**Distribution Code Consultation DCRP/18/05/PC**

**Engineering Recommendation (EREC) G5 Issue 5 (2018)**

*Harmonic voltage distortion and the connection of non-linear and resonant plant and equipment to transmission systems and distribution networks in the United Kingdom*

**Target Audience:**

The requirements in EREC G5 are intended for persons who:

* Propose to connect equipment with harmonic emission or resonant plant to the public electricity supply system that has the potential for causing or modifying voltage harmonic distortion.
* Propose to alter such a disturbing equipment/installation as mentioned above, connected to the public electricity supply system that would result in material changes in voltage distortion.
* Carry out assessments of the connection of disturbing equipment and the resultant voltage distortion and issue harmonic limits.
* Measure voltage distortion caused by disturbing equipment for the purpose of checking conformance with requirements in EREC G5.

**Date Published: Wednesday xx June 2018**

**Deadline for responses: 17:00 Friday xx July 2018**

**Summary:**

This joint Distribution Code and Grid Code public consultation is seeking the views from industry stakeholders on the proposed modification to Engineering Recommendation G5, subsequently referred to as EREC G5 Issue 5.

This modification has been prepared under the authority of the Distribution Code Review Panel (DCRP) and Grid Code Review Panel (GCRP) of Great Britain – EREC G5 being a Qualifying Standard and Licence Standard under the Distribution Code and Grid Code.

The DCRP and GCRP establish and maintain governance arrangements for standards referenced in the Distribution and Grid Codes that have a material effect on Users of the Distribution and Transmission Systems. As such, EREC G5 is approved by the Authority (Ofgem) before publication.

# The proposed EREC G5 Issue 5 constitutes a full technical revision of Issue 4 published in 2005 and has been extended, amongst other things, to cover assessment for concurrent connections

# 1. Introduction

EREC G5 defines planning levels and compatibility levels for the assessment of voltage distortion from Network User’s equipment and installations with harmonic emission to be connected to transmission systems and distribution networks in the United Kingdom.

Voltage distortion from one and the aggregated impact resulting from several pieces of equipment are covered. The requirements apply to new connections of disturbing equipment to the public electricity supply system as well as changes to existing connections, in so far as they affect voltage distortion.

EREC G5 has been modified as outlined below:

1. Planning and compatibility levels for individual harmonics have been revised, while keeping the planning and compatibility levels for voltage total harmonic distortion (THD) the same as G5 Issue 4 (G5/4). As a result for some harmonics these levels have increased. No planning or compatibility level has decreased compared to G5 Issue 4.
2. Defining voltage ranges for which the tables of planning and compatibility levels are applicable. These voltage levels have been adapted to align with typical voltages in use in the UK.
3. The planning and compatibility levels are now extended to 5 kHz (the 100th harmonic). The measurement of harmonics above 2.5 kHz is at the discretion of the NO (see below for definition) facilitating the connection. It is also recommended to consider the assessment of these harmonics at the discretion of the NO.
4. Clearly defining interharmonics and revising interharmonic limits in accordance with IEC 61000-34-30, IEC 61000-4-7 and IEC 61000-2-2.
5. Revising limit for voltage notches in terms of the notch depth and duration.
6. Updating the three stages of assessment. G5 Issue 5 similar to its predecessor, Issue 4, has three stages of connection process. These are Stage 1 for connection of equipment to LV, Stage 2 for connection of equipment which failed Stage 1 and any other connection to voltages below 33 kV, and Stage 3 for any other connection.
7. Stage 1 has been completely revised; it is designed for connections at LV. It is designed as a linear process such that assessments are applied in stages and substages. If a substage is passed, then the connectee can connect; if the substage is failed, then the next substage of assessment is undertaken. In total there are four substages in Stage 1.
8. Stage 2 has been completely revised; it is designed for connection at voltages below 33 kV and for those connectees that have failed Stage 1. It has also been designed as a linear process, such that assessments are applied in substages.
9. A new section has been added to Issue 5 that sets criteria for the connection of resonant plant, such as power factor correction capacitors to LV and voltages up to 11 kV. This ensures that the network background harmonic levels are not amplified excessively.
10. Stage 3 has been completely revised; it is designed for connections above 33 kV and for those connectees that have failed Stage 2. The connection process has been clearly outlined.
11. In Stage 3, the harmonic limits are based on the apportionment of the harmonic headroom. This is a major difference between G5 Issue 5 and Issue 4.
12. Defining the minimum requirement and format for harmonic specification that NO has to issue to a connectee, to ensure consistency.
13. Requirement for the compliance report has been included in Issue 5 to ensure consistency.
14. G5 Issue 4 did not provide any guidance on the concurrent connections, when two or more connectees apply to connect to the network in the vicinity of each other in a short time window. G5 Issue 5 sets the connection process for such cases.

**2. Proposal**

The joint Working Group that has overseen the revision of EREC G5 is now seeking comments from wider industry stakeholders on the proposals highlighted in this consultation paper and the contents of the Draft EREC G5 Issue 5.

A copy of the Draft EREC G5 Issue 5 and the comment proforma are included in the consultation pack.

In the consultation paper, NO is a generic term embracing transmission network owner and/or operator companies and distribution network owner and/or operator companies. The terms network owner, network operator and system operator in this EREC are intended to apply to owners and operators of transmission systems and distribution networks – referred to as NOs in this document – in so far as the requirements are applicable to their statutory and regulatory duties and responsibilities.

**2.1 Revised Planning and Compatibility Levels**

Section 5 of EREC G5 Issue 5 contains planning and compatibility levels.

**2.1.1 Planning Level, EREC 5 Issue 5, Section 5.2**

The values for planning levels in EREC G5 Issue 5 have been changed in two ways from those in EREC G5 Issue 4:

1. The values have been changed to the higher of those in international standards and those in EREC G5 Issue 4.
2. The voltage ranges have been selected to better align with voltage levels in use on the GB system.

To align with international standards the values of planning levels from EREC G5 Issue 4 and IEC6100-3-6 were considered. Where they were different the higher of the two limits was selected. The justification for this choice is that both standards lead to acceptable level of distortion on the system that they were used in and thus adopting the higher for each frequency would also be acceptable. It is important to note that Voltage Total Harmonic Distortion (THD) planning level was not changed and was retained at the level in EREC G5 Issue 4.

The voltage ranges that the planning levels are stated for have been changed in ERG5 Issue 5.

In EREC G5 Issue 4 voltage ranges were:

* 400V and below
* 6.6,11,20 kV
* Greater than 20 kV and less than 145 kV
* 275 and 400kV

In EREC G5 Issue 5, these have been changed to:

* 400 V and below
* 0.4 kV < V ≤ 25 kV
* 25 kV < V ≤ 66 kV
* 66 kV < V ≤ 230 kV
* 230 kV < V

The justification for the change was to better align with voltage levels used on the GB system. These were chosen in consultation with network owners on the workgroup.

By changing the voltage ranges the 4 groups from EREC G5 Issue 4 are replace with 5 in EREC G5 Issue 5. The values for planning levels for these groups were mapped across from the EREC G5 Issue 4 with the same values using the mapping:

* 400 V → 400 V
* 6.6,11,20 kV → Greater than 400 V and less than or equal 25 kV
* Greater than 20kV and less than 145kV → Greater than 66 kV and less than or equal 230 kV
* 275 and 400kV → above 230 kV

For the new group, greater than 25 kV and less than or equal 66 kV, the values of planning levels were linearly interpolated from the values for voltage levels either side. This is to allow grading of planning levels across voltage levels from 22 kV to 132 kV.

* + 1. **Compatibility Level, EREC 5 Issue 5 Section 5.3**

The values for compatibility levels in EREC G5 Issue 5 have been change from those in EREC G5 Issue 4 using the same method and justification as used to change the planning levels, as described in Section 0.

**2.2 Harmonic above 50th**

The values for planning levels and compatibility levels in EREC G5 Issue 5 have been changed from those in EREC G5 Issue 4 to extend the frequency range. The limits now go up to 5 kHz (100th harmonic) rather than the old limits ending at 2.5 kHz (50th harmonic).

The justification for this change is due to polluting equipment increasingly emitting at frequency above the 2.5 kHz range. A report has been produced to justify this change which considers the equipment being connected, simulation of higher order harmonics and measurement of the higher order harmonics on the system.

The Sub-Workgroup report on harmonics above 50th order is given in **Error! Reference source not found.**.

Consideration for harmonics above 50th order in planning is recommended, due to the growth of equipment with emission at higher order harmonics in the network and the adverse effect of such harmonics. However EREC 5 Issue 5 leaves this consideration to the discretion of the NO facilitating the new connection. The Inclusion of harmonics above 50th order in assessments requires reliable measurement through voltage transducer with suitable bandwidth.

**2.3 Limits for Interharmonics**

Limits for interharmonics within EREC G5 Issue 4 have been revised. Based on IEC 61000-4-30 and IEC 61000-4-7, clear definition for measurement of interharmonics is given in EREC G5 Issue 5. According to the aforementioned standards, interharmonic components between two integer harmonics are grouped and summated using the square root of squares rule. Each group consisting of seven interharmonic components. The limits provided in EREC G5 Issue 5 apply to individual interharmonics or to the group of interharmonics depending on the frequency range.

**2.4 Limits for Voltage Notches**

Limits for voltage notches have been revised in EREC G5 Issue 5 to add an additional requirement on the area of the notch on the voltage waveform. The equation used in this limit was derived to align with international standards (IEEE 519).

The justification for this change was to align with international standards and capture the effect of notching as an area of the waveform, which is related to the duration of the notch, rather than just considering the depth of the notch.

**2.5 Stage 1 and Stage 2**

One of the main differences of Stage 1 and Stage 2 is in the presentation of the processes compared to that in EREC G5 Issue 4. EREC G5 Issue 5 includes distinct flowcharts for each substage with clear connections to the previous and next substages. The failure and pass conditions and data requirements for each substage are clearly illustrated. Appendix B describes the Stage 1 and Stage 2 process with worked examles.

The main technical modifications in EREC G5 Issue 5 can be summarised as shown below:

* Stages 1 and 2 are split into distinct sub-stages for improved clarity.
* Unconditional connection of equipment compliant with the EMC harmonic emission standard IEC 61000-3-2 irrespective of aggregate rating.
* Design to meet minimum short-circuit power requirements for equipment that is compliant with IEC 61000-3-12 to control voltage distortion.
* Updated tables of permitted aggregate equipment rated power by converter technology type to cater for new technology and established harmonic current emission profiles.
* New sub-stage which provides for scaling the tabled values of permitted aggregate equipment rated power according to harmonic ‘headroom’.
* Removal of current emission tables in response to manufacturer request to prevent misuse in contracts.
* Extension of full Stage 2 prediction to all harmonic orders.
* Refined full Stage 2 calculations which account for skin effect and total harmonic distortion; this enables higher harmonic current emission.

**2.5.1 Stage 1 connection process**

Stage 1 has been completely revised. The revised standard has also been written in more accessible way such that the process of connection should be more understandable for those with limited experience in using standards.

Stage 1 is designed for connection at LV. It is designed in a linear process such that assessments are applied in stages and substages. If a sub-stage is passed the customer can connect, if the sub-stage is failed the next sub-stage of assessment is undertaken. In total there are four sub-stages in Stage1.

The substages are designed such that earlier substages require less data from the network user but use conservative assumptions. As the connection progresses through the substages more data is required but by having more data the pass criteria can be relaxed in terms of conservative assumptions made in the process.

The first substage of Stage 1 – Stage 1A – also allows for self-certification, in accordance with IEC 61000-3-2. If a connectee connects plant or equipment compliant with the relevant international product standard, then they may connect with no assessment or referral to the NO.

The second substage of Stage 1 – Stage 1B – uses manufacturer statements concerning compliance with the relevant international product standard as the basis of assessment. In this stage, equipment rating as well as the short circuit power at the PCC are required.

The third substage of Stage 1, Stage 1C, is based on equipment technology type, rated power and short-circuit power level.

Under Stage 1 the final substage is Stage 1D; this is a refined version of Stage 1C that takes into account the actual background harmonic level, which may be determined by measurement by the relevant NO.

The benefits of this approach are that it will facilitate straightforward connection for connectees, as there are fewer requirements on them to provide data, which may be difficult for smaller parties.

* + 1. **Stage 2 connection process**

Stage 2 is designed for connection at PCC voltage levels below 33 kV and those that have failed Stage 1. It is also designed in a linear process such that assessments are applied in substages. Point of common coupling (PCC) is defined as a point in the public supply system, electrically nearest to a connectee’s installation, at which other network users’ loads are, or may be, connected. Note that supply system is considered as being public in relation to its use and not its ownership.

Stage 2 includes three substages: Stage 2A and Stage 2B follow the same concept and have the same benefits as Stage 1C and Stage 1D. Those connections which fail at Stage 1 may be connected under one of the three substages at Stage 2, which each require more data from the connectee and the network. If a connection fails at Stage 2, then assessment under Stage 3 will be carried out unless the PCC is LV, in which case, no connection is possible without mitigation.

For a Stage 2 connection assessment, small converter loads may be connected on the basis of equipment technology type, rated power and short-circuit power level under the Stage 2A assessment procedure. For loads where a more-detailed assessment is required, Stage 2B – a refined version of Stage 2A – is provided, which takes into account the actual background harmonic levels.

Under Stage 2, the final substage of assessment is Stage 2C, where a prediction of the harmonic voltage distortion post-connection is derived and compared with planning levels. This calculation is based on a simple reactance model for the source with a multiplying factor to allow for any low-order harmonic resonance. The frequency dependency of network resistance is also considered.

Where the assessment has indicated that mitigation measures may be necessary, a conditional connection may be made if the extent of the assessment’s non-compliance with the limits is considered to be within the margin of uncertainty of the assessment process.

* 1. **Resonant Plant connection process**

There have been several incidences where connection of power factor correction capacitor banks at LV has caused capacitor failures or other equipment malfunction. In order to manage such situations, the assessment of resonant plant has been included in EREC G5 Issue 5. This is a new section compared to EREC G5 Issue4. Resonant plant is defined as a network or item of connectee plant or equipment (such as power factor correction capacitors, cables or active-front-end converters/inverters) that may modify the background harmonic level as a result of interaction with the rest of the network, without emitting any harmonic current or voltage.

A resonant plant assessment is applicable to connection of any resonant plant and equipment, such as power factor correction capacitors, long cables or any other plant or equipment that can be considered predominately capacitive at any range of harmonic frequencies. This is due to their potential to magnify background harmonic levels beyond the planning levels. This type of plant needs to be assessed for harmonic distortion compliance whether it is emitting harmonics or not.

The assessment for LV and voltages below 33 kV is based on conservative approaches with an assumption for the background harmonic levels and fault levels. For voltage levels below 33 kV, a simple assessment methodology is followed.

All resonant plant connection at 33 kV or above is subject to a Stage 3 assessment.

**2.7 Stage 3 Connection Process**

The revision of Stage 3 assessment was one of the main objectives of the revision of EREC G5 Issue 4.

The Stage 3 assessment in EREC 5 Issue 4 was based on emission data from the connectee’s equipment. This data was used by the NO to assess the impact of the new connection and subsequently issue harmonic limits. The allocation of limits was based on a first come-first served methodology, meaning that the first connectee in the connection queue would receive the whole of the harmonic headroom, if it was needed, based on the emission data and assessment. The harmonic headroom was calculated using the measured background harmonic level and the planning level.

In the cases where multiple connections were expected to connect within similar timescales, the order of allocating limits and issuing the harmonic specification was determined by the date at which the connection offer was signed by the connectee. This feature of Issue 4 was retained in Issue 5.

Allocation of the whole headroom caused concerns for many connectees as well as the NOs as, for example, a small connectee could receive the whole of the headroom if it was first in the queue and the next in the line, which may be a large size connectee, would receive a very small limit. Alternatively, the second connectee could wait for the first to become part of the network, i.e. fully commissioned and operational, and then receive their harmonic specification after new background measurement was carried out. This in turn could introduce long delays in the second connectee’s project.

An increase in the number of connections of non-linear equipment at all voltage levels has led to a need to revise Stage 3 assessment in EREC 5 Issue 4 to allow fairer allocation of harmonic headroom and avoid delays in the issuing the harmonic specification.

EREC 5 Issue 5 uses apportionment of harmonic headroom to set the limits for each connection. For connection to distribution networks, the apportionment is fixed where half (50%) of the whole harmonic headroom is allocated to the first connectee in the connection queue. For the transmission network, the apportionment is carried out in relation to the size of the connection. **Error! Reference source not found.** presents a worked example for typical connections at 400 kV.

EREC 5 Issue 5 is the same as Issue 4 for the consideration of the impact of the connectee on the remote nodes. Remote nodes surrounding the point of common coupling are to be included in the assessment to ensure that the remote nodes remain compliant.

* + 1. **Stage 3 Connection Process- harmonic specification**

EREC G5 Issue 4 provided no guidance on what data the NO should provide to the connectee when the NO set limits as part of the Stage 3 process.

EREC 5 Issue 5 also clearly outlines the minimum requirement for the harmonic specification. It is clearly stated that it is responsibility of the NO providing connection at the point of common coupling to issue the harmonic specification. EREC G5 Issue 5 provides guidance on the minimum requirement for data to be provided by the NO such that a connectee can design to meet their limits. The limits are issued in the form of a harmonic specification. EREC G5 Issue 5 also provides an example format in which this data may be presented.

The justification for this change is to achieve consistency in the data and format that the connectee receives.

* + 1. **Requirement for compliance**

EREC G5 Issue 5 adds a new section with guidance on how the connectee can demonstrate compliance with the limits set by the NO. The compliance process has been defined in EREC 5 Issue 5, where the connectee submit a report confirming compliance with the harmonic specification issued by the NO responsible for the connection.

NO have always required connectees to demonstrate compliance with the harmonic limits. However, EREC G5 Issue 4 offered no guidance on how this could be achieved. EREC G5 Issue 5 provides guidance to the connectee on what is needed, as a minimum, in a compliance report to demonstrate compliance with the harmonic limits and guidance to NO on compliance verification.

The justification for this addition is to provide transparency and consistency to NO and connectee about how compliance with this standard will be assessed. The NO has responsibility to carry out measurement before, during and after commissioning.

* + 1. **Concurrent connections**

EREC G5 Issue 5 adds a new section on guidance on how to set limits for concurrent connections; where multiple connectees seek to connect at the same or to electrically close nodes at the same time.

EREC G5 Issue 4 provided no explicit guidance on how to set limits for concurrent connections. The common interpretation of the standard was that the first connectee had to fully complete their design and become part of the network before a second connectee could be set limits. This resulted in delays for the second connectee. This was becoming more material as the number of connectees has been increasing over the last few years.

EREC G5 Issue 5 adds guidance on how harmonic limits can be set for a second connectee before the first connectee’s design has been finalised. The method assumes that the first connectee uses all the distortion headroom allowable under its harmonic specification. This is likely to give a lower limit to the second connectee than if they were to wait until the first connectee becomes part of the background. However the new method will allow the second connectee to connect earlier than under the method in EREC G5 Issue 4. Therefore the new method gives the connectee with option of connecting earlier than under the method in EREC G5 Issue 4 or waiting and potentially having more relaxed limits.

The justification for this change is to facilitate the increase in the number of connections. Defining a clear process for managing concurrent connection will stop the setting of harmonic limit from being a limitation in the connection of a new connectee.

1. **Applicable Distribution Code Objectives**

The Applicable Distribution Code Objectives are to**:**

1. permit the development, maintenance, and operation of an efficient, co-ordinated, and economical system for the distribution of electricity; and
2. facilitate competition in the generation and supply of electricity; and
3. efficiently discharge the obligations imposed upon distribution licensees by the distribution licences and comply with the Regulation and any relevant legally binding decision of the European Commission and/or the Agency for the Co-operation of Energy Regulators; and
4. promote efficiency in the implementation and administration of the Distribution Code.
5. **Consultation Questions**
6. Do you agree with the planning levels for different voltage levels given in tables in Section 5.2?
7. Do you agree with the compatibility levels for different voltage levels given in tables in Section 5.3?
8. Considering the growth in the network of equipment with harmonic emission at high order harmonics, do you agree with the extension of planning and compatibility levels to harmonics above 50th order, subject to the discretion of the relevant NO facilitating the connection?
9. Do you agree with the use of grouped interharmonic measurement, to align with relevant IEC standards?
10. Do you agree with the limits proposed in Section 5.4 for interharmonics?
11. Do you agree with the limits proposed in Section 5.6 for voltage notches?
12. Do you agree with the Stage 1 connection process, proposed in Section 7 that sets the procedure for connection of equipment to PCC voltages below 400 V?
13. Do you agree with the Stage 2 connection process, proposed in Section 8 that sets the procedure for connection of equipment that failed Stage 1 and to the PCC voltages below 33 kV?
14. Do you agree with the *inclusion* of a process, proposed in Section 9, for the connection of resonant plant such as power factor correction capacitors and/or cables to the PCC voltage levels of 400 V and 11 kV?
15. Do you agree with the quick and conservative initial assessment for connection of resonant plants to PCC voltage levels of 400 V and 11 kV? Failing the initial assessment would require assessment of resonant plant under Stage 3 assessment process.
16. According to EREC 5, Issue 5, under Stage 3, it is the responsibility of the existing NO to which the connectee connects to carry out harmonic assessment and issue the harmonic specification which include harmonic limits. Do you agree with this?
17. In EREC 5 Issue 5, setting the harmonic limits under Stage 3 is based on the apportionment of the headroom. Do you agree with the apportionment of headroom instead of first come-first served approach where the whole of the headroom is allocated to the first connectee in the queue?
18. Due to the difference in number of connection, network arrangement and operational requirement, do you agree with the proposed different apportionments procedures for connection above 132 kV and for connection at or below 132 kV proposed in Stage 3, section 10.4.3.1 and 10.4.3.2?
19. It is a requirement within EREC 5, Issue 5, to assess connection of resonant plant such as capacitor banks and cables and to ensure compliance with the harmonic limits. Do you agree with this requirement?
20. Do you agree with the requirements of the compliance report that connectee’s have to submit for a Stage 3 assessment?
21. **Next Steps**

Responses to this consultation should be sent to the Distribution Code Review Panel Secretary at [dcode@energynetworks.org](mailto:dcode@energynetworks.org) by **17:00 Friday 20 July 2018** on the pro-forma provided expressly for the purpose, or via any other convenient means. The pro-forma is can be found in the consultation pack. Responses after this date may not be considered.

1. **Consultation Pack**

The DCRP/18/05/PC Consultation pack can be found here - <http://www.dcode.org.uk/consultations/open-consultations/>

**For more information, please contact:**

David Spillett – Distribution Code Administrator - [**dcode@energynetworks.org**](mailto:dcode@energynetworks.org)

1. **Appendix A**

Sub-Workgroup report on harmonics above 50th order.



1. **Appendix B**

Attached present the connection process for Stage 1 and Stage 2 for typical connections to voltages up to 33 kV. Worked examples are also included.

    

1. **Appendix C**

EREC 5 Issue 5 uses apportionment of the harmonic headroom available at the point of common coupling to set harmonic limits for the connectee. Similar to Issue 4, the headroom is calculated using the planning level and measured background harmonic level. In order to manage the impact of the new connectee on the remote nodes and to ensure compliance with the planning levels, similar to EREC 5 Issue 4, the remote nodes are included in the assessment. This is achieved by calculating the transfer coefficient between the PCC and other substations in the network. The transfer coefficients are calculated by harmonic simulation.

In setting the limits, the harmonic headroom is apportioned. For connections to voltages below 132 kV, 50% of the available headroom is allocated, irrespective of the MVA size of the connection. For connections to voltages above 132 kV, the headroom is apportioned in proportion to the ratio of the size of the connection and a specified constant, β, whose value is 1000, 1500 and 2000, respectively for voltages above 132 kV and below 275, 275 kV and 400 kV. The ratio is termed kM

The values of β for different voltage levels have been determined based on the historical and known future connectees’ MVA that have been or will be connected to the network. Using the ratio, kM, a multiplier is determined from the apportionment multiplier curve, which in turn operates on the harmonic headroom. This multiplier varies between 10% and 66% of the headroom. For example, a 2000 MVA connection at 400 kV can only be given 66% of the headroom. The apportionment multiplier curve has a knee point at kM =0.25, which gives a multiplier equal to 0.5 or 50% of the headroom. The knee point has been set to be approximately equal to the 25-percentile of the all past and known future connection. The slope of the apportionment curve between kM=0.05 and kM=0.25 is ten times higher than the slope of the curve between kM=0.25 and kM=1.00. This has been so set to bias the curve towards smaller sized connection, i.e. in proportion, the smaller MVA size connection receive higher limits such that impractically small limits are avoided.

For connections to voltages below 132 kV, a constant 0.5 apportionment multiplier is used. This is due to the number of connections and the variety and complexity of network configuration and topology at this voltage level.

The worked examples below are to illustrate implementation of the methodology when setting the harmonic limits.

* 1. **Examples: Application of Stage 3 Assessment**

In this section a number scenarios are considered to demonstrate the application of Stage 3 assessment process. For simplicity, only one harmonic is considered, however, the same procedure applies to all harmonics.

* 1. **Single Connection**

Consider **Error! Reference source not found.**, which shows part of a 400 kV system. A 800 MVA wind farm (generator) applies to connect to Node X.

Harmonic transfer coefficients from Node X to all other nodes are calculated from harmonic model simulation for all scenarios considered in the study, which include intact as well as depleted network conditions. The transfer coefficients are given in Table A. 1.

Harmonic measurement results at all nodes are given in Table A. 2. Assume the harmonic order under study is in the range for α=1.4 and the Planning Level is 2%.

B

X

Y

A

C

**Figure A. 1- Study Network**

Table A. 1- Highest Harmonic Transfer coefficients from Node X to other Nodes

Table A. 2- Pre-existing Background Harmonic Level

|  |  |  |
| --- | --- | --- |
| From | To | Transfer coefficient |
| X | Y | 2 |
| X | A | 0.8 |
| X | B | 3 |
| X | C | 1.5 |

|  |  |
| --- | --- |
| Node | Vbg (%) |
| X | 0.5 |
| Y | 1.0 |
| A | 1.5 |
| B | 1.2 |
| C | 0.25 |

The harmonic headroom at the PCC is calculated.

For Node Y, the same is used and then the headroom is transferred to Node X.

The other headrooms are calculated in the same way and are shown in Table A. 3.

Table A. 3- Harmonic Headrooms

|  |  |
| --- | --- |
| Node | Headroom (%) |
| HX | 1.79 |
| HY-X | 0.71 |
| HA-X | 1.14 |
| HB-X | 0.41 |
| HC-X | 1.28 |

As can be seen the smallest headroom is 0.41% at Node B when transferred to Node X. Therefore, in this case the limiting node is Node B.

Parameter k is now calculated. Since the connection is at 400 kV, then β=2000.

From the normalised curve, for k=0.4, M would be equal to 0.532.

For the harmonic under consideration, the incremental and total limits are calculated by multiplying the appropriate headroom, i.e. 0.41by M=0.532, as shown below.

The harmonic limits for the harmonic under consideration are given in Table A. 4.

**Table A. 4- Harmonic Limit Table for the First Connection at Node X**

|  |  |  |  |
| --- | --- | --- | --- |
| Harmonic order h | Pre-existing background harmonic voltage at the PCC prior to connection of the User’s Equipment  (% of fundamental) | Incremental harmonic Voltage Distortion Limits ( ) due to harmonic current/voltage emission at the PCC  (% of fundamental) | Total Harmonic Voltage Emission Limits ()  (% of fundamental) |
| h | 0.5 | 0.22 | 1.21 |
|  |  |  |  |

* 1. **Two Concurrent Connection at the same PCC**

Assume, following the signing of the first connectee of 800 MVA, the second connection of 2000 MVA applies to connect to Node X. Considering β of 2000 for 400 kV systems, k is equal to 1 for the second connection.

From the normalised curve, M=0.66.

The new harmonic headroom at Node X is calculated from:

The harmonic headrooms of the other nodes transferred to Node X are modified by the incremental harmonic limit of the first connection. For example for Node B, the modified transferred headroom is given below:

Node B is still the limiting node.

The headrooms are now apportioned and the incremental and total limits are calculated.

The harmonic limits for the harmonic under consideration for the second connection at Node X are given in

Table **A. 5**.

**Table A. 5 - Harmonic Limit Table for the Second Connection at Node X**

|  |  |  |  |
| --- | --- | --- | --- |
| Harmonic order h | Pre-existing background harmonic voltage at the PCC prior to connection of the User’s Equipment  (% of fundamental) | Incremental harmonic Voltage Distortion Limits ( ) due to harmonic current/voltage emission at the PCC  (% of fundamental) | Total Harmonic Voltage Emission Limits ()  (% of fundamental) |
| h | 1.21 | 0.19 | 1.66 |
|  |  |  |  |

**7.4 Two Concurrent Connection at Different Nodes**

Now consider the second connectee applying for connection to Node Y.

The harmonic transfer coefficients from Node X to other nodes are assumed to be the same as before, given in Table 3. The harmonic transfer coefficients from Node Y to other nodes, including Node X should also be obtained from the harmonic model, which are shown in Table A. 6.

**Table A. 6- Harmonic Transfer coefficients from Node Y**

|  |  |  |
| --- | --- | --- |
| From | To | Transfer coefficient |
| Y | X | 1.6 |
| Y | A | 3 |
| Y | B | 1.4 |
| Y | C | 1.1 |

The pre-existing background harmonic levels and thus the harmonic headroom at all nodes are calculated, taking into account the incremental limit issued to the first connectee at Node X. Pre-existing background harmonic level at Node X however is assumed to have risen to the total limit issued, as shown below:

For Node Y the pre-existing background harmonic level is given below.

For Node A to C the pre-existing background harmonic levels are calculated as given below:

The headroom at Node Y is calculated using the modified pre-existing background harmonic level.

In the same way, the new harmonic headrooms are calculated and transferred to Node Y.

As can be seen the limiting remote node is Node A.

The multiplier M is 0.66 (for k=1, M=0.66).

The harmonic limits for the harmonic under consideration for the second connection at Node Y are given in Table A. 7.

**Table A. 7- Harmonic Limit Table for the Second Connection at Node Y**

|  |  |  |  |
| --- | --- | --- | --- |
| Harmonic order h | Pre-existing background harmonic voltage at the PCC prior to connection of the User’s Equipment  (% of fundamental) | Incremental harmonic Voltage Distortion Limits ( ) due to harmonic current/voltage emission at the PCC  (% of fundamental) | Total Harmonic Voltage Emission Limits ()  (% of fundamental) |
| h | 1.22 | 0.18 | 1.68 |
|  |  |  |  |