to actual system characteristics are assessed. The objective is to assess whether the harmonic emission level of the PPM U_{hi} at the Point of Interconnection (POI) is within the allowable emission limits E_{Uhi} for the PPM.

The planning levels are harmonic voltage levels that can be used for the purpose of determining individual emission limits, taking into consideration all distorting 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. Planning levels for harmonics are equal to or lower than compatibility levels and they should allow co-ordination of harmonic voltages between different voltage levels. Table 3 provides indicative planning levels for harmonic voltages in MV, HV and EHV systems.

Odd harmonics non-multiple of 3			Odd harmonics multiple of 3			Even harmonics		
Harmonic order h	Harmonic voltage %		Harmonic order h	Harmonic voltage %		Harmonic order h	Harmonic voltage %	
	MV	HV-EHV		MV	HV-EHV		MV	HV-EHV
5	5	2	3	4	2	2	1,8	1,4
7	4	2	9	1,2	1	4	1	0,8
11	3	1,5	15	0,3	0,3	6	0,5	0,4
13	2,5	1,5	21	0,2	0,2	8	0,5	0,4
$17 \leq h \leq 49$	$1{,}9 \cdot \frac{17}{h} - 0{,}2$	$1{,}2 \cdot \frac{17}{h}$	$21 < h \leq 45$	0,2	0,2	$10 \leq h \leq 50$	$0{,}25 \cdot \frac{10}{h} + 0{,}22$	$0{,}19 \cdot \frac{10}{h} + 0{,}16$

Table 3 – Indicative planning levels for harmonic voltages in MV, HV and EHV systems

The idea behind Stage 2 approach is to provide the right methodology in order to define individual harmonic emission limits for each customer as to ensure that the planning levels for the MV system will be maintained. Consider a typical MV system as per Figure 2.

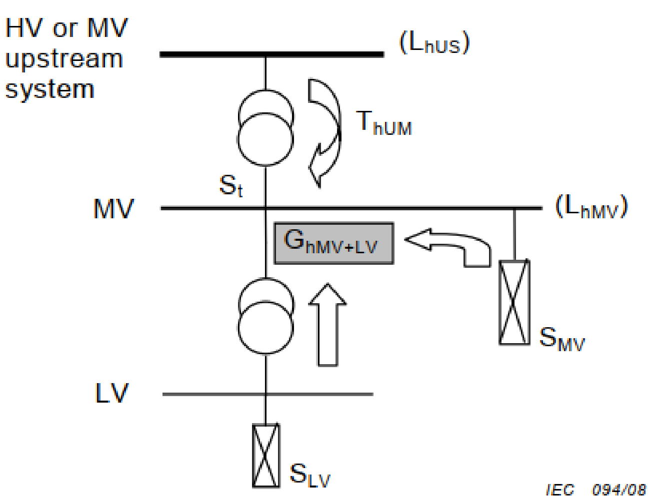

Figure 2 – Example of a system for sharing global contributions in MV

By application of the general summation law, it is necessary to determine the global contribution of all harmonic sources present in a particular MV system. Indeed, for each harmonic order, the actual harmonic voltage in a MV system results from the vector summation of the harmonic voltage coming from the upstream system (note that upstream system may be a HV or another MV system for which intermediate planning levels have been set before) and of the harmonic voltage resulting from all distorting installations connected to the considered MV and LV system. This total harmonic voltage should not exceed the planning level of the MV system, given by:

$$L_{hMV} = \sqrt[\alpha]{G_{hMV+LV}^{\alpha} + (T_{hUM} \cdot L_{hUS})^{\alpha}} \qquad \text{(Equation 1)}$$

and thus the global harmonic voltage contribution that can be allocated to the total of MV and LV installations supplied from the considered MV system is given by:

$$G_{hMV+LV} = \sqrt[\alpha]{L_{hMV}^{\alpha} - (T_{hUM} \cdot L_{hUS})^{\alpha}} \qquad \text{(Equation 2)}$$

where:

G_{hMV+LV} is the maximum global contribution of the total of MV and LV installations that can be supplied from the MV busbar to the h_{th} harmonic voltage in the MV system (expressed in percent of the fundamental voltage),

L_{hMV} is the planning level of the h_{th} harmonic in the MV system,

L_{hUS} is the planning level of the h_{th} harmonic in the upstream system,

T_{hUM} is the transfer coefficient of harmonic voltage distortion from the upstream system to the MV system under consideration at harmonic order h,

α is the summation law exponent

Therefore, it becomes evident from the above that it is the maximum global contribution G_{hMV+LV} that can be supplied from the MV busbar to the h_{th} harmonic voltage in the MV system to all customers connected to this busbar as to be able to maintain the selected planning levels in the MV system. It would be too optimistic and incompatible with the stipulations of IEC61000-3-7 to assess the PPM individual emission levels directly against the planning levels. However, it has been noticed that sometimes not the proper consideration on this requirement is given.

Table 4 presents a comparison of the maximum global contribution in the MV level G_{hMV+LV} (calculated for transfer coefficient from the upstream network T_{hUM} equal to 0.9) to the MV planning levels L_{hMV}. The comparison shows that the maximum global contribution G_{hMV+LV} is typically a fraction of the planning levels.

h order	MV planning limits L_{hMV}	Maximum global MV+LV contribution in the MV G_{hMV+LV}	G_{hMV+LV} / L_{hMV}
2	1.80000	0.54000	30.00%
3	4.00000	2.20000	55.00%
4	1.00000	0.28000	28.00%
5	5.00000	4.11291	82.26%
6	0.50000	0.24514	49.03%
7	4.00000	3.01461	75.37%
8	0.50000	0.24514	49.03%
9	1.20000	0.54537	45.45%
10	0.47000	0.25675	54.63%
11	3.00000	2.67909	89.30%
12	0.42833	0.31841	74.34%
13	2.50000	2.10416	84.17%
14	0.39857	0.29669	74.44%
15	0.30000	0.13077	43.59%
16	0.37625	0.28040	74.53%
17	1.70000	1.31286	77.23%
18	0.35889	0.26773	74.60%
19	1.50000	1.14727	76.48%
20	0.34500	0.25759	74.66%
21	0.20000	0.08718	43.59%
22	0.33364	0.24930	74.72%
23	1.20435	0.90179	74.88%
24	0.32417	0.24239	74.77%
25	1.09200	0.80816	74.01%
26	0.31615	0.23654	74.82%
27	0.20000	0.08718	43.59%
28	0.30929	0.23152	74.86%
29	0.91379	0.65894	72.11%
30	0.30333	0.22718	74.89%
31	0.84194	0.59840	71.07%
32	0.29813	0.22338	74.93%
33	0.20000	0.08718	43.59%
34	0.29353	0.22002	74.96%
35	0.72286	0.49734	68.80%
36	0.28944	0.21704	74.98%
37	0.67297	0.45460	67.55%
38	0.28579	0.21437	75.01%
39	0.20000	0.08718	43.59%
40	0.28250	0.21197	75.03%
41	0.58780	0.38077	64.78%
42	0.27952	0.20980	75.05%
43	0.55116	0.34853	63.23%
44	0.27682	0.20782	75.07%
45	0.20000	0.08718	43.59%
46	0.27435	0.20602	75.09%
47	0.48723	0.29120	59.77%
48	0.27208	0.20436	75.11%
49	0.45918	0.26543	57.81%
50	0.27000	0.20284	75.13%

Table 4 – Comparison of the maximum global contribution in the MV level G_{hMV+LV} to the MV planning levels L_{hMV}

4.2.2 The effect of the transfer coefficient from the upstream system

According to IEC61000-3-6:2008, T_{hUM} can be determined by simulation or measurements. For an initial simplified evaluation, the transfer coefficients T_{hUM} from the upstream system on a MV system can be taken as equal to 1. In practice however, it may be less than 1 (e.g. 2/3), due to the presence of downstream system elements, or higher than 1 (typically between 1 and 3), due to resonance. It is the responsibility of the system operator or owner to determine the relevant values depending on the system characteristics.

Table 5 presents a comparison of the maximum global contribution in the MV level G_{hMV+LV}, calculated for transfer coefficient from the upstream network T_{hUM} equal to 1, 0.9 and 0.8. The maximum global contribution in the MV level G_{hMV+LV} for the different values of T_{hUM} is presented as a percentage of the MV planning levels L_{hMV}.

It should be noted that the dependency is inversely proportional, meaning that as the transfer coefficient increases the maximum global contribution in the MV level G_{hMV+LV} decreases. Also, it is important to highlight that when the transfer coefficient from the upstream network T_{hUM} is equal to 1, the maximum global contribution in the MV level G_{hMV+LV} for the triplen harmonics of order 15 and above (orders 15, 21, 27, 33, 39, 45) becomes zero. This means that under Stage 2 approach there is no allowable headroom for harmonic emissions of these orders for new connections, and as a result Stage 3 assessment should be followed for compliance assessment.

h order	G_{hMV+LV} / L_{hMV} for T_{hUM} = 1	G_{hMV+LV} / L_{hMV} for T_{hUM} = 0.9	G_{hMV+LV} / L_{hMV} for T_{hUM} = 0.8
2	22.22%	30.00%	37.78%
3	50.00%	55.00%	60.00%
4	20.00%	28.00%	36.00%
5	79.30%	82.26%	85.05%
6	39.07%	49.03%	57.84%
7	71.16%	75.37%	79.30%
8	39.07%	49.03%	57.84%
9	34.49%	45.45%	55.01%
10	46.09%	54.63%	62.31%
11	86.60%	89.30%	91.65%
12	66.91%	74.34%	80.41%
13	80.00%	84.17%	87.73%
14	67.05%	74.44%	80.48%
15	0.00%	43.59%	60.00%
16	67.17%	74.53%	80.54%
17	70.83%	77.23%	82.53%
18	67.27%	74.60%	80.60%
19	69.83%	76.48%	81.98%
20	67.36%	74.66%	80.64%
21	0.00%	43.59%	60.00%
22	67.43%	74.72%	80.69%
23	67.65%	74.88%	80.80%
24	67.50%	74.77%	80.72%
25	66.45%	74.01%	80.16%
26	67.56%	74.82%	80.76%
27	0.00%	43.59%	60.00%
28	67.62%	74.86%	80.79%
29	63.83%	72.11%	78.79%
30	67.67%	74.89%	80.81%
31	62.38%	71.07%	78.04%
32	67.71%	74.93%	80.84%
33	0.00%	43.59%	60.00%
34	67.76%	74.96%	80.86%
35	59.15%	68.80%	76.41%
36	67.79%	74.98%	80.88%
37	57.34%	67.55%	75.53%
38	67.83%	75.01%	80.90%
39	0.00%	43.59%	60.00%
40	67.86%	75.03%	80.91%
41	53.24%	64.78%	73.58%
42	67.89%	75.05%	80.93%
43	50.90%	63.23%	72.51%
44	67.92%	75.07%	80.94%
45	0.00%	43.59%	60.00%
46	67.94%	75.09%	80.96%
47	45.43%	59.77%	70.15%
48	67.96%	75.11%	80.97%
49	42.18%	57.81%	68.84%
50	67.99%	75.13%	80.98%

Table 5 – Comparison of the maximum global contribution in the MV level G_{hMV+LV} for different for transfer coefficient from the upstream network T_{hUM}

4.2.3 Individual emission limits per customer E_{Uhi}

According to IEC61000-3-6:2008, the allowable global contribution to the overall level of disturbance G_{hMV+LV} is apportioned to each individual installation. This ensures that the disturbance level due to the emissions of all customers connected to the system will not exceed the planning level.

For each customer only a fraction of the global emission limits G_{hMV+LV} will be allowed, typically according to the ratio between the agreed power Si and the total supply capability St of the MV system, according to Equation 3. Such a criterion is related to the fact that the agreed power of a customer is often linked with his share in the investment costs of the power system.

$$E_{Uhi} = G_{hMV+LV} \sqrt[\alpha]{\frac{S_i}{S_t}}$$ (Equation 3)

where:

E_{Uhi} is the harmonic voltage emission limit of order h for the installation (i) directly supplied at MV (%),

G_{hMV+LV} is the maximum global contribution of the total of MV and LV installations that can be supplied from the considered MV system to the hth harmonic voltage in the MV system

Si = Pi /cosϕi is the agreed power of customer installation i, or the MVA rating of the considered distorting installation (either load or generation),

St is the total supply capacity of the considered system including provision for future load growth (in principle, St is the sum of the capacity allocations of all installations including that of downstream installations that are or can be connected to the considered system, taking diversity into consideration). St might also include the contribution from dispersed generation, however more detailed consideration will be required to determine its firm contribution to St and its effective contribution to the short-circuit power as well,

α is the summation law exponent (see Table 3).

Table 6 presents an example of the calculated individual emission limits for a generation installation of 15.87 MVA agreed power, connected on a 10kV system with a total supply capacity of 43.3 MVA (2500A). A transfer coefficient of harmonic voltage distortion from the upstream system to the MV system under consideration T_{hUM} equal to 0.9 has been considered. Last column on Table 6 presents the individual emission limits for this customer as a percentage of the MV planning levels.

h order	MV planning limits L_{hMV}	Maximum global MV+LV contribution in the MV G_{hMV+LV}	Emission limits E_{uhi}	E_{uhi} / L_{hMV}
2	1.80000	0.54000	0.19791	11.00%
3	4.00000	2.20000	0.80630	20.16%
4	1.00000	0.28000	0.10262	10.26%
5	5.00000	4.11291	2.00805	40.16%
6	0.50000	0.24514	0.11969	23.94%
7	4.00000	3.01461	1.47183	36.80%
8	0.50000	0.24514	0.11969	23.94%
9	1.20000	0.54537	0.26627	22.19%
10	0.47000	0.25675	0.12535	26.67%
11	3.00000	2.67909	1.62190	54.06%
12	0.42833	0.31841	0.19277	45.00%
13	2.50000	2.10416	1.27385	50.95%
14	0.39857	0.29669	0.17962	45.07%
15	0.30000	0.13077	0.07917	26.39%
16	0.37625	0.28040	0.16975	45.12%
17	1.70000	1.31286	0.79480	46.75%
18	0.35889	0.26773	0.16208	45.16%
19	1.50000	1.14727	0.69455	46.30%
20	0.34500	0.25759	0.15595	45.20%
21	0.20000	0.08718	0.05278	26.39%
22	0.33364	0.24930	0.15092	45.24%
23	1.20435	0.90179	0.54594	45.33%
24	0.32417	0.24239	0.14674	45.27%
25	1.09200	0.80816	0.48925	44.80%
26	0.31615	0.23654	0.14320	45.29%
27	0.20000	0.08718	0.05278	26.39%
28	0.30929	0.23152	0.14016	45.32%
29	0.91379	0.65894	0.39892	43.66%
30	0.30333	0.22718	0.13753	45.34%
31	0.84194	0.59840	0.36227	43.03%
32	0.29813	0.22338	0.13523	45.36%
33	0.20000	0.08718	0.05278	26.39%
34	0.29353	0.22002	0.13320	45.38%
35	0.72286	0.49734	0.30109	41.65%
36	0.28944	0.21704	0.13139	45.40%
37	0.67297	0.45460	0.27521	40.90%
38	0.28579	0.21437	0.12978	45.41%
39	0.20000	0.08718	0.05278	26.39%
40	0.28250	0.21197	0.12832	45.42%
41	0.58780	0.38077	0.23052	39.22%
42	0.27952	0.20980	0.12701	45.44%
43	0.55116	0.34853	0.21100	38.28%
44	0.27682	0.20782	0.12581	45.45%
45	0.20000	0.08718	0.05278	26.39%
46	0.27435	0.20602	0.12472	45.46%
47	0.48723	0.29120	0.17629	36.18%
48	0.27208	0.20436	0.12372	45.47%
49	0.45918	0.26543	0.16069	34.99%
50	0.27000	0.20284	0.12280	45.48%

Table 6 –Individual emission limits per customer E_{Uhi}

4.2.4 Allowable total harmonic distortion THDv

According to IEC61000-3-6:2008, the planning limit for the total harmonic distortion in the medium voltage is 6.5%. As per definition of total harmonic distortion (Equation 4), the value of THDv results from weighting the root mean square (RMS) voltage of all the harmonic frequencies (from the 2nd harmonic on) over the RMS voltage of the fundamental frequency.

$$THD = \frac{\sqrt{\sum_{n=2}^{\infty} V_{n\_rms}^2}}{V_{fund\_rms}}$$ (Equation 4)

This means that the THDv planning limit is derived from the planning limits of each harmonic order. Therefore, it would make sense that when assessing the distortion emission of a new installation according to Stage 2 methodology, an individual limit for the THDv should also be calculated. As in the case of the calculation of harmonic emission limits for each order/frequency, this would ensure that the disturbance level due to the emissions of all customers connected to the system will not exceed the planning level.

IEC61000-3-6:2008 does not explicitly provide the methodology to calculate the THDv limit. It may also appear confusing among consultants and RSOs that the limit provided for the THDv in the PGM compliance verification document from Netbeheer Nederland or in Dutch NE is also 6.5% when assessing the compliance of new PGMs connected in the medium voltage. Hereafter, a reasonable approach is described on the calculation of the THDv limit when assessing the compliance with the distortion planning limits of a new installation connected in the medium voltage.

The approach is based on calculating the THDv by application of Equation 4 on the planning levels of harmonic voltages in the MV level as provided in IEC61000-3-6:2008. This would result in a value of THDv = 9.61%, a value greater than the 6.5% that is suggested as the planning level limit for THDv. This suggests that even if the actual emission limits in each harmonic order were lying below the planning levels, the THDv of the emitted distortion could violate the 6.5% planning limit. This is explained by the fact that THDv is essentially a measure of the aggregated heating effect of the harmonic emissions on a system, rather than an indicator of electromagnetic compatibility, a role that is fundamentally served by the limits on emission levels of each individual harmonic order.

The reasonable approach when assessing a new installation, is that the individual limit on the THDv per customer should be derived from the harmonic emission limits that have been calculated for this customer according to Stage 2 methodology. However, a reduction factor should be applied, in analogy and proportional to the reduction factor that has been applied to the 9.61% value in order to derive the 6.5% planning level, i.e. 6.5/9.61 = 0.67637 or 67.637%. This factor can be applied in all cases of an MV system. As an example, the installation of described in paragraph 4.2.3, should have a THDv limit of 0.67637x 3.74% = 2.53%, where 3.74% is the THDv as calculated from the emission limits E_{Uhi} of Table 6.

4.2.5 The effect of background harmonic impedance

The harmonic emission level from an installation into the power system is the magnitude of the harmonic voltage (or current) vector at each harmonic frequency, which is caused by the considered installation at the POI. This is illustrated in Figure 3 by the vector Uhi and its contribution to the measured harmonic vector at the POI, once the installation has been connected.

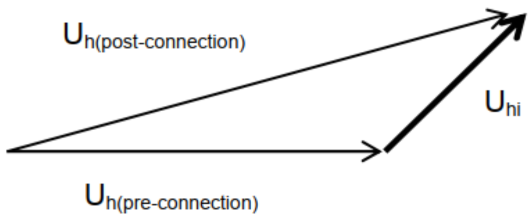

Figure 3 – Illustration of the emission vector Uhi and its contribution to the measured harmonic vector at the POI

For the pre-connection assessment of emission levels, the customer plant is considered only as a source of harmonic current. Therefore, the harmonic voltage emission level U_{hi} of a new installation at the POI fundamentally depends on two factors, the magnitude of the new installation harmonic current emission at each order and the magnitude of the system impedance at the same order (background harmonic impedance) as 'seen' at the POI.

The assessment of the harmonic impedance can be a very complex problem. Furthermore, the harmonic impedance of the system may vary significantly with time. So, when important changes are expected between the present and the future system configuration, a different set of harmonic impedance data should be provided in order for the customer to assess his emission levels for both situations and to achieve an optimal design of his equipment.

For enabling a pre-connection assessment of emission levels, the harmonic impedance of the system needs to be determined, usually obtained by simulation. As for the assessment of emission levels, the determination of the system harmonic impedance should consider the different normal operating conditions including system abnormal operating conditions where these situations may last for a specified portion of the time, for example more than 5 % of time annually based on a statistical average. Known or foreseeable future system changes should be included. In particular, the various reactive compensation or filter states (e.g. shunt capacitor states) have to be considered.

The variations of the system harmonic impedance due to the tolerance on the electrical parameters of the network components and inaccuracies in the modelling should be accounted for by assessing the impedance over an equivalent frequency range of deviation for each harmonic (the tolerance on the inductive and capacitive components of the apparatus can be converted in terms of equivalent frequency deviations). For high harmonic orders, this should also allow considering possible resonance between some harmonic frequencies.

A system minimum fault level at the POI should typically reproduce a worst-case system impedance

that encompasses any of the above considerations related to the fundamental frequency. Where required (e.g. for large installations) the system harmonic impedance data should be given in the form of a locus or a table giving the minimum and maximum expected magnitude and phase angle variations of impedance over the harmonic range of interest, or the network data needed to calculate this impedance data provided. However, in the absence of such data, which is the actual case during a Stage 2 assessment, a harmonic impedance over the harmonic range of interest (typically 100-2500Hz, i.e. 50 orders) should be reproduced in order to conduct the pre-connection assessment of the harmonic emissions.

IEC61000-3-6:2008 suggests that, based on several site measurements, "worst case impedance curves" have been defined in some countries. If calculations using those empirical curves indicate that an installation can be connected (i.e. still meet the voltage emission limits at the POI), this may be done with minimum risk. However, if these calculations give results that indicate that the installation’s emission levels will exceed the voltage emission limits, a more refined approach should be used. At low voltage, the maximum impedance curve is derived from the short circuit power and is taken as varying directly with the harmonic number in a straight-line relationship. At 11 kV, the maximum impedance curve is shown in Figure 4 for a typical urban substation without large capacitors or filters. It is derived from the short circuit power and is taken as rising from its value at 50 Hz on a line directly related to twice the fundamental impedance by the harmonic number up to 400 Hz. Thereafter it drops to the line related to the fundamental impedance by the harmonic number.

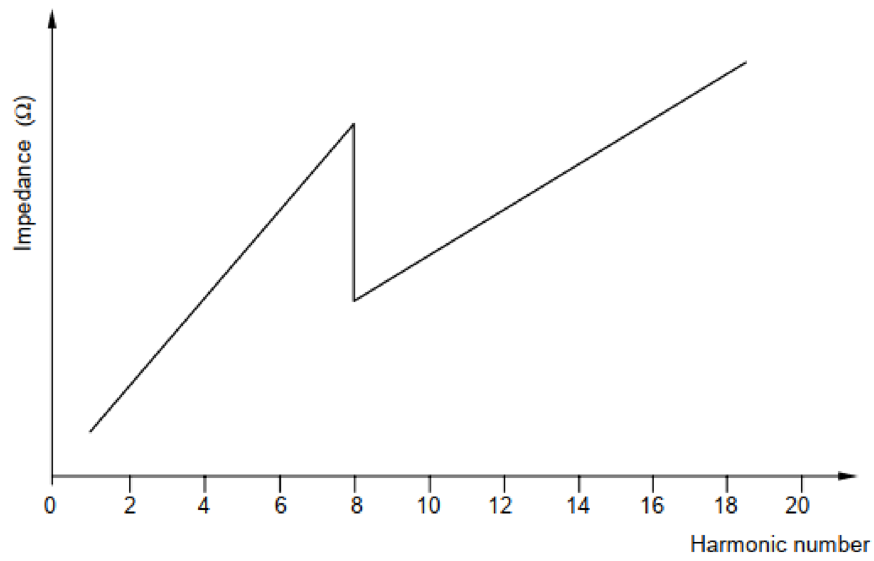

Figure 4 – Example of maximum impedance curve for a 11 kV system

Up to h = 8: $Z_h = 2\ h\ X_1$, above h = 8: $Z_h = h\ X_1$.

At 33 kV, the maximum impedance values are taken as 1,25 times those that would be derived directly from the short circuit power up to 800 Hz. Specific measurements might be required according to circumstances when considering frequencies above that level. Above 33 kV such generalization is not possible.

However, it has been observed that the above requirements on the harmonic impedance are not always taken into consideration during a Stage 2 pre-connection assessment. More specifically, in many cases of new connections in the medium voltage level, the harmonic impedance is taken as varying directly with the harmonic number in a straight-line relationship, an assumption that results in a more optimistic approach and the calculation of lower emission levels. Hereafter, an example is presented in order to highlight the above remarks. The harmonic voltage emissions of a PPM connected at 10kV level are calculated and compared for two cases of background harmonic impedance. In Case 1 the harmonic impedance is taken as varying directly with the harmonic number in a straight-line relationship, while in Case 2 the provisions of IEC61000-3-6:2008 for the worst-case impedance curve at 11kV as described earlier is considered. The same case of PPM as in paragraph 4.2.3 is considered in the example i.e. Si = 15.87 MVA. The fault level at the 10kV POI has a value of 106.18MVA. Figure 5 presents the network harmonic impedance of Case 1 as modelled in Powerfactory software and Figure 6 the network harmonic impedance of Case 2.

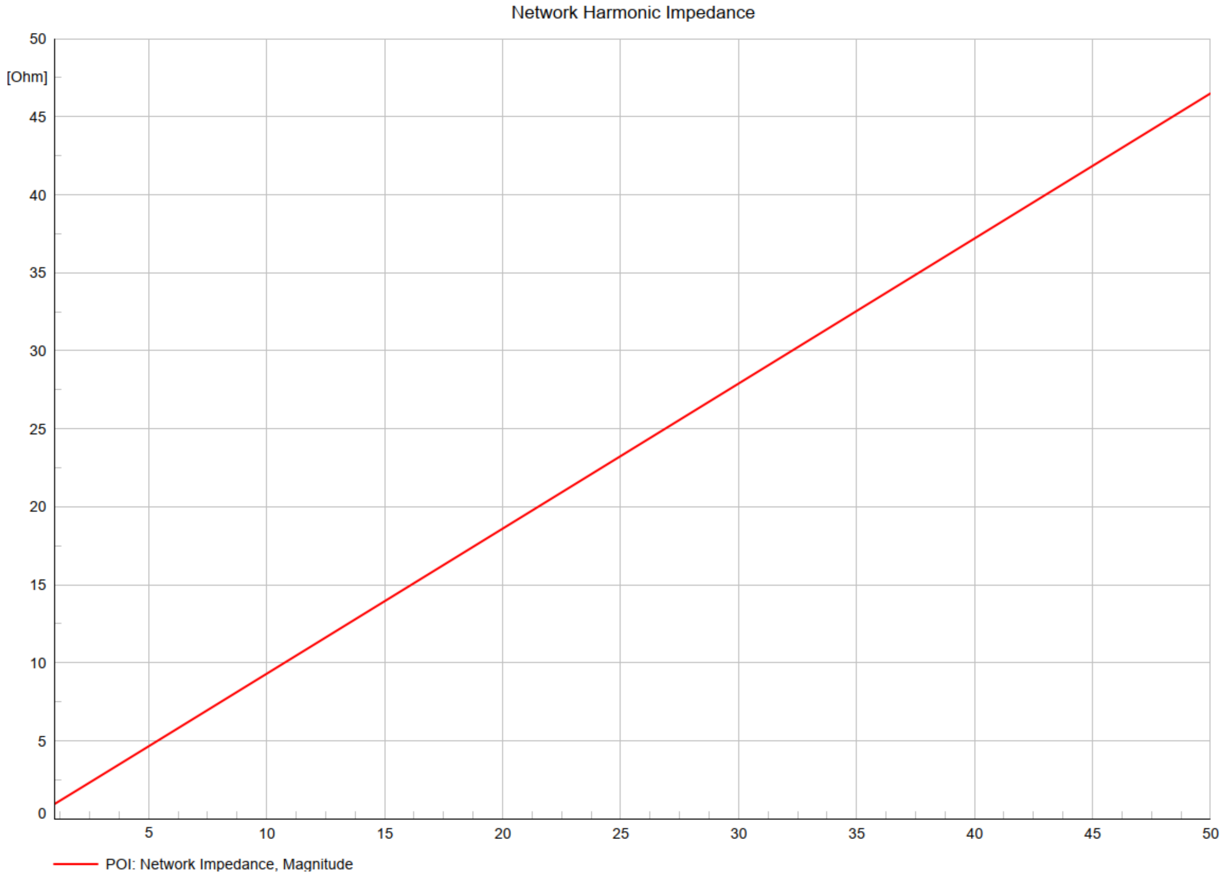

Figure 5 – Network harmonic impedance Powerfactory model, Case 1

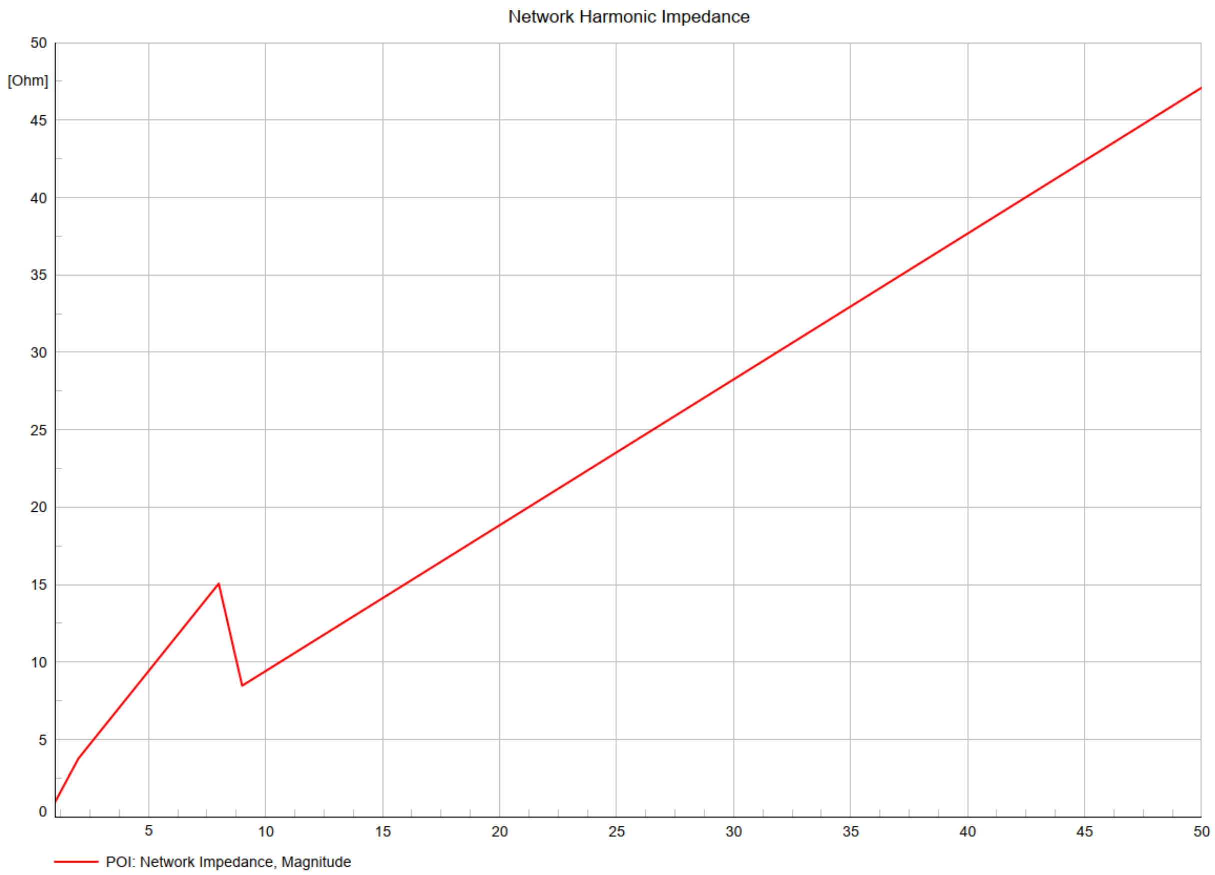

Figure 6 – Network harmonic impedance Powerfactory model, Case 2

The individual harmonic emissions Uhi up to the 50th order (2500 Hz) have been calculated for both cases. Figure 7 presents a comparison of the emissions of the two cases. It is evident that the emissions in Case 1, especially in the region of 100-400Hz (2nd to 8th order) are much lower (50%) compared to Case 2 where the provisions of IEC61000-3-6:2008 for the harmonic impedance curve have been considered.

Also, the total harmonic distortion has been calculated for the 2 cases which, as expected, follows the same trend, i.e. has a lower value in Case 1 (THDv = 0.981%) compared to Case 2 (THDv = 1.177%).

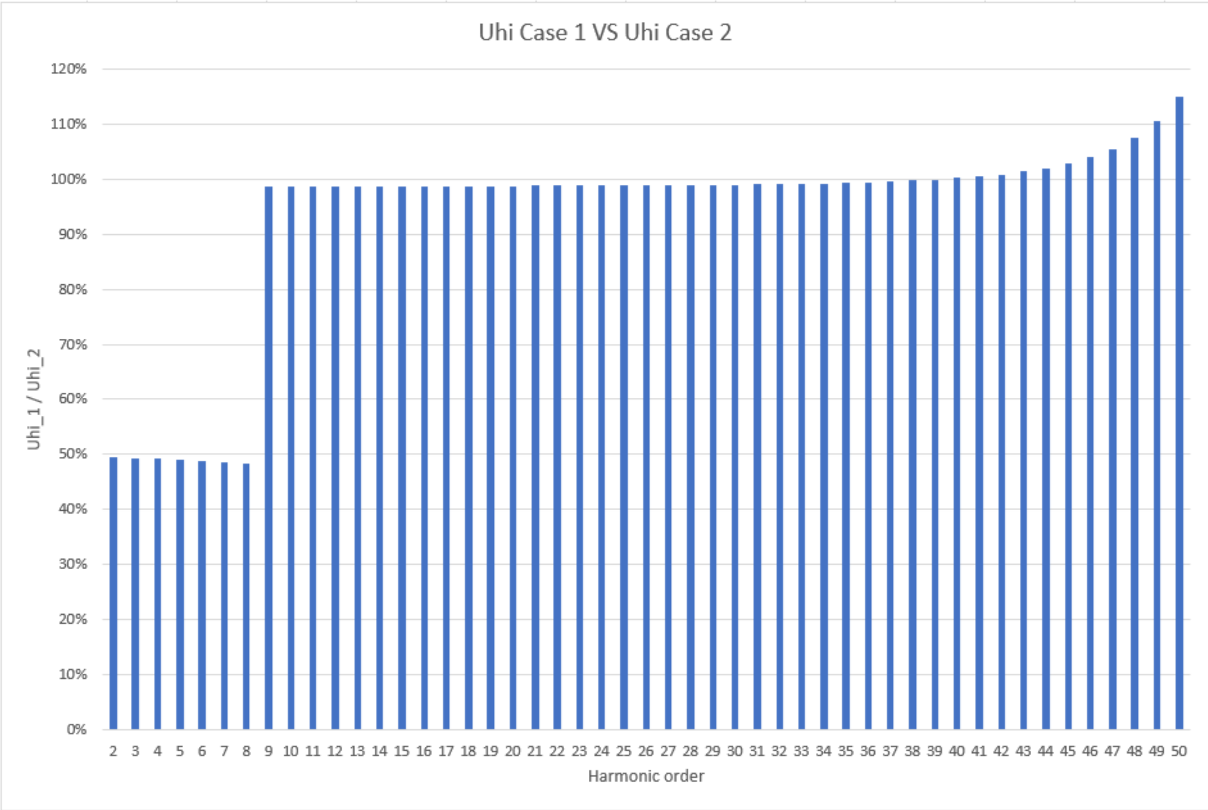

Figure 7 –Case 2 calculated harmonic emissions as % of Case 1 results

5 Conclusions & Recommendations

- A review of the requirements on harmonic emission levels of new installations arising from the Dutch NE, is presented in the beginning of this report. The Dutch NE references two documents, namely *IEC/TR 61000-3-6:2008* and *Richtlijnen voor toelaatbare harmonische stromen geproduceerd door apparatuur met een vermogen groter dan 11 kVA*, on which an assessment of a new installation should be conducted in accordance with. However, it should be noted that the two documents provide guidelines for harmonic emission limits that are not aligned in-between and such inconsistency may impose uncertainty or confusion during the assessment of a new installation.

- Also, a review of the general principles and methodologies of IEC/TR 61000-3-6:2008 is presented. IEC/TR 61000-3-6:2008 is the basic standard according to Dutch NE, under which the assessment of the harmonic distortion emitted from new installations should be conducted. However, our concern is that certain requirements in the methodologies are prone to be applied improperly or even disregarded, resulting in either too optimistic or too conservative assessment of the distortion. The lack of a published supportive guideline on the application of the standard may also be a reason for the misinterpretations of the methodologies. The aim is to raise concern among the relevant stakeholders, especially RSOs, with the purpose of ensuring that there is a uniform and consistent application of the standard when assessing the compliance of new Distributed Generation plants. Such an initiative can promote equality and fairness in the way that new Distributed Generation plants under development are treated, and furthermore assist RSOs in controlling and managing the level of harmonic distortion across the distribution network, which is essentially the main objective of a harmonic assessment being required under Dutch NE.

- Further analysis follows, focused on the sensitivities of IEC/TR 61000-3-6:2008 Stage 2 methodology, which is the basic approach when conducting a pre-connection assessment of the compliance with harmonic emission requirements of new Distributed Generation plants. These sensitivities are considerations and requirements that are fundamental in the quantitative application of IEC/TR 61000-3-6:2008 Stage 2 methodology and any misinterpretation or wrong application of them can impact a lot the calculated results, even shift the assessment from the zone of compliance to that of non-compliance. Furthermore, these sensitivities have an impact on both the calculation of individual emission limits for a new installation E_{Uhi} and, also on the calculation of the emission levels corresponding on this installation U_{hi}. Regarding the emission limits, the impact of planning levels, transfer coefficient from the upper system and the total supply capacity of the system are analysed. Finally, regarding the emission levels, the impact of the network harmonic impedance representation at the POI is presented.

6 References

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

[2] – DIgSILENT PowerFactory 2021

[3] – 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

[4] – IEC TR 61000-3-6:2008 – Electromagnetic compatibility (EMC) – Part 3-6: Limits - Assessment of emission limits for the connection of distorting installations to MV, HV and EHV power systems

[5] – Richtlijnen voor toelaatbare harmonische stromen geproduceerd door apparatuur met een vermogen groter dan 11 kVA – June 1997 – EnergieNed

[6] – IEC/TR 61000-2-12:2003 – Electromagnetic compatibility (EMC) – Part 2-12: Environment - Compatibility levels for low-frequency conducted disturbances and signalling in public medium-voltage power supply systems

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