



# **Power Quality Requirements for Connection to the Transmission System**

**Revision: 1.0**  
**Date: September 2015**

## **Introduction and Purpose of this Document**

The purpose of this document is to provide clarity to Customers seeking connection to the Transmission System about their Power Quality requirements prior to the energisation of the new Facility. These technical requirements are intended to ensure that the quality of supply to all Transmission customers remains within the parameters described in the Grid Code, in line with EirGrid's current practice for new connections / modifications and with International Standards (IEC 61000).

### **Scope**

The Power Quality requirements described in this document refer to Harmonic Voltage Distortion, Rapid Voltage Changes and Voltage Flicker at the interface between the Facility and the Transmission System.

### **Applicability**

The Power Quality requirements described in this document apply to all new connections to the Transmission System – i.e DSO Connections, Generators, Interconnectors and Demand Customers. These requirements are not intended to apply retrospectively to existing Customer connections; however they will be imposed in situations where an existing Facility undergoes a modification that has material impact on their harmonics or voltage fluctuations emission levels.

### **Co-Ordinated Roles and Responsibilities**

It is EirGrid's responsibility to plan and develop the Transmission System to maintain the voltage supply at the Transmission System within the quality indices defined in the Grid Code (CC 10.13.) and in EirGrid's Policy on Harmonics (included in an Appendix of this document). In doing so, EirGrid can allocate emission limits to new Customer connections to ensure that the collective impact of all new connections does not result in breaches of the adopted Power Quality indices thresholds. The allocated Power Quality limits are intended to restrict the electrical disturbances caused by the new Customer's Facility in order to avoid propagation onto the Transmission System that could impair the power supply to other existing customers.

It should be noted that the shallow connection circuit(s) for new Customers' connections are deemed part of the Transmission System and it is EirGrid's responsibility to ensure adequate Power Quality at the Connection Point before the new Facility is energised. Therefore, it is EirGrid's responsibility to mitigate any potential issues associated with shallow connection methods (for example amplification

of background harmonic distortion introduced by radial underground cable connections) prior to the energisation of the new Facility.

It is the Customer's responsibility to design and operate the Facility to ensure that their contribution at the Connection Point do not exceed the limits allocated to them.

### **Data Supplied by EirGrid to the Customer**

The following information will be provided by EirGrid to the new Customer 18 months prior to the scheduled energisation date. Any additional data required by the Customer to design the Facility in accordance with the allocated emission limits will be provided by EirGrid in a timely manner, upon Customer's request.

#### **Data related to Harmonic Voltage Distortion:**

- Allocated Harmonic Distortion Limits (see Section 2.1 for typical format)
- Background Harmonic Distortion Levels at Connection Point (see Section 2.2 for typical format)
- Transmission System Impedance Loci at Connection Point (see Section 2.3 for typical format)

#### **Data related to Voltage Fluctuations:**

- Rapid Voltage Change Limits (see Section 3.1 for typical format)
- Voltage Flicker Limits (see Section 3.2 for typical format)
- Minimum Transmission System Short-Circuit Power at Connection Point (see Section 3.3 for typical format)

### **Data Supplied by the Customer to EirGrid**

Prior to the connection of the Facility to the Transmission System, the Customer must submit a detailed Power Quality assessment report demonstrating that the Facility is designed to comply with the allocated limits. The minimum information required in this report is detailed in Section 4.2. The Power Quality assessment report must be submitted to EirGrid at least 12 months before the scheduled energisation date of the Facility.

Note that submission of the Power Quality report is an important pre-requirement for connection. Late submission of this report may delay the energisation of the Customer's Facility.

## **Review of Customer’s Power Quality report by EirGrid**

EirGrid will review the Power Quality study report and will issue comments to the Customer if necessary. This review will be limited to a high-level inspection of the method of analysis and process followed in the study.

Accepting and reviewing the report shall not be deemed to be a guarantee or endorsement by EirGrid of the accuracy of the Power Quality assessment report and the submission of the required power quality report will not represent proof of compliance with the allocated Power Quality limits. Compliance with the said limits will be solely based on testing and monitoring at the commissioning phase and during a period post-energisation.

## **Structure of this Document**

This document is structured as follows:

**Section 1** – provides definition of the technical terms used throughout this document.

**Section 2** – provides a sample of the format and contents of Harmonic Distortion Limits, pre-connection Background Harmonic Distortion Levels and Transmission System Impedance Loci that will be provided to the Customer.

**Section 3** – provides a sample of the format and contents of the Voltage Fluctuation Limits and Minimum Short-Circuit Power at the Connection Point that will be provided to the Customer.

**Section 4** – describes in detail the process and timelines for exchange of information between EirGrid and the Customer to meet the pre-connection Power Quality requirements:

4.1 – covers the requirement by the Customer to submit a Power Quality study report to EirGrid.

4.2 – covers the minimum information that must be included in the Customer’s Power Quality study report.

4.3 – describes the information provided by EirGrid and the intended application of this data. A suggested methodology for the Power Quality studies to be carried out by the Customer is also included.

**Appendix** – includes EirGrid’s Policy on Harmonics.

**Note:** EirGrid will review this information document periodically and make revisions necessary to reflect changing processes, standards and industry practices.

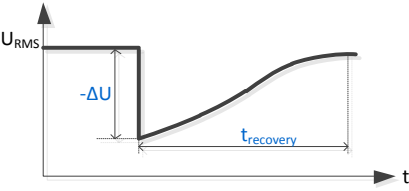
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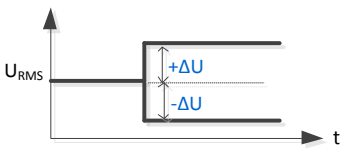
# 1. Definitions

The following definitions used herein are specific to EirGrid and may present slight differences from definitions given to these terms by international standards like IEC or IEEE.

<b>Harmonics Related</b>	
<b>Allocated Harmonic Distortion Limit (AHDL)</b>	<p>The Allocated Harmonic Distortion Limit to a Facility is the maximum Incremental Harmonic Voltage Distortion Level (IHVDL) that the Facility is allowed to introduce in the Transmission System voltage.</p> <p>The AHDL is assessed at the Connection Point and it is expressed as a percentage of the Root Mean Square (RMS) value of the fundamental frequency voltage. The AHDL applies to the THD and to each individual harmonic order from the 2<sup>nd</sup> up to, and including, the 40<sup>th</sup>.</p>
<b>Harmonic Voltage Distortion Level (<math>U_h</math>)</b>	<p>The Harmonic Voltage Distortion Level of the <math>h^{th}</math> order (<math>U_h</math>) is the RMS value of the steady-state sinusoidal voltage waveform at a frequency of <math>(50 \times h)</math> Hz which is present in the voltage waveform in addition to its fundamental frequency component.</p> <p>The Harmonic Voltage Distortion Level is expressed as a percentage of the RMS value of the fundamental frequency component.</p> <p>The Harmonic Voltage Distortion Level is measured according to the class-A method defined in IEC 61000-4-30 and 61000-4-7. The minimum measurement period is one week (i.e. seven days) of normal business activity. Unless otherwise stated, the following index shall be used: 95% weekly value of the measured Harmonic Voltage Distortion Level (<math>U_h</math>) over 10 minute periods.</p>
<b>Incremental Harmonic Voltage Distortion Level (IHVDL)</b>	<p>The Incremental Harmonic Voltage Distortion Level attributed to a Facility is defined as the change in magnitude of the Harmonic Voltage Distortion Level (measured at the Connection Point) which is solely caused by the connection of that Facility to the Transmission System.</p> <div style="text-align: center;"> </div> <p>The Incremental Harmonic Voltage Distortion Level attributed to the Facility is a combination of:</p> <ul style="list-style-type: none"> <li>(a) New distortion caused by harmonic voltages or currents generated by the Customer's Equipment,</li> <li>and</li> </ul>

	(b) Amplification of the existing Harmonic Voltage Distortion Level (measured at the Connection Point) caused by an interaction between the Facility and the Transmission System harmonic impedance (for example due to resonances).
<b>Transmission System Impedance Loci</b>	<p>A set of diagrams defining the range of possible Transmission System impedances (in the R-X plane) for the harmonic orders subject to limits – i.e. from the 2<sup>nd</sup> up to, and including, the 40<sup>th</sup> harmonic order. The Transmission System impedance may adopt any value on the edge or within the loci.</p> <p>The Transmission System Impedance Loci issued to a Facility is calculated at the Connection Point and does not include the effect of the Facility under study. These impedance loci are defined for a range of Transmission System operating scenarios, under intact and single contingency network conditions, for which the Allocated Harmonic Distortion Limits must be met.</p>
<b>Total Harmonic Voltage Distortion (THD)</b>	<p>The Total Harmonic Voltage Distortion is the RMS value of the sum of all individual Harmonic Voltage Distortion Levels (<math>U_h</math>) up to a specified order <math>H</math>, where <math>H</math> is set to be 40.</p> $THD = \sqrt{\sum_{h=2}^H U_h^2}$
<b>Voltage Fluctuation Related</b>	
<b>Rapid Voltage Change</b>	<p>A Rapid Voltage Change is defined as a sudden and noticeable change of the fundamental frequency RMS voltage in one or more phases over several cycles. Rapid Voltage Changes are defined as a percentage of the nominal Transmission System voltage (i.e. 400kV, 220kV or 110kV).</p> <p>In this document, Rapid Voltage Changes are grouped in two categories:</p> <ul style="list-style-type: none"> <li>• Temporary Voltage Depression</li> <li>• Step Change</li> </ul>
<b>Temporary Voltage Depression</b>	<p>A Temporary Voltage Depression is a Rapid Voltage Change characterised by a sudden drop in fundamental frequency RMS voltage with a slow recovery to a new steady state level. Temporary Voltage Depressions are typically caused by motor starting or by energisation or transformers and reactors.</p> 
<b>Step Change</b>	A Step Change is a Rapid Voltage Change characterised by a single, rapid variation of



	<p>the fundamental frequency RMS Voltage between two steady states. Step Changes can take the form of voltage drops or voltage increases and are typically caused by the switching of reactive power compensation devices, fluctuating loads, generation or lines/cables.</p> 
<p><b>Voltage Flicker</b></p>	<p>Voltage Flicker, or flicker, is the impression of unsteadiness of visual sensation induced by a light stimulus whose luminance or spectral distribution fluctuates with time. These changes are caused by rapid, regular changes to the voltage level of the electrical supply to the light source in question. The frequency band to which the human eye is particularly sensitive is from 0.1 to 25 Hz.</p> <p>Flicker is measured in “Flicker Severity” and is characterised by two quantities:</p> <ul style="list-style-type: none"> <li>• <math>P_{st}</math> : Short-term flicker. Value obtained over 10 min periods.</li> <li>• <math>P_{lt}</math> Long-term flicker. Value obtained over 2 hour periods.</li> </ul> $P_{lt} = \sqrt[3]{\frac{1}{12} \cdot \sum_{j=1}^{12} (P_{stj})^3}$ <p>The Voltage Flicker <b>Emission Limit</b> <math>E_{P(ST/LT)}</math> is the maximum allowable <math>P_{ST/LT}</math> contribution available to the Facility.</p> <p>The Voltage Flicker <b>Planning Levels</b> are the maximum <math>P_{st}</math> and <math>P_{lt}</math> adopted by EirGrid for planning purposes to control the cumulative impact of all fluctuating connections to the Transmission System. These thresholds are 0.8 for <math>P_{st}</math> and 0.6 for <math>P_{lt}</math>.</p>

For any other terms not defined in this section, please refer to the “General Conditions of Connection and Transmission Use of System” available in EirGrid website under the following link:

[http://www.eirgrid.com/media/GeneralConditionsofConnectionandUseofSystem\(July%202013\).pdf](http://www.eirgrid.com/media/GeneralConditionsofConnectionandUseofSystem(July%202013).pdf)

## 2. Harmonic Distortion Limits

### 2.1. Allocated Harmonic Distortion Limits

The Customer's Facility shall be designed and operated to ensure that the Incremental Harmonic Voltage Distortion Level at the Connection Point due to the new Facility does not exceed the limits defined in Table 1 below.

**Table 1 - Allocated Harmonic Distortion Limits (applicable at the Connection Point)**

<b>MEC = <span style="color: red;">XX.XX</span> MW</b>	
Harmonic Order (multiple of 50Hz)	Allowed Harmonic Distortion Limit [in % of fundamental Voltage]
2	<span style="color: red;">X.XX</span>
3	<span style="color: red;">X.XX</span>
4	<span style="color: red;">X.XX</span>
5	<span style="color: red;">X.XX</span>
6	<span style="color: red;">X.XX</span>
7	<span style="color: red;">X.XX</span>
8	<span style="color: red;">X.XX</span>
9	<span style="color: red;">X.XX</span>
10	<span style="color: red;">X.XX</span>
11	<span style="color: red;">X.XX</span>
12	<span style="color: red;">X.XX</span>
13	<span style="color: red;">X.XX</span>
14	<span style="color: red;">X.XX</span>
15	<span style="color: red;">X.XX</span>
16	<span style="color: red;">X.XX</span>
17	<span style="color: red;">X.XX</span>
18	<span style="color: red;">X.XX</span>
19	<span style="color: red;">X.XX</span>
20	<span style="color: red;">X.XX</span>
21	<span style="color: red;">X.XX</span>
22	<span style="color: red;">X.XX</span>
23	<span style="color: red;">X.XX</span>
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26	<span style="color: red;">X.XX</span>
27	<span style="color: red;">X.XX</span>
28	<span style="color: red;">X.XX</span>
29	<span style="color: red;">X.XX</span>
30	<span style="color: red;">X.XX</span>
31	<span style="color: red;">X.XX</span>
32	<span style="color: red;">X.XX</span>
33	<span style="color: red;">X.XX</span>
34	<span style="color: red;">X.XX</span>
35	<span style="color: red;">X.XX</span>
36	<span style="color: red;">X.XX</span>
37	<span style="color: red;">X.XX</span>
38	<span style="color: red;">X.XX</span>
39	<span style="color: red;">X.XX</span>
40	<span style="color: red;">X.XX</span>

**Note:** the individual harmonic limits to be included in Table 1 above are calculated by EirGrid on a case-by-case basis for each new Customer's connection. This limits are calculated in line with EirGrid's *Policy on Harmonics* (included in the Appendix) and in compliance with the Power Quality requirements defined in the Grid Code (Section CC 10.13).

## 2.2. Background Harmonic Distortion Levels

For the purposes of designing the facility in accordance to the limits defined in Table 1, the Customer is required to assume the Background Harmonic Distortion levels at the Connection Point presented in Table 2 below. This data will be obtained from measurements (when available) or derived from studies carried out by EirGrid with measurements in neighbouring Transmission Stations.

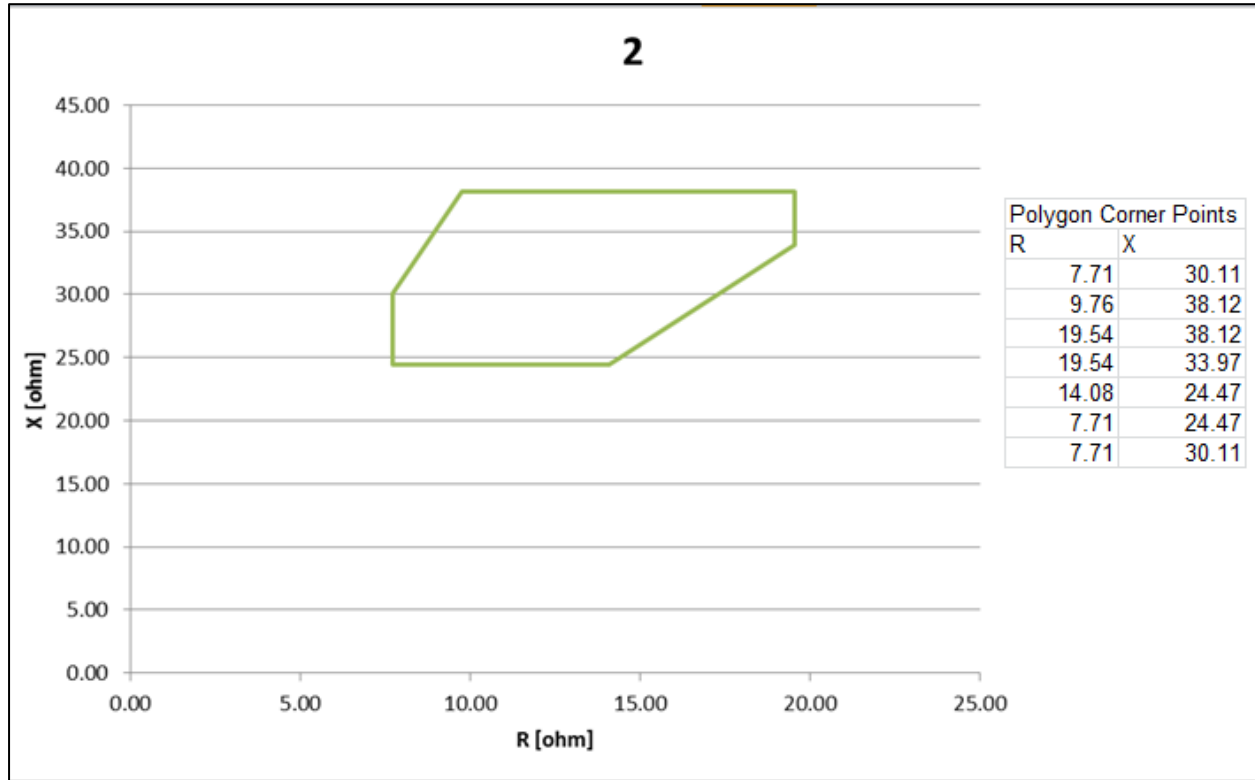
**Table 2 - Pre-Connection Background Harmonic Voltage Distortion at the Connection Point**

Harmonic Order (multiple of 50Hz)	Background Harmonic Voltage Distortion Level [in % of fundamental voltage]
2	x.xx
3	x.xx
4	x.xx
5	x.xx
6	x.xx
7	x.xx
8	x.xx
9	x.xx
10	x.xx
11	x.xx
12	x.xx
13	x.xx
14	x.xx
15	x.xx
16	x.xx
17	x.xx
18	x.xx
19	x.xx
20	x.xx
21	x.xx
22	x.xx
23	x.xx
24	x.xx
25	x.xx
26	x.xx
27	x.xx
28	x.xx
29	x.xx
30	x.xx
31	x.xx
32	x.xx
33	x.xx
34	x.xx
35	x.xx
36	x.xx
37	x.xx
38	x.xx
39	x.xx
40	x.xx

**Note:** the pre-connection Background harmonic distortion will be populated with measured or calculated data applicable to each individual Customer’s connection.

### 2.3. Transmission System Impedance Loci

The Transmission Impedance Loci, as seen at the Connection Point, will be provided in the format shown below. Each locus will capture individual harmonic frequencies or bands of frequencies.



### 3. Voltage Fluctuation Limits

#### 3.1. Rapid Voltage Change Limits

Table 3 – Allocated Rapid Voltage Change Limits (applicable at the Connection Point)

Type of Rapid Voltage Change	$\Delta U/U_N$ Limit [%]
Temporary Voltage Depression	-5 <i>Voltage must recover to a normal steady-state within 3 seconds.</i>
Step Change	$\pm 3$

The limits defined in Table 3 apply to rapid voltage changes that occur no more than 10 times per hour and are caused by disturbances in the Facility. More frequent voltage changes are subject to emission limits for flicker (Table 4).

Note: the limits presented in Table 3 are typical. More limiting values may be applied in some situations.

#### 3.2. Voltage Flicker Limits

Table 4 – Allocated Voltage Flicker Emission Limits (applicable at the Connection Point)

Flicker Emission Limits	
$E_{Pst}$ (short term)	<b>x.xx</b> <i>The 95% probability weekly value of the flicker emission level should not exceed <math>E_{Pst}</math></i>
$E_{Plt}$ (long term)	<b>x.xx</b> <i>The 95% probability weekly value of the flicker emission level should not exceed <math>E_{Plt}</math></i>

Note: the individual flicker emission limits (Table 4) will be calculated by EirGrid on a case-by-case basis following the methodology described in IEC/TR 61000-3-7:2008. The following minimum limits will apply:  $E_{Pst}$  (short term)  $\geq 0.35$  and  $E_{PLt}$  (long term)  $\geq 0.25$ .

#### 3.3. Minimum Short-Circuit Power

The Voltage Fluctuation Limits specified in sections 3.1 and 3.2 above are applicable under the minimum Transmission System short-circuit power defined in Table 5.

Table 5 - Minimum Short-Circuit Power at Connection Point

$S_{sc}$ [MVA]	X/R
<b>x.xx</b>	<b>x.xx</b>

## **4. Power Quality Study Requirement**

### **4.1. Submission of Power Quality Study Report**

Prior to the connection of the Facility to the Transmission System, the Customer must submit to EirGrid a detailed Power Quality assessment report demonstrating that the Facility is designed to comply with the limits defined in sections 2 (Harmonic Voltage Distortion) and 0 (Voltage Fluctuation).

This study report must be submitted to EirGrid at least **12 months** before the scheduled energisation date of the Facility.

EirGrid will review the Power Quality study report and will issue comments to the Customer if necessary. This review will be limited to a high-level inspection of the method of analysis and process followed in the study. EirGrid will not perform an exhaustive check of the data, assumptions or calculation results presented in the Customer's Power Quality study report.

Note that submission of the required power quality report will not represent proof of compliance with the allocated Power Quality limits. Compliance with the said limits will be solely based on testing and monitoring at the commissioning phase and during a period post-energisation.

Any subsequent modification in the Facility that could affect its disturbance emission levels will require submission of a new power quality study report to demonstrate that compliance with the allocated limits is still maintained. In some cases, EirGrid may need to review the power quality limits associated with the modification. Such modifications include, but are not limited to, changes in the length of internal collector network, changes in harmonic filters or reactive power compensation devices, changes in the reactive power control mode, changes in the turbines, transformers or other apparatus, changes in MEC or MIC, etc.

### **4.2. Minimum Requirements for the Power Quality Study Report**

The study report submitted by the Customer must contain the calculation results for prospective maximum harmonic voltage distortion and voltage fluctuations caused by the connection of the Facility to the Transmission System. The report must also include all information needed to demonstrate that the Facility is designed to comply with the allocated power quality limits.

The power quality study report must contain, as a minimum, the following items:

- A detailed single-line diagram of the Facility showing the key electrical parameters of the main equipment including, but not restricted to: MV cables (types and lengths), static reactive power compensation devices, harmonic filters, FACTS devices, transformers (rating, impedance, transformation ratio and winding vector group), generators, motors, power electronic converters, etc.
- Detailed manufacturer data including electrical characteristics, operating modes and electrical disturbance emissions (with test reports) for all disturbance producing equipment (e.g. power and types of converters, pulse numbers, impedances, short-circuit power, power and types of induction generators and motors, inrush currents from transformers and induction machines).
- Detailed manufacturer datasheets (and test reports where available) showing electrical characteristics of the main pieces of plant, such as MV cables, transformers, generators, reactors, capacitors, SVCs, STATCOMs, harmonics filters, etc.
- Detailed description of the methodology and assumptions underlying the assessment of maximum disturbance levels from the Facility and their justification.
- Detailed description of the models and references to the simulation tools used for the assessment.
- If the prospective disturbance levels caused by the Facility exceed the allocated limits, the report must describe and analyse the characteristics and performance of the proposed mitigation measures.

The Harmonics Assessment section must include, as a minimum, the following:

- Electrical characteristics of any capacitor banks and harmonic filters components, including the detuning frequency.
- Identification of potential resonances between the Facility (cables, capacitors, harmonic filters, etc.) and the Transmission System.
- Tables with maximum harmonic current injections (for harmonics of orders  $n = 2$  to 40) from any disturbance producing equipment (e.g. power electronic converters, variable frequency drives, arc furnaces, etc.). Any assumed aggregation for the entire Facility should also be included.



- Impedance graphs (R-X) showing the following information for each harmonic order from 2 to 40 (i.e. one graph per harmonic order as illustrated in Figure 1):
  - Scatter plot of the Facility harmonic impedance values (as seen at the Connection Point, but excluding the Transmission System) under a range of operating conditions, including the most unfavourable equipment outages and sectionalising conditions. See section 4.3.2.
  - Transmission System Harmonic Impedance Loci, as provided by EirGrid in section 2.3.
  - Identification of the combined pair of impedance points (Transmission System impedance and Facility) leading to the highest Harmonic Voltage Distortion at the Connection Point.

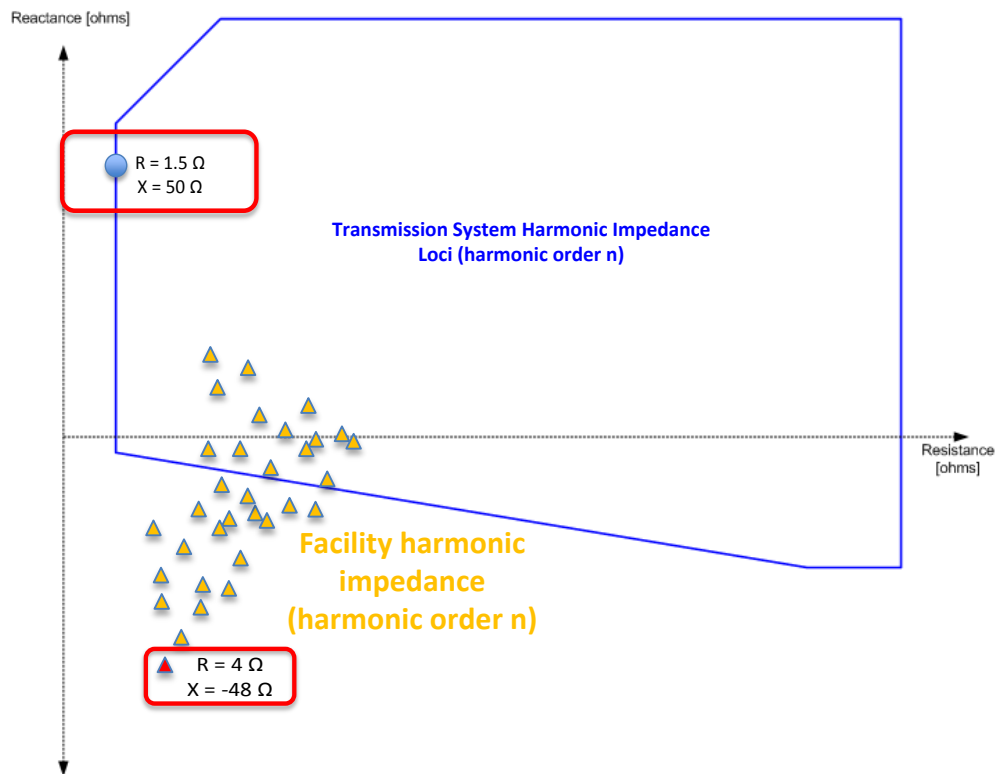


Figure 1 – Example of impedance graph showing Transmission System and Facility harmonic impedance (order n)

- The report must include a table with the following calculation results for all harmonics of orders  $n = 2$  to 40. See Figure 3 for an illustration of the incremental harmonic distortion levels caused by a Facility and the compliance assessment criteria.

- Background Harmonic Distortion (provided by EirGrid in section 2.2) -  $V_{BCK}$
- Maximum amplification factor  $k$  (calculated as described in section 4.3.3)
- Maximum modification of the Background Harmonic Voltage Distortion at the Connection Point caused solely by interactions between the Facility and the Transmission System impedance (i.e. neglecting any new harmonic emission from equipment in the Facility)  $(k - 1) \cdot V_{BCK}$
- Maximum Harmonic Voltage Distortion at the Connection Point caused solely by new harmonic contribution from the Facility (i.e. neglecting the pre-existing background harmonic voltage distortion).  $V_{INC}$
- Maximum aggregated Incremental Harmonic Voltage Distortion Level at the Connection Point taking into account the combined effect of background harmonic distortion amplification and the new harmonic contribution from non-linear equipment in the Facility.  $IHVDL = (k - 1) \cdot V_{BCK} + V_{INC}$
- Assessment of compliance against the Allocated Harmonic Distortion Limits (as set out in Section 2.1 of this document).

**Table 6 – Example of Harmonic Voltage Distortion Assessment**

<b>Harmonic Order</b>	$V_{BCK}$	$k$	<i>Background modification without new harmonic injections <math>(k - 1) \cdot V_{BCK}</math></i>	<i>New Harmonic Voltage Distortion without Background Distortion <math>V_{INC}</math></i>	<i>Incremental Harmonic Voltage Distortion Level caused by the Facility <b>IHVDL</b></i>	<i>Compliance with Allocated Limit</i>
n	0.5%	1.01	0.005%	0.35%	0.355%	Yes (0.4%)

The Voltage Fluctuation assessment must include, as a minimum, the following:

- Detailed manufacturer data for information of any fluctuating load (e.g. wind turbines)
- Description of the calculation methods.

- Table of calculated emission levels at the Connection Point for the following disturbance generated within the Facility and compliance assessment against the limits provided in section 0 :
  - Voltage Flicker: short term and long term
  - Rapid Voltage Limits: Temporary Voltage Depression and Step Change
- Description of mitigation measures and their effect on emission levels as well as any planned operating conditions or restrictions (for example, maximum number of transformers that can be energised simultaneously by a single switching operation).

### **4.3. Power Quality Assessment Study**

#### **4.3.1. Use of Transmission System Data**

The Transmission System Impedance Loci (section 2.3) and Background Harmonic Distortion Levels (section 2.2) are provided to enable the Customer design the Facility in compliance with the Allocated Harmonic Distortion limits set out in section 2.1 of this document. The Facility must be designed to comply with such limits for any Transmission System impedance value on the edge or within the provided loci.

The minimum three-phase short-circuit power  $S_{SC}$  of the Transmission System (section 3.3) is provided to enable the Customer design the Facility in compliance with the Voltage Fluctuation limits set out in this document: (i) Rapid Voltage Change in section 3.1 and (ii) Voltage Flicker in section 3.2.

The Transmission System Impedance Loci and minimum short-circuit power provided to the Customer relate only to the Transmission System, as seen at the Connection Point, and do not include the effect of the Facility. In the calculation of these figures, EirGrid typically take into account a range of variations in demand and generation portfolio dispatch as well as Transmission network topologies (including single outages) corresponding to the existing and future (planned) transmission system. In brief, the Transmission System impedance data provided by EirGrid is based on:

- (i.) Loci for harmonics assessment: Intact network and single contingency scenarios.
- (ii.) Minimum short-circuit power for voltage fluctuation assessment: Single contingency.

#### **4.3.2. Operating Conditions to be considered in the Customer's study**

In assessing disturbance emission levels generated by the Facility, the study must account for all possible operating conditions within the Facility (including MV busbar couplings/sectionalising, inter-array MV cable outages, switching status of reactive power compensation devices or harmonic filters, number of connected generators, motors, transformers, etc.). Each of these operating points must be tested against the Transmission System data provided by EirGrid as follows:

- For assessment of Harmonic Voltage Distortion, the Customer must check the Facility against each point on the edge and within the Transmission System Impedance Loci (provided in section 2.3) to identify the combination that leads to the highest Harmonic Voltage Distortion level at the Connection Point.
- For Voltage Fluctuation assessment, the Customer must check the Facility against the minimum system short-circuit power ( $S_{SC}$ ) at the Connection Point (provided in section 3.3).

Any possible operating point in the Facility that is excluded from the analysis above must be justified – for instance if the probability of occurrence is deemed to be very low.

#### **4.3.3. Assessment of Harmonic Voltage Distortion**

The impact of the Facility on the Harmonic Voltage Distortion Level at the Connection Point must be assessed considering characteristic and non-characteristic harmonic orders from 2 to 40. This assessment must include the combined effect of new harmonic contribution generated by the non-linear equipment installed in the Facility and the modification of the background harmonic voltage distortion caused by interaction between the Facility and the Transmission System impedance (for example due to resonances).

The Transmission System Impedance Loci (section 2.3) and Background Harmonic Voltage Distortion (section 2.2) serve as input to the Customer assessment of emission levels.

The Transmission System Impedance Loci provided by EirGrid does not include the effect of the Facility, but the Customer must account for this effect in the harmonics assessment. The interaction between the Facility and the Transmission System impedance can amplify or modify existing background harmonic distortion due to resonance or near-resonance conditions. The Facility must be designed and operated to comply with the harmonic limits set out in this document once any amplifying effect of possible resonances is taken into account.

For equipment whose harmonic emission levels are dependent on the equipment loading (or output), the study must account for the most onerous operating conditions leading to the highest harmonic emission levels.

The following assessment procedure is suggested (see Figure 3 for illustration). However, the Customer can use alternative approaches to demonstrate compliance with the allocated limits, which must be clearly documented in the study report.

**Step 1. Calculation of the Background Harmonic Distortion Amplification factor (*k*)**

Defined as the ratio between the Background Harmonic Voltage Distortion at the Connection Point before and after the energisation of the Facility<sup>1</sup>. Harmonic contributions from disturbance-producing equipment within the Facility are excluded. Using the simplified diagram shown in Figure 2, the amplification factor *k* can be calculated as:

$$k = \frac{V_{BCK(post-connection)}}{V_{BCK(pre-connection)}} = \left| \frac{Z_{CF}}{Z_{CF} + Z_{TS}} \right|$$

Where:

**V<sub>BCK(pre-connection)</sub>** is the Background Harmonic Distortion Level at the Connection Point prior to the connection of the Facility. Provided in section 2.2 of this document.

**V<sub>BCK(post-connection)</sub>** is the Background Harmonic Distortion Level at the Connection Point, after the connection of the Facility, but ignoring any harmonic contribution from disturbance-producing equipment within the Facility (i.e. without active harmonic sources in the Facility).

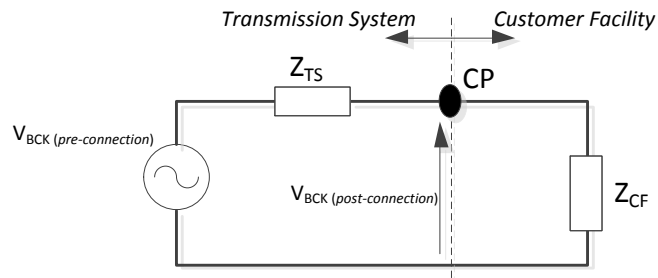
**Z<sub>CF</sub>** is the equivalent harmonic impedance of the Facility only, as seen from the Connection Point. A change in the Facility switching configuration or operating condition can result in a change in the harmonic impedance of the Facility, as seen at the Connection Point. Therefore, the calculation of Z<sub>CF</sub> must cover all switching operating conditions expected in the Facility, once is in normal operation, and during planned/unplanned outages of equipment.

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<sup>1</sup> It must be noted that the effect of the Facility can result in an amplification and also in a reduction of the background harmonic distortion. The amplification factor *k* can, in theory, take any value between 0 and ∞.

$Z_{TS}$  is the Transmission System harmonic impedance only, as seen from the Connection Point. It is defined by the loci provided in section 2.3 of this document.

Note: each of the parameters defined above apply to all harmonic orders from  $n = 2$  to 40.



**Figure 2 – Simplified diagram showing connection of the Facility (without harmonic injections) to the Transmission System**

The assessment must consider all possible operating conditions of the Facility (i.e. a range of values for  $Z_{CF}$ ) and of the Transmission System (i.e. all  $Z_{TS}$  points within the provided loci), as detailed in section 4.3.2, to identify the combination that leads to the highest amplification factor  $k$  at each harmonic frequency. Therefore, an automated process to scan through all possible combinations might be necessary.

## **Step 2. Calculation of the incremental contribution to Harmonic Voltage Distortion at the Connection Point caused by Disturbance Producing Equipment within the Facility ( $V_{INC}$ )**

Carry-out harmonic load flow calculations with a detailed model representation of the Facility, including all active harmonic sources from the equipment in the Facility, and a passive network equivalent representation of the Transmission System at the Connection Point (obtained from Transmission System Impedance loci). Pre-existing harmonic voltage distortions at the Connection Point are not considered in this step.

All possible operating conditions of the Facility and Transmission System must be considered. The combination of Facility operating conditions and Transmission System Impedance ( $Z_{TS}$ ) that leads to the highest Harmonic Voltage Distortion at the Connection Point must be identified for each harmonic frequency as the limiting condition.

This calculation applies to all harmonic orders from  $n = 2$  to 40.

### **Step 3. Calculation of aggregate effect of background amplification and new harmonic contributions from the Facility (IHVDL). Assessment against Allocated Harmonic Distortion Limits**

The overall effect of the Facility on the Harmonic Voltage Distortion at the Connection Point is calculated from the outcome of Step-1 and Step-2, for each harmonic order, as:

$$\text{IHVDL} = (k - 1) \cdot V_{\text{BCK}} + V_{\text{INC}}$$

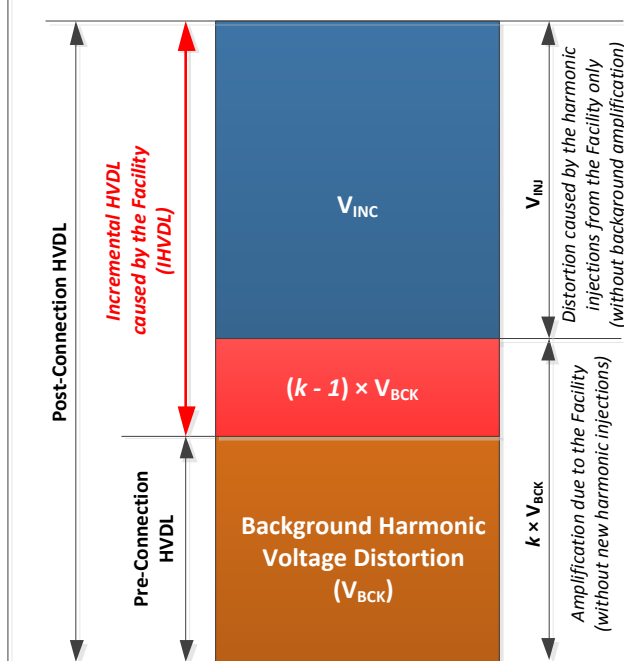
Where IHVDL is the Incremental Harmonic Voltage Distortion Level attributed to a Facility, as defined in section 1 of this document.

Compliance with the limits set out in section 2.1 of this document (AHDL) is achieved if the following condition is true for each individual harmonic order and THD:

$$\text{IHVDL} \leq \text{AHDL}$$

It is acknowledged that the aggregation method described above is a simplification and can lead to some over-estimation of the harmonic effects caused by the Facility at the Connection Point. Given its simplicity, the method is deemed acceptable as a first assessment criterion. However, if the Facility, as designed, fails to meet this condition, the Customer can carry-out additional analysis or propose and justify an alternative aggregation method to demonstrate compliance with the allocated limits under all operating conditions.

Harmonic Voltage Distortion Level (HVVDL)



**Compliance Criteria**

Incremental Harmonic Voltage Distortion Level (IHVDL)	≤	Allocated Harmonic Distortion Limit (AHDL)
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$$[(k - 1) \times V_{BCK} + V_{INC}] \leq AHDL$$

Figure 3 – Compliance Assessment Criteria for Harmonic Voltage Distortion

**4.3.4. Assessment of Voltage Fluctuation**

Emission limits apply to Voltage Flicker and Rapid Voltage Changes caused by fluctuations in generation output, fluctuating loads and switching operations within the Facility. These limits apply to voltages for all three phases, and the most strongly affected phase must comply with the limits.

The assessment studies must be carried out using an appropriate simulation tool and including a detailed model of the Facility under a range of operating conditions. The Transmission System impedance, as seen at the Connection Point, must be represented as a Thevenin equivalent derived from the minimum short-circuit power (and associated X/R ratio) provided by EirGrid.

Assessment of “Flicker” emission levels must be carried out in accordance with the procedure described in IEC 61000-3-7. These studies must cover a range of operating conditions, including but not limited to (i) normal operation under various wind speeds, (ii) wind turbine start-up at cut-in wind speed and (iii) wind turbine start-up at rated or higher wind speed conditions.

The assessment of “Temporary Voltage Depression” must include simulations of wind turbine generator (WTG) transformer energisation. These studies must assume the most onerous switching instant (point of wave) with remnant flux in the magnetic core (at least 60% of nominal). Furthermore, the scope of the switching study must cover simultaneous energisation of multiple transformers (for



instance a full MV cable array) to determine the maximum number of transformers that can be energised simultaneously. Sympathetic inrush from other previously energised transformers must also be considered. Where the Facility contains large motors, the studies must include simulations of motor starting (individual or multiple starts). In this assessment, the Customer must evaluate compliance with the limits provided in section 3.1 in terms of both, instantaneous voltage depression and recovery time.

The assessment of “Step Change” must include the switching of all major equipment within the Facility (especially capacitive devices) and the sudden trip of some parts or the entire Facility. For the tripping scenario, the Customer must assess the most onerous generation output level with leading and lagging power factors covering the full range specified in the Grid Code.

## **Appendix: EirGrid Policy on Harmonics**



## EirGrid Policy

Policy on Harmonics									
Issue No. 2	December 2013								
Revision No 1	This policy has been updated to incorporate corrections made as a result of application of the previous version of the Policy (issue No.1).								
Background	<p>The Connection Conditions in the Grid Code sets out a requirement for all Users to ensure that their contribution to the <b>Harmonic Voltage Distortion Level</b> at the <b>Point of Connection (POC)</b> does not exceed the limits allocated to them following consultation with the TSO.</p> <p>Traditionally, the <b>Harmonic Voltage Distortion Levels</b> in the <b>Transmission System</b> have been very low and <b>Distortion Limits</b> have rarely been imposed on <b>User's</b> connections. However, a rise in <b>Harmonic Voltage Distortion Levels</b> has been observed over the past few years, especially in weak areas of the <b>Transmission System</b>. It is expected that the installation of new underground cable circuits and the proliferation of electronic non-linear equipment in new <b>Users'</b> facilities can increase the <b>Harmonic Voltage Distortion Levels</b> in the <b>Transmission System</b> beyond acceptable levels.</p> <p>This Policy formally defines the applicable criteria and the actions that EirGrid must implement when planning and developing the <b>Transmission System</b> to ensure that an adequate quality of supply (in terms of Harmonics) is provided to all <b>Users</b> at the <b>Point of Connection</b>.</p>								
Definitions	<p><b>Allocated Harmonic Distortion Limit:</b> The <b>Allocated Harmonic Distortion Limit</b> to a new <b>User's</b> connection is the maximum <b>Incremental Harmonic Voltage Distortion Level</b> that the <b>User's</b> facility is allowed to introduce in the <b>Transmission System</b> voltage.</p> <p>The <b>Allocated Harmonic Distortion Limit</b> is assessed at the <b>Point of Connection (POC)</b> and it is expressed as a percentage of the RMS value of the fundamental frequency voltage.</p> <p>The <b>Allocated Harmonic Distortion Limit</b> applies to the THD and to each individual harmonic order from the 2<sup>nd</sup> up to, and including, the 40<sup>th</sup>.</p> <p><b>Harmonic Distortion Headroom (DH<sub>h</sub>):</b> The <b>Harmonic Distortion Headroom</b> at the <b>h<sup>th</sup></b> order is the difference between the <b>Harmonic Planning Level</b> and the <b>Harmonic Voltage Distortion Level</b> (measured or calculated) at the <b>h<sup>th</sup></b> order.</p> <p>The harmonic order "<b>h</b>" is an integer number greater than 1 and its corresponding frequency is obtained by multiplying the harmonic order "<b>h</b>" by the fundamental frequency 50Hz.</p> <p>The <b>Harmonic Distortion Headroom</b> is calculated using the IEC/TR 61000-3-6 general summation law as defined below:</p> $DH_h = \sqrt[\alpha]{(L_h)^\alpha - (U_h)^\alpha}$ <p>where <b>L<sub>h</sub></b> is the <b>Harmonic Planning Level</b> at the <b>h<sup>th</sup></b> order, <b>U<sub>h</sub></b> is the <b>Harmonic Voltage Distortion Level</b> at the <b>h<sup>th</sup></b> order and <b>α</b> is the summation exponent as per table below<sup>1</sup>.</p> <table border="1" style="margin-left: auto; margin-right: auto; border-collapse: collapse; text-align: center;"> <thead> <tr style="background-color: #d9ead3;"> <th style="padding: 2px;">Harmonic order</th> <th style="padding: 2px;">α</th> </tr> </thead> <tbody> <tr> <td style="padding: 2px;">h &lt; 5</td> <td style="padding: 2px;">1</td> </tr> <tr> <td style="padding: 2px;">5 ≤ h ≤ 10</td> <td style="padding: 2px;">1.4</td> </tr> <tr> <td style="padding: 2px;">h &gt; 10</td> <td style="padding: 2px;">2</td> </tr> </tbody> </table>	Harmonic order	α	h < 5	1	5 ≤ h ≤ 10	1.4	h > 10	2
Harmonic order	α								
h < 5	1								
5 ≤ h ≤ 10	1.4								
h > 10	2								

<sup>1</sup> Extract from IEC/TR 61000-3-6, Edition 2.0 2008-02

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**Harmonic Planning Levels ( $L_h$ ):** The **Harmonic Planning Levels** are EirGrid's planning limits for **Harmonic Voltage Distortion Levels** and THD. These limits must be maintained in the planning and development of the **Transmission System** and must be used for setting **Allocated Harmonic Distortion Limits** to User's connections (see Table 1). The **Harmonic Planning Levels** are expressed as a percentage of the RMS value of the fundamental frequency voltage.

The **Harmonic Planning Levels** apply to the THD and to each individual harmonic order from the 2<sup>nd</sup> up to, and including, the 40<sup>th</sup>.

**Harmonic Planning Margin:** The **Harmonic Planning Margin** is a portion of the **Harmonic Distortion Headroom** in a **Transmission Node** that is retained by EirGrid while setting **Allocated Harmonic Distortion Limits** to User's connections (see Figure 2).

**Harmonic Voltage Distortion Level ( $U_h$ ):** The **Harmonic Voltage Distortion Level** of  $h^{\text{th}}$  order is the RMS value of the steady-state sinusoidal voltage waveform at a frequency of ( $50 \times h$ ) Hz which is present in the voltage waveform in addition to its fundamental frequency component.

The **Harmonic Voltage Distortion Level** is expressed as a percentage of the RMS value of the fundamental frequency voltage.

**Incremental Harmonic Voltage Distortion Level ( $|U_{h(i)}|$ ):** The **Incremental Harmonic Voltage Distortion Level** attributed to the User's facility (i) is the incremental change in magnitude of the **Harmonic Voltage Distortion Level** ( $U_h$ ) measured at the **Point of Connection (POC)** which is solely caused by the connection of the User's facility. This is illustrated in Figure 1, where  $h$  is the harmonic order,  $U_{h(\text{pre-connection})}$  is the **Harmonic Voltage Distortion Level** at the POC prior to the User's connection and  $U_{h(\text{post-connection})}$  is the **Harmonic Voltage Distortion Level** at the POC arising after the User's connection.

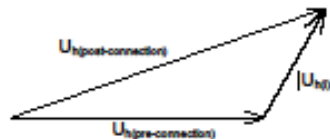


Figure 1 – Illustration of Harmonic Voltage Emission Level

The **Incremental Harmonic Voltage Distortion Level**  $|U_{h(i)}|$  attributed to the User's facility (i) is a combination of:

- (a) Distortion caused by harmonic voltages or currents generated by the User's facility, and
- (b) Amplification of the existing **Harmonic Voltage Distortion Level** caused by an interaction between the User's facility and the **Transmission System** harmonic impedance (for example due to resonances).

**Point of Connection (POC):** The **Point of Connection** is the physical point where the User's facility is joined to the **Transmission System**. This point is typically the HV bushings of the User's Grid Connected Transformers.

**Total Harmonic Voltage Distortion (THD):** The **Total Harmonic Voltage Distortion** is the RMS value of the sum of all individual **Harmonic Voltage Distortion Levels** ( $U_h$ ) up to a specified order  $H$ . For the purposes of this policy,  $H$  is defined as 40.

$$THD = \sqrt{\sum_{h=2}^H U_h^2}$$



## EirGrid Policy

**Transmission Node:** A **Transmission Node** is defined as a busbar in a sub-station which is part of the **Transmission System**. In single-bay substations (where a busbar does not exist), the high voltage circuit breaker is designated as the **Transmission Node**.

**Transmission System:** The system consisting of high voltage electric lines, cables and sub-stations operated by the TSO. The **Transmission System** in Ireland comprises 400kV, 220kV and most 110kV networks. The 110kV network in the greater Dublin area and some special 110kV demand stations are controlled by the DSO and, thus, not deemed part of the **Transmission System**.

**User:** The term **User** refers to the DSO, Transmission connected Generators, Transmission connected Demand Customers and Interconnectors.

**For the purposes of this Policy, the following generally used terms are interpreted as per associated definitions below:**

**Connection Point:** See **Point of Connection** definition.

**Distortion Limit:** See **Allocated Harmonic Distortion Limit** definition.

**Emission Level:** See **Incremental Harmonic Voltage Distortion Level** definition.

**Emission Limit:** See **Allocated Harmonic Distortion Limit** definition.

**Planning Levels:** See **Harmonic Planning Levels** definition.

**Planning Limits:** See **Harmonic Planning Levels** definition.

### Policy

#### **Harmonic Planning Levels**

EirGrid has adopted the "Indicative planning levels for harmonic voltages" defined in IEC/TR81000-3-6: 2008 for HV and EHV power systems as internal quality objectives, which are defined in this policy as **Harmonic Planning Levels** (see Table 1). EirGrid shall plan and develop the **Transmission System** to maintain the **Harmonic Voltage Distortion Levels** and THD within the adopted **Harmonic Planning Levels**. In doing so, **Allocated Harmonic Distortion Limits** are applicable for **User's** connections.

The **Harmonic Planning Levels** must be maintained under intact network conditions (N) and following a single contingency (N-1).

Table 1 – EirGrid Harmonic Planning Levels for 110kV, 220kV and 400kV Networks<sup>2</sup>

Odd harmonics non-multiple of 3		Odd harmonics multiple of 3		Even harmonics	
Harmonic order h	Harmonic Voltage Distortion [% of $U_{H(20+40)}$ ]	Harmonic order h	Harmonic Voltage Distortion [% of $U_{H(20+40)}$ ]	Harmonic order h	Harmonic Voltage Distortion [% of $U_{H(20+40)}$ ]
5	2	3	2	2	1.4
7	2	9	1	4	0.8
11	1.5	15	0.3	6	0.4
13	1.5	21	0.2	8	0.4
$17 \leq h \leq 37$	$1.2 \cdot \frac{17}{h}$	$21 < h \leq 39$	0.2	$10 \leq h \leq 40$	$0.19 \cdot \frac{10}{h} + 0.16$
THD $\leq$ 3%					

<sup>2</sup> Extract from IEC/TR 61000-3-6, Edition 2.0 2008-02, limited to the 40<sup>th</sup> harmonic order.

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Note: The **Harmonic Planning Levels** apply to the THD and to each individual harmonic order from the 2<sup>nd</sup> up to, and including, the 40<sup>th</sup>.

### **Transmission System Development in Compliance with the Harmonic Planning Levels**

In the prudent planning and development of the **Transmission System**, EirGrid shall endeavour to ensure that the introduction of new transmission circuits, reactive compensation devices or any other equipment will not result in the **Harmonic Planning Levels** being exceeded at any location of the **Transmission System**. When in breach, mitigating solutions shall be implemented at appropriate locations in the **Transmission System** to reduce the **Harmonic Voltage Distortion Levels** and THD below the **Harmonic Planning Levels**.

### **Allocated Harmonic Distortion Limits to Users**

In order to guarantee that the **Harmonic Voltage Distortion Levels** and THD are maintained below the **Harmonic Planning Levels** at all **Transmission Nodes**, EirGrid must assess the impact of the connection of new **Users**. As a result of this assessment, specific **Allocated Harmonic Distortion Limits** can be imposed on **Users'** connections.

The method adopted by EirGrid for calculating the **Allocated Harmonic Distortion Limits** for each new **User's** connection is based on Stage 2 of IEC/TR 61000-3-6, with some enhancements aimed to distribute the emission limitation burden as equitably as possible. The main principles in the allocation method are described below (illustrated in Figure 2 for a **Transmission Node** with  $N$  **Users** connections):

- (i) Carry-out measurements of existing background **Harmonic Voltage Distortion Levels** and THD.
- (ii) Calculate the **Harmonic Distortion Headroom**.
- (iii) Retain 25% of the **Harmonic Distortion Headroom** as **Harmonic Planning Margin**.
- (iv) Allocate a portion of the remaining distortion capacity (taking into account interactions from neighbouring **Transmission Nodes**) to the **User's** connection. The apportioning of distortion capacity is on a MW pro-rata basis between all **Users** connecting at the same **Transmission Node**. This method guarantees harmonics access rights to all **Users** in proportion to their relative size, allowing a fair distribution of the available distortion capacity.

### **Measurements of Background Harmonic Voltage Distortion**

The class A measurement method for **Harmonic Voltage Distortion Level** defined in IEC 61000-4-30 and 61000-4-7 shall be used. The minimum measurement period is one week (i.e. seven days) of normal business activity. The following index shall be used:

- The 95% weekly value of the measured **Harmonic Voltage Distortion Level** ( $U_h$ ) over 10 minute periods.

As a minimum, a set of one-week measurements must be taken from each existing **Transmission Node** under assessment. When assessing a future **Transmission Node**, the measurements should be taken as electrically close as is practicable to the location of the new **Transmission Node**.

### **Roles and Responsibilities**

Table 2 below summarises the co-ordinated roles and responsibilities between EirGrid and the **Users** to limit the **Harmonic Voltage Distortion Levels** in the **Transmission System**. This approach facilitates adequate electromagnetic compatibility (EMC) for harmonics between the expected disturbances in the **Transmission System** and the immunity of the **User's** equipment.





## EirGrid Policy

Table 2 – Roles and Responsibilities

EirGrid	User
Plan and Develop the Transmission System to maintain the Harmonic Voltage Distortion Levels and THD below the Harmonic Planning Levels	Maintain Incremental Harmonic Voltage Distortion Levels within the Allocated Harmonic Distortion Limits
Allocate Harmonic Distortion Limits to Users, when necessary, to prevent the Harmonic Voltage Distortion Levels and THD reaching the Planning Levels	

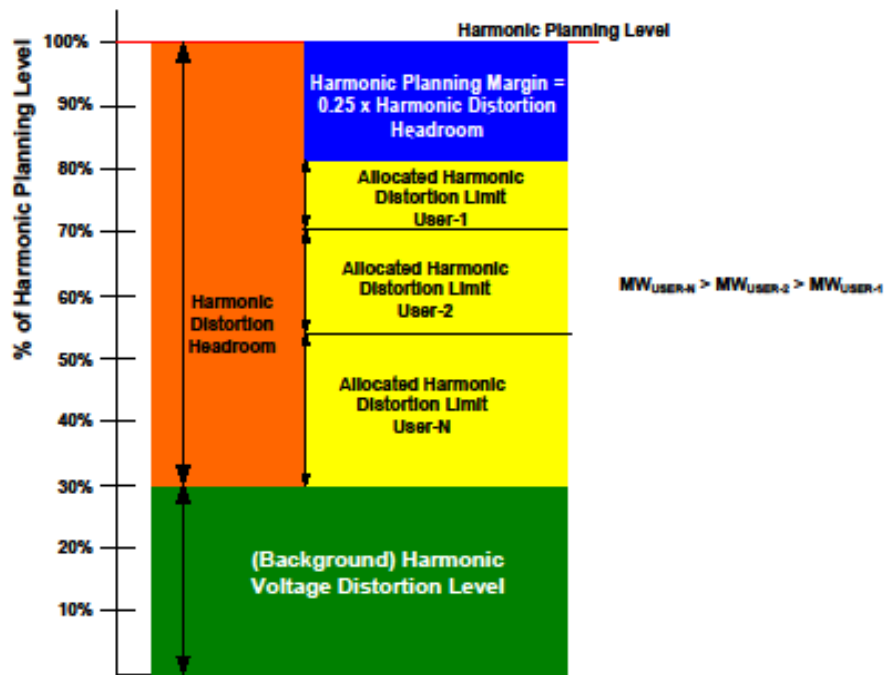





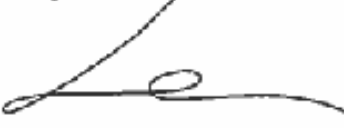


Figure 2 – Illustration of Allocation of Distortion Limits

Application	This policy applies beyond the sign-off date.
Derogation	Derogation from this policy will be by exception, following EirGrid's Derogation Policy.

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## EirGrid Policy

Sign-Off	<b>Prepared by:</b>  Marta Gal Escudero	Date: 20 December 2013
	<b>Checked/Reviewed by:</b>  Yvonne Coughlan Manager Transmission Access Planning	Date: 20/12/13
	 Louis Fisher Manager Transmission Network Planning	Date: 20/12/13
	 Mario Duarte Manager Grid Planning Strategy, Standards and Data	Date: 20.12.2013
	 Mark Norton Manager Technology and Innovation	Date: 20/12/13
	<b>Approved:</b>  Michael Walsh Director Future Grids	Date: 6/1/14

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