Electricity Distribution

nationalgrid

Company Directive

STANDARD TECHNIQUE: SD6F/2

Connection design process for Customer Installations and equipment with the potential to disturb Voltage Quality - PCC ≥33kV

Policy Summary

This Standard Technique (ST) relates to connection design process for Customer installations and associated equipment that may have the potential to disturb Voltage Quality. This ST applies to Customer installations with a Point of Common Coupling (PCC) equal to or greater than 33kV.

Author: **Simon Scarbro**

Implementation Date: **October 2021**

Approved by

Paul Jewell
System Development Manager

Date: **11th October 2021**

Target Staff Group	**Staff responsible for Primary System Design**
Impact of Change	**Amber - the change aligns policy with changes to EREC P28 and EREC G5**
Planned Assurance checks	**Following the roll out of training, one PSD Engineer per WPD License area will be checked.**

All references to Western Power Distribution or WPD must be read as National Grid Electricity Distribution or NGED

IMPLEMENTATION PLAN

Introduction

This Standard Technique (ST) defines the design procedure for the connection of Customer installations and associated equipment that may have the potential to disturb Voltage Quality.

This ST applies to Customer installations with a Point of Common Coupling (PCC) equal to or greater than 33kV. For other cases see ST:SD6J or ST:SD5G as appropriate.

Main Changes

Following the publication of SD6J/2 it is necessary to reduce the scope of SD6F to only cover connection with a PCC equal to or greater than 33kV. In addition, the connection design procedure has been updated to align with the changes made to ENA EREC P28 regarding Voltage Fluctuations/Flicker, ENA EREC G5 Stage 3 regarding Harmonics and POL:SD2 and POL:SD3 regarding Voltage Step Change. In addition, an updated connection design procedure for voltage unbalance is included; note that at the time of writing EREC P29 is under revision and the process will need to be updated again in the future to align.

Impact of Changes

This ST modifies the approach to connection of potentially disturbing Customer equipment/installations to the network where the PCC is equal to or greater than 33kV.

Target Staff Group	**Staff responsible for Primary System Design**
Impact of Change	**Amber – the change aligns policy with changes to EREC P28 and EREC G5**

Implementation Actions

PSD familiarisation training will be completed during October 2021. The presentation used during that training is also available here.

Implementation Timetable

This ST is implemented with immediate effect.

REVISION HISTORY

Document Revision / Review Table		
Date	**Changes / Comments**	**Author**
10/09/2021	• Complete technical revision.	S. Scarbro
8/11/2012	• Data Collection Forms have been updated and Tables 2 and 3 have been revised to reflect this.	S. Scarbro

Contents

1.0 INTRODUCTION

This Standard Technique (ST) defines the design procedure for the connection of Customer installations and associated equipment that may have the potential to disturb Voltage Quality. Such installations are known as Relevant Customer Installations in this document.

The aim is to control the level of disturbance to Voltage Quality created by connection of such Relevant Customer Installations in a co-ordinated manner in accordance with the Distribution Code plus relevant Engineering Recommendations and WPD Policy.

2.0 SCOPE

This ST relates to connection design for Relevant Customer Installations with a Point of Common Coupling (PCC) of 33kV or greater. Examples of such Relevant Customer Installations include Distorting Installations, Fluctuating Installations and Unbalanced Installations and those installations with Resonant Plant that can amplify levels of Voltage Distortion.

For cases with a PCC below 33kV see ST:SD6J or ST:SD5G as appropriate.

3.0 REFERENCES

This document makes reference to, or should be read in conjunction with, the documents listed below. The issue and date of the documents listed shall be those applicable at the date of issue of this document, unless stated otherwise.

3.1 ENA Documents

NUMBER	TITLE
EREC G5	Engineering Recommendation G5/5 (EREC G5/5): Harmonic voltage distortion and the connection of harmonic sources and/or resonant plant to transmission systems and distribution networks in the United Kingdom. London: ENA.
EREC G97	Engineering Recommendation G97 (EREC G97): Process for the connection of non-linear and resonant plant and equipment in accordance with EREC G5. London: ENA.
EREC G99	Engineering Recommendation G99 (EREC G99): Requirements for the connection of generation equipment in parallel with public distribution networks on or after 27 April 2019. London: ENA.
EREC P24	Engineering Recommendation P24 (EREC P24): AC traction supplies to British Rail. London: ENA.

EREC P28	Voltage fluctuations and the connection of disturbing equipment to transmission systems and distribution networks in the United Kingdom. London: ENA.
EREC P29	Planning limits for voltage unbalance in the UK for 132kV and below. London: ENA.
ETR 116	Report on voltage unbalance due to British Rail AC traction supplies. London: ENA.

3.2 British Standards

NUMBER	TITLE
BS EN 61400-21-1	Wind energy generation systems. Measurement and assessment of electrical characteristics. Wind turbines.

3.3 International Standards

NUMBER	TITLE
IEC TR 61000-3-6	Electromagnetic compatibility (EMC). Limits. Assessment of emission limits for the connection of distorting installations to MV, HV and EHV power systems.
IEC TR 61000-3-7	Electromagnetic compatibility (EMC). Limits. Assessment of emission limits for the connection of fluctuating installations to MV, HV and EHV power systems.
IEC TR 61000-3-13	Electromagnetic compatibility (EMC). Limits. Assessment of emission limits for the connection of unbalanced installations to MV, HV and EHV power systems.

4.0 DEFINITIONS

TERM	DEFINITION
Background Flicker	The level of Flicker that exists before the connection of the Relevant Customer Equipment under assessment.
Background Harmonic Distortion	The level of Voltage Distortion that exists before the connection of the Relevant Customer Equipment under assessment.
Background Voltage Unbalance	The level of Voltage Unbalance that exists before the connection of the Relevant Customer Equipment under assessment.
Connection Agreement	The terms and conditions under which the Customer's installation may be connected (and remain connected) to WPD's Distribution System.
Connection Offer	A formal written offer to the applicant Customer to provide connection to WPD's Distribution System. The Connection Offer sets out the terms and the connection charge for making the connection. Once accepted, the Connection Offer becomes a binding agreement between WPD and the Customer.
Customer	The person/company requesting the connection.

Distorting Installation	A Customer installation, or plant or equipment therein, which can cause distortion of the voltage or current into the Distribution System to which it is connected.
Distribution Code	A code required to be prepared by a Distribution Network Operator pursuant to condition 9 of a Distribution Licence.
Distribution Licence	A distribution licence granted under Section 6(1)(c) of the Electricity Act 1989 (as amended by the Utilities Act 2000 and the Energy Act 2004).
Distribution System	The system, as defined in the Distribution Licence, consisting (wholly or mainly) of electric lines owned or operated by WPD and used for the distribution of electricity.
Distribution Network Operator (DNO)	The holder of a Licence to distribute electricity.
EREC G5 Stage 3 Compliance Report	A report prepared by the Customer (or their consultant) about their Distorting Installation. Its purpose is to demonstrate compliance to WPD with the EREC G5 Stage 3 Harmonic Specification issued to them.
EREC G5 Stage 3 Harmonic Specification	A document prepared by WPD setting out the conditions and limits, including Background Harmonic Distortion and the connection limits at the PCC, for harmonic compliance in accordance with EREC G5 Stage 3.
EREC P28 Compliance Report	A report prepared by the Customer (or their consultant) about their Fluctuating Installation. Its purpose is to demonstrate compliance with EREC P28 to WPD.
EREC P28 Stage 3 Flicker Specification	A document prepared by WPD setting out the conditions and limits, including Background Flicker levels and the connection limits at the PCC, for Flicker compliance in accordance with EREC P28 Stage 3.
EREC P29 Compliance Report	A report prepared by the Customer (or their consultant) about their Unbalanced Installation. Its purpose is to demonstrate compliance with EREC P29 to WPD.
EREC P29 Stage 3 Voltage Unbalance Specification	A document prepared by WPD setting out the conditions and limits, including Background Voltage Unbalance levels and the connection limits at the PCC, for Voltage Unbalance compliance in accordance with EREC P29. For the purposes of this document this is referred to as Stage 3.

Flicker	Impression of unsteadiness of visual sensation induced by a light stimulus whose luminance or spectral distribution fluctuates with time.
Flicker Severity	Measure of visual severity of Flicker based on intensity of Flicker annoyance.
Fluctuating Installation	A Customer installation, or plant or equipment therein, which is characterized by repeated or sudden power fluctuations, or start-up or inrush currents which can produce Flicker or rapid voltage changes on the Distribution System to which it is connected.
Good Industry Practice	The best or common practice that includes standards, practices, methods and procedures conforming to the contractual obligations and all applicable law and regulatory requirements.
Harmonic Source	Customer plant and/or equipment that may result in a harmonic distortion due to an emission of harmonic current and/ or voltage, including inter-harmonics and sub-harmonics.
Harmonic Voltage	Sinusoidal voltage with a frequency equal to an integer multiple of the fundamental frequency of the voltage.
Harmonic Voltage Limit	Maximum permitted Harmonic Voltage in terms of an Incremental Harmonic Voltage Limit or Total Harmonic Voltage Limit.
Incremental Flicker Limit	Maximum permitted Flicker change that the Relevant Customer Equipment under assessment may produce at the PCC.
Incremental Harmonic Voltage Limit	Maximum permitted Harmonic Voltage change that the Relevant Customer Installation under assessment may produce at the PCC.
Incremental Voltage Unbalance Limit	Maximum permitted Voltage Unbalance change that the Relevant Customer Equipment under assessment may produce at the PCC.
Interharmonic Voltage	Sinusoidal voltage with a frequency not equal to an integer multiple of the fundamental frequency of the voltage.
Long-term Flicker Severity (P_{lt})	Measure of visual severity of Flicker calculate from a sequence of twelve short-term flicker severity values over a two hour period.
Modification Offer	A formal written offer to the applicant Customer made pursuant to Clause 14 of the National Terms of Connection in relation to any proposed modification to one or more Relevant Customer Installations.

Power Quality	Characteristics of the electricity at a given point on an electrical system, evaluated against a set of reference technical parameters.
Point of Common Coupling (PCC)	Point in the public supply system which is electrically closest to the installation concerned and to which other customers are or might be connected.
Rapid Voltage Change (RVC)	Change in RMS voltage over several cycles.
Relevant Customer Installation	Any Customer installation, or plant or equipment therein, with the potential to adversely affect Voltage Quality. Examples of such Customer installations include Distorting Installations, Fluctuating Installations and Unbalanced Installations and also those with Resonant Plant which can amplify levels of Voltage Distortion.
Resonant Plant	Customer's plant and/or equipment that may materially modify the Background Harmonic Distortion as a result of interaction with the public supply system impedance without emitting any harmonic current or voltage.
Short-term Flicker Severity (P_{st})	Measure of visual severity of Flicker derived from the time series output of a flickermeter over a 10-minute period.
Step Voltage Change	Change from the initial voltage level to the resulting voltage level after all generating unit automatic voltage regulator and static VAR compensator actions and transient decay have taken place, but before any other automatic or manual tap-changing and switching actions have commenced.
Supplier	A person/company who holds a Supply Licence granted under section 6(1)(d) of the Electricity Act 1989 (as amended).
Total Harmonic Voltage Limit	Maximum permitted total Harmonic Voltage level that shall be allowed to exist at the PCC after the Relevant Customer Installation under assessment is connected.
Unbalanced Installation	A Customer installation, or plant or equipment therein, which is characterized according to its operation by unequal line currents, either magnitude and/or phase angle, which can give rise to Voltage Unbalance on the Distribution System to which it is connected.
Voltage Distortion	Distortion of the voltage waveform.
Voltage Fluctuation	Series of voltage changes that can be regular or irregular.

Voltage Quality	Characteristics of voltage at a given point in a public supply system evaluated against a set of reference technical parameters.
Voltage Unbalance	Unbalance of the voltage where the magnitude of the phase voltages or the phase angles between consecutive phases are not equal.

5.0 RESPONSIBILITIES

5.1 Customer Responsibilities

The Connection Agreement sets out the terms and conditions under which Relevant Customer Installations may be connected (and remain connected) to WPD's Distribution System. Inherent in accepting these terms and conditions is the acceptance of the requirement to comply with the Distribution Code, including the technical requirements under EREC P28, EREC G5 and EREC P29 which relate to control of Voltage Fluctuations, Voltage Distortion and Voltage Unbalance, respectively.

If a Customer would like to modify an existing connection then this proposed change is controlled by the relevant clauses on modification in the Connection Agreement.

5.1.1 Customer Responsibilities – Limitation of Voltage Fluctuations

In relation to the control of Voltage Fluctuations, given the scope of this ST all connections comprising Fluctuating Installations are subject to EREC P28 Stage 2 or 3 assessment for Flicker and subject to EREC P28 limits for Step Voltage Change and Rapid Voltage Change. For such a connection the Connection Offer issued by WPD is subject to the Customer demonstrating compliance with EREC P28 and so the Customer is responsible for:

- Preparing the EREC P28 Compliance Report to demonstrate compliance with EREC P28.
- Providing all the necessary data, in respect of their electrical installation including existing and proposed Fluctuating Installations, for the purpose of the EREC P28 Compliance Report.
- Ensuring that the EREC P28 Compliance Report is carried out in accordance with Good Industry Practice.
- If required by WPD, demonstrating their capability, or that of their appointed third party, to undertake the EREC P28 Compliance Report. This may take the form of evidence of previous work undertaken in this area, or other similar evidence.
- Providing WPD with the EREC P28 Compliance Report and any proposed Voltage Fluctuation mitigation measures.

5.1.2 Customer Responsibilities – Limitation of Voltage Distortion

In relation to the control of Voltage Distortion, given the scope of this ST, all connections comprising Distorting Installations are subject to EREC G5 Stage 3 assessment. Under EREC G5 Stage 3 the Customer is responsible for:

- Preparing the EREC G5 Stage 3 Compliance Report to demonstrate compliance with the limits in the EREC G5 Stage 3 Harmonic Specification issued by WPD.
- Providing all the necessary data, in respect of their electrical installation including existing and proposed Harmonic Sources or Resonant Plant, for the purpose of the EREC G5 Stage 3 Compliance Report.
- Ensuring that the EREC G5 Stage 3 Compliance Report is carried out in accordance with Good Industry Practice.
- If required by WPD, demonstrating their capability, or that of their appointed third party, to undertake the EREC G5 Stage 3 Compliance Report. This may take the form of evidence of previous work undertaken in this area, or other similar evidence.
- Providing WPD with the EREC G5 Stage 3 Compliance Report and any proposed harmonic mitigation measures.

5.1.3 Customer Responsibilities – Limitation of Voltage Unbalance

In relation to the control of Voltage Unbalance, given the scope of this ST, all connections comprising Unbalanced Installations are subject to EREC P29 assessment against planning limits. For such a connection the Connection Offer issued by WPD is subject to the Customer demonstrating compliance with EREC P29 and so the Customer is responsible for:

- Preparing the EREC P29 Compliance Report to demonstrate compliance with EREC P29.
- Providing all the necessary data, in respect of their electrical installation including existing and proposed Unbalanced Installations, for the purpose of the EREC P29 Compliance Report.
- Ensuring that the EREC P29 Compliance Report is carried out in accordance with Good Industry Practice.
- If required by WPD, demonstrating their capability, or that of their appointed third party, to undertake the EREC P29 Compliance Report. This may take the form of evidence of previous work undertaken in this area, or other similar evidence.
- Providing WPD with the EREC P29 Compliance Report and any proposed Voltage Unbalance mitigation measures.

5.2 WPD Responsibilities

When planning a new connection to a Distribution System, the DNO hosting the connection is responsible for the overall coordination of the level of disturbance to Voltage Quality. The DNO is responsible for issuing the Connection Agreement which includes requirements as necessary to control the level of disturbance to Voltage Quality at the PCC (e.g. EREC G5 Stage 3 Harmonic Specification) that can be caused by the Customer's installation.

WPD is responsible for the provision of system data to Customers as necessary to comply with planning and technical requirements of the Distribution Code, including those relating to Voltage Quality under EREC P28, EREC G5 and EREC P29.

In relation to the control of:

- Flicker, WPD is responsible for preparing the EREC P28 Stage 3 Flicker Specification.
- Voltage Distortion, WPD is responsible for preparing the EREC G5 Stage 3 Harmonic Specification in accordance with EREC G97.
- Voltage Unbalance, WPD is responsible for preparing the EREC P29 Stage 3 Voltage Unbalance Specification.

WPD is responsible for reviewing submissions in relation to Voltage Quality prepared by the Customer (or on their behalf) seeking connection/modification of their installation in order to decide if energisation/modification can proceed.

Note that WPD is empowered under the ESQC Regulations 2002 (as amended) to challenge Customers in circumstances where their proposed connection/modification may cause unacceptable Voltage Quality.

6.0 DESIGN REQUIREMENTS

This section sets out the connection design requirements for Relevant Customer Installations with a PCC at a nominal voltage equal to or greater than 33kV that have the potential to adversely affect Voltage Quality. This section divides into three parts to cover:

- Fluctuating Installations
- Distorting Installations
- Unbalanced Installations.

Appendix A provides examples of the five types of Voltage Quality disturbances associated with various Relevant Customer Installation features:

- Flicker
- Step Voltage Change
- Rapid Voltage Change
- Voltage Distortion
- Voltage Unbalance.

6.1 Connection Design – Fluctuating Installations

6.1.1 Need for Assessment - Circumstances where the Assessment may be Curtailed

EREC P28 defines the technical design requirements for connection of Customer disturbing equipment and Fluctuating Installations that may cause Voltage Fluctuations in the form of Step Voltage Changes, Rapid Voltage Changes and Flicker.

On this basis, a new or modified connection with any capability to cause Voltage Fluctuations is subject to assessment under EREC P28. However, in some cases the proposed equipment may not cause a material change to the Voltage Quality, even if the power or current can change rapidly. For example, where the ratio of the fault level at the PCC to the aggregate equipment rating is very high (e.g. ≥10,000); for example, with a 33kV fault level at the PCC of 250MVA this permits connection of an aggregate equipment rating of 25kVA without detailed assessment. If the equipment has no special inrush/starting characteristic (e.g. resistive load) then the required ratio can be reduced by a factor of 10 (e.g. ≥1,000); for example, with a 33kV fault level at the PCC of 250MVA this permits connection of an aggregate equipment rating of 250kVA without detailed assessment.

6.1.2 EREC P28 Assessment

EREC P28 defines the technical design requirements for connection of Customer disturbing equipment and Fluctuating Installations that may cause Voltage Fluctuations in the form of Step Voltage Changes, Rapid Voltage Changes and Flicker. EREC P28 defines planning levels for each of these types of Voltage Fluctuation and these are used for the EREC P28 assessment.

The assessment process adopted involves:

- Derivation of the EREC P28 Specification by WPD for the Customer, where appropriate
- Preparation of EPEC P28 Compliance Report by the Customer for submission to WPD for approval/comment.

The following text describes the assessment process corresponding to Step Voltage Changes, Rapid Voltage Changes and Flicker.

6.1.2.1 Step Voltage Change Assessment

Step Voltage Change covers the voltage change between two RMS levels before tap-changing takes place. Examples are the Step Voltage Change associated with Customer import/export power variation, Customer circuit breaker tripping or Customer operational switching. A general limit of 3% for Step Voltage Change is defined in EREC P28. Note that the definition of Step Voltage Change is such that the steady state voltage change part of a Rapid Voltage Change (RVC), $\Delta V_{steadystate}$, can also be a Step Voltage Change, ΔV_{step}. Note also that the step voltage change planning level, $\Delta V_{step\text{-}planning\ level}$, and RVC steady state voltage change planning level, $\Delta V_{steadystate\text{-}planning\ level}$, are both set at 3% of nominal voltage.

The assessment process for Step Voltage Change involves presentation of analysis in relation to Step Voltage Change in the EREC P28 Compliance Report by the Customer for submission to WPD for approval/comment.

6.1.2.1.1 Step Voltage Change Analysis – EREC P28 Compliance Report

The Customer is responsible for preparing the Step Voltage Change analysis and its presentation in the EREC P28 Compliance Report to demonstrate compliance with the planning levels as detailed in POL:SD2 or POL:SD3, as applicable.

The content of the EREC P28 Compliance Report in respect of Step Voltage Change must include:

- Presentation of the step voltage change values at the PCC (i.e. V_{step}) due solely to the Relevant Customer Installation for its worst credible operating condition taking into account the fault level and X/R ratio as advised by WPD.

- Demonstration of compliance with the planning levels as detailed in POL:SD2 or POL:SD3, as applicable, at the PCC, $V_{step\text{-}planning\ level}$. That is, $V_{step} \leq V_{step\text{-}planning\ level}$.

The PSD Engineer responsible for Power Quality shall review the EREC P28 Compliance Report in respect of Step Voltage Change in a timely manner and verify compliance with the planning limits in POL:SD2 or POL:SD3, as applicable, or comment accordingly. Note that the EREC P28 Compliance Report may demonstrate the need for the Customer to employ mitigation, select different equipment etc, and this may conceivably delay the proposed connection.

6.1.2.2 Rapid Voltage Change Assessment

The term Rapid Voltage Change (RVC) was introduced in Issue 2 of EREC P28 to cover fast changes in RMS voltage such as associated with transformer energisation and motor starting. Rapid Voltage Changes are described as comprising two parts; namely, maximum voltage change, ΔV_{max}, and steady state voltage change, $\Delta V_{steadystate}$, and planning levels are defined for these in Table 4 of EREC P28, referred to here as $V_{max\text{-}planning\ level}$ and $V_{steadystate\text{-}planning\ level}$. Note that the definitions of these terms are such that a step voltage change, ΔV_{step}, can also be a steady state voltage change, $\Delta V_{steadystate}$, and that in certain circumstances the maximum voltage change, ΔV_{max}, can equate to the steady state voltage change, $\Delta V_{steadystate}$ (e.g. voltage change associated with switching a Customer capacitor bank). Note also that the step voltage change planning level, $\Delta V_{step\text{-}planning\ level}$, and RVC steady state voltage change planning level, $\Delta V_{steadystate\text{-}planning\ level}$ are both set at 3% of nominal voltage.

The assessment process for Rapid Voltage Change involves preparation of the EREC P28 RVC Compliance Report by the Customer for submission to WPD for approval/comment.

6.1.2.2.1 RVC Analysis - EREC P28 Compliance Report

The Customer is responsible for preparing the RVC analysis and its presentation in the EREC P28 Compliance Report to demonstrate compliance with the planning levels in Table 4 of EREC P28.

The content of the EREC P28 Compliance Report in respect of RVCs must include:

- Presentation of the maximum and steady-state voltage change values at the PCC (i.e. V_{max} and $V_{steadystate}$) due solely to the Relevant Customer Installation for its worst credible operating condition taking into account the fault level and X/R ratio as advised by WPD.
- Demonstration of compliance with the EREC P28 Table 4 planning levels at the PCC. That is, $V_{max} \leq V_{max\text{-}planning\ level}$ and $V_{steadystate} \leq V_{steadystate\text{-}planning\ level}$.

The PSD Engineer responsible for Power Quality shall review the EREC P28 Compliance Report in respect of RVCs in a timely manner and verify compliance with the planning limits in Table 4 of EREC P28 or comment accordingly. Note that the EREC P28 Compliance Report may demonstrate the need for the Customer to employ mitigation, select different equipment etc, and this may conceivably delay the proposed connection.

6.1.2.3 Flicker Assessment

Flicker refers to the adverse visual effect caused by Voltage Fluctuations such as associated with continuously fluctuating Customer load (e.g. due to wind turbines, arc furnaces, induction furnace melt cycle, welders, motor starting, battery energy storage import/export changes etc.). Flicker is measured using Short-term Flicker Severity, P_{st}, and Long-term Flicker Severity, P_{lt}, corresponding to observation periods of 10 minutes and 2 hours respectively; the P_{lt} is derived from twelve P_{st} values as defined in EREC P28.

The assessment process for Flicker comprises of three stages. For connections within the scope of this ST, where Flicker assessment is required this is done with Stage 2 initially. If Stage 2 is not passed then alternative connection points and Flicker reduction options are evaluated and, if the proposal still does not pass Stage 2, then it is assessed under Stage 3.

Planning levels for Flicker are defined in Table 2 of EREC P28 and are used in Flicker assessment under Stage 3 only.

6.1.2.3.1 Stage 2 Flicker Assessment

Stage 2 Flicker assessment predicts the Short-term Flicker Severity value at the PCC due to the Relevant Customer Installation, $P_{st\text{-}Customer}$, and compares it against the Stage 2 limit, $P_{st\ Stage\ 2\ limit}$, of 0.5. It passes Stage 2 if the predicted value is no more than 0.5 (i.e. $P_{st\text{-}Customer} \leq P_{st\ Stage\ 2\ limit}$) and fails if it exceeds this value (i.e. $P_{st\text{-}Customer} > P_{st\ Stage\ 2\ limit}$). If it fails then alternative connection points and Flicker reduction options are evaluated and, if it still does not pass Stage 2, then it is assessed under Stage 3. Note that Stage 2 considers the impedance/fault level at the PCC but does not consider the impact of Background Flicker; at Stage 3 the Background Flicker is also included in the assessment.

Note that a link to the 'WPD Connection Guide - Connections subject to ENA EREC P28/2 stage 2 assessment' can be found in Appendix C. This can be used to explain the EREC P28 assessment process and the need for an EREC P28 Compliance Report.

6.1.2.3.2.1 Stage 2 Flicker Analysis - EREC P28 Compliance Report

The Customer is responsible for preparing the Stage 2 Flicker analysis and its presentation in the EREC P28 Compliance Report to demonstrate compliance with the Stage 2 limit in EREC P28.

The content of the EREC P28 Compliance Report in respect of Stage 2 Flicker analysis must include:

- Presentation of the incremental Flicker values at the PCC (i.e. $P_{st\text{-}inc}$) due solely to the emission from the Relevant Customer Installation for its worst credible operating condition taking into account the fault level and X/R ratio as advised by WPD.
- Demonstration of compliance with the EREC P28 Stage 2 limit by showing compliance with the Incremental Flicker Limit for Short-term Flicker Severity for Stage 2 at the PCC. That is, $P_{st\text{-}inc} \leq 0.5$.

The PSD Engineer responsible for Power Quality shall review the EREC P28 Compliance Report in respect of Flicker in a timely manner and verify compliance with the Stage 2 limit of EREC P28 or comment accordingly. Note that the EREC P28 Compliance Report may demonstrate the need for the Customer to employ mitigation, select different equipment etc, and this may conceivably delay the proposed connection.

6.1.2.3.2 Stage 3 Flicker Assessment

Stage 3 Flicker assessment considers both Short- and Long-term Flicker Severity at the PCC. It involves evaluating the incremental Flicker due to the Relevant Customer Installation and also the combined effect of that with the Background Flicker. If the levels are in excess of the limits then it is necessary to evaluate alternative Customer connection options or Flicker reduction options. If it still fails after those have been considered then connection is not permitted.

The Stage 3 process splits into two distinct parts:

- Derivation of the EREC P28 Stage 3 Flicker Specification by WPD for the Customer
- Preparation of the Stage 3 Flicker analysis and its presentation in the EREC P28 Compliance Report by the Customer for submission to WPD for approval/comment.

Note that a link to the 'WPD Connection Guide - Connections subject to ENA EREC P28/2 stage 3 assessment' can be found in Appendix C. This can be used to explain the EREC P28 Stage 3 assessment process and the need for an EREC P28 Stage 3 Compliance Report.

Requirements for the review of the Stage 3 Flicker analysis aspect of the EREC P28 Compliance Report are provided in Appendix D.

6.1.2.3.2.1 EREC P28 Stage 3 Flicker Specification

The EREC P28 Stage 3 Flicker Specification comprises four parts:

- 95^{th}-percentile Background Flicker levels at the PCC, pre-connection, $P_{st\text{-}background}$ and $P_{lt\text{-}background}$.

- Incremental Flicker Limits for Short- and Long-term Flicker Severity, $P_{st\text{-}inc\ limit}$ and $P_{lt\text{-}inc\ limit}$
- Relevant planning levels, $P_{st\ planning\ level}$ and $P_{lt\ planning\ level}$, at the PCC
- Minimum credible fault level based on initial symmetrical short-circuit current of the network as seen from the PCC and associated X/R ratio.

Preparation of the EREC P28 Stage 3 Flicker Specification may commence once the Customer has formally accepted the Connection Offer. The specification is prepared by WPD Primary System Design using the 'ERECP28_S3_Flicker_Specification.xlsx' spreadsheet.

6.1.2.3.2.1.1 Background Flicker Data

Under EREC P28 Stage 3 it is necessary to determine the Background Flicker by measurement at the PCC or nearest practical nodes. Where reasonably practicable, this measurement shall be performed under normal operating conditions and shall be used to determine the 95th-percentile of seven contiguous days of measurement of 10-minute mean values for background Short- and Long-term Flicker Severity, $P_{st\text{-}background}$ and $P_{lt\text{-}background}$.

6.1.2.3.2.1.2 Incremental Flicker Limits

This section describes how to calculate the Incremental Flicker Limits that form part of the EREC P28 Stage 3 Flicker Specification.

The method for derivation of the Incremental Flicker Limits is defined in detail below.

The outcomes from this analysis are:

- Incremental Flicker Limit for short-term flicker severity, $P_{st\text{-}inc\ limit}$
- Incremental Flicker Limit for long-term flicker severity, $P_{lt\text{-}inc\ limit}$.

The method involves two steps:

- Calculation of the Flicker headroom
- Calculation of the Incremental Flicker Limits.

Note that it is at WPD's discretion to either allocate the full headroom between background level and planning level or just a part of it to the Customer. In order to preserve some headroom for future connections, without being overly restrictive, our normal approach shall be to allocate 75% of the available headroom in defining the Incremental Flicker Limits for Short- and Long-term Flicker Severity, $P_{st\text{-}inc\ limit}$ and $P_{lt\text{-}inc\ limit}$.

The Flicker headroom is calculated as below:

$$P_{st-headroom} = \sqrt[\propto]{P_{st-planning\ level}{}^{\propto} - P_{st-background}{}^{\propto}} \quad (1)$$

$$P_{lt-headroom} = \sqrt[\propto]{P_{lt-planning\ level}{}^{\propto} - P_{lt-background}{}^{\propto}} \quad (2)$$

where

- $P_{st\text{-}headroom}$ is the short-term flicker severity headroom at the PCC
- $P_{st\text{-}planning\ level}$ is the short-term flicker severity planning level at the PCC
- $P_{st\text{-}background}$ is the short-term flicker severity background level at the PCC
- $P_{lt\text{-}headroom}$ is the long-term flicker severity headroom at the PCC
- $P_{lt\text{-}planning\ level}$ is the long-term flicker severity planning level at the PCC
- $P_{lt\text{-}background}$ is the long-term flicker severity background level at the PCC
- α is the summation exponent. The default assumption is $\alpha = 3$. For further detail see EREC P28/2.

The Incremental Flicker Limits shall be calculated as below:

$$P_{st-inc\ limit} = MP_{st-headroom} \quad (3)$$

$$P_{lt-inc\ limit} = MP_{lt-headroom} \quad (4)$$

where

- $P_{st\text{-}inc\ limit}$ is the incremental short-term flicker severity limit at the PCC
- $P_{lt\text{-}inc\ limit}$ is the incremental long-term flicker severity limit at the PCC
- M is the apportionment multiplier
- $P_{st\text{-}headroom}$ is the short-term flicker severity headroom at the PCC
- $P_{lt\text{-}headroom}$ is the long-term flicker severity headroom at the PCC.

The apportionment multiplier, M, shall normally be set at a default value of 0.75; however, other values may be used where this can be justified (e.g. a value of 0.5 where further Fluctuating Installations may be expected to seek connection).

Once the Incremental Flicker Limits have been derived these shall be communicated to the Customer. See Section 7.1 and Appendix B reference the Connection Agreement and format for the EREC P28 Stage 3 Flicker Specification.

6.1.4 Stage 3 Flicker Analysis - EREC P28 Compliance Report

The Customer is responsible for preparing the Stage 3 Flicker analysis and its presentation in the EREC P28 Compliance Report to demonstrate compliance with the limits in the EREC P28 Stage 3 Flicker Specification issued by WPD.

The content of the EREC P28 Compliance Report in respect of Stage 3 Flicker analysis must include:

- Presentation of the incremental Flicker severity at the PCC (i.e. $P_{st\text{-}inc}$ and $P_{lt\text{-}inc}$) due solely to the emission from the Relevant Customer Installation for its worst credible operating condition taking into account the fault level and X/R ratio from the EREC P28 Stage 3 Flicker Specification.
- Presentation of the combined Flicker severity at the PCC due to the Relevant Customer Installation and Background Flicker level from the EREC P28 Stage 3 Flicker Specification (i.e. $P_{st\text{-}inc}$ combined with $P_{st\text{-}background}$ giving $P_{st\text{-}combined}$ and $P_{lt\text{-}inc}$ combined with $P_{lt\text{-}background}$ giving $P_{lt\text{-}combined}$).
- Demonstration of compliance with the EREC P28 Stage 3 Flicker Specification by showing compliance with the Incremental Flicker Limits (i.e. $P_{st\text{-}inc\ limit}$ and $P_{lt\text{-}inc\ limit}$) at the PCC. That is, $P_{st\text{-}inc} \leq P_{st\text{-}inc\ limit}$ and $P_{st\text{-}inc} \leq P_{lt\text{-}inc\ limit}$.
- Demonstration of compliance with the EREC P28 planning levels at the PCC. That is, $P_{st\text{-}combined} \leq P_{st\text{-}planning\ level}$ and $P_{lt\text{-}combined} \leq P_{lt\text{-}planning\ level}$.

The combined Flicker level at the PCC due to the Relevant Customer installation and Background Flicker level is calculated as below:

$$P_{st-combined} = \sqrt[\propto]{P_{st-inc}{}^{\propto} + P_{st-background}{}^{\propto}} \quad (5)$$

$$P_{lt-combined} = \sqrt[\propto]{P_{lt-inc}{}^{\propto} + P_{lt-background}{}^{\propto}} \quad (6)$$

where

- $P_{st\text{-}inc}$ is the incremental short-term flicker severity at the PCC due solely to the emission from the Relevant Customer Installation

- $P_{lt\text{-}inc}$ is the incremental long-term flicker severity at the PCC due solely to the emission from the Relevant Customer Installation
- $P_{st\text{-}background}$ is the short-term flicker severity background level at the PCC
- $P_{lt\text{-}background}$ is the long-term flicker Severity background level at the PCC
- α is the summation exponent. The default assumption is $\alpha = 3$. For further detail see EREC P28/2.

The PSD Engineer responsible for Power Quality shall review the EREC P28 Compliance Report in respect of Flicker in a timely manner and verify compliance with the EREC P28 Stage 3 Flicker Specification or comment accordingly. Note that the EREC P28 Compliance Report may demonstrate the need for the Customer to employ mitigation, select different equipment etc, and this may conceivably delay the proposed connection.

Appendix D provides a checklist for the review of the EREC P28 Compliance Report.

6.1.5 Network Design – Step Voltage Change Associated With Fluctuating Installations

POL: SD2 and POL:SD3 specify network design requirements for 132kV and 66kV/33kV respectively. These Policy documents define Step Voltage Change limits for various network events and operations upstream of the Customer Exit Point:

- Tripping of metering circuit breaker
- Secured outage
- Specific secured events
- Load management scheme failure
- Fast frequency response event
- Frequent network operational switching
- Infrequent network operational switching.

Limits are defined for each of these events/operations. So in addition to satisfying EREC P28 in relation to a proposed Customer connection or modification of that connection it is also necessary to consider the impact of a proposal upon compliance with the specified network design limits.

6.2 Connection Design – Distorting Installations

Given the scope of this ST, in relation to the control of Voltage Distortion all Customer connections comprising Distorting Installations are subject to EREC G5 Stage 3. Examples of features of Relevant Customer Installations that cause Voltage Distortion are given in Appendix A.

6.2.1 Need for Assessment - Circumstances where the Assessment may be Curtailed

EREC G5/5 defines the technical design requirements for connection of Customer Harmonic Sources and Resonant Plant, known collectively as 'relevant equipment'. The need to apply EREC G5/5 arises through the Distribution Code.

Both 'Harmonic Source' and 'Resonant Plant' are defined terms in EREC G/5:

- Harmonic source is 'any plant or equipment that is connected or a new user is seeking to connect to the public supply system that may result in a harmonic distortion due to an emission of harmonic current and/or voltage, including inter-harmonics and sub-harmonics'.

- Resonant Plant is 'any plant or equipment that is connected or a new user is seeking to connect to the public supply system, such as power factor correction capacitors, cables or active-front-end converters/inverters, that may materially modify the Background Harmonic Distortion as a result of interaction with the public supply system without emitting any harmonic current or voltage'.

On this basis, a new or modified connection with any Harmonic Source or Resonant Plant is subject to assessment under EREC G5/5. However, in some cases the proposed equipment may be insufficient to make a material change. For a modified connection there is the following provision in EREC G5/5 in section 1:

'In the case of modification, the relevant NO may, at its discretion, decide that reassessment against this EREC is not required; for example, if the modification does not constitute a material change to the new user's plant and equipment. In this context, modification is as defined in the terms of the relevant connection agreement.'

Given the scope of this ST, the opportunity to avoid Stage 3 assessment is severely limited. An example where reassessment would not be required is were Relevant Equipment is replaced with identical Relevant Equipment which does not change the harmonic emission or harmonic impedance of the Relevant Customer Installation. Another example is where the aggregate rating of the Customer equipment is much smaller than the fault level at the PCC.

6.2.2 EREC G5 Stage 3 Assessment

Under EREC G5/5, Stage 3 assessment applies to 'relevant equipment', as explained in 6.2.1, with a PCC ≥33kV or where the PCC is at 11kV or 6.6kV and has failed EREC G5/5 Stage 2C.

The Stage 3 process splits into two distinct parts:

- Derivation of the EREC G5 Stage 3 Harmonic Specification by WPD's appointed consultant for the Customer

- Preparation of the EREC G5 Stage 3 Compliance Report by the Customer for submission to WPD for approval/comment.

Note that a link to the 'WPD Connection Guide - Connections subject to ENA EREC G5/5 stage 3 assessment' can be found in Appendix C. This can be used to explain the EREC G5 Stage 3 assessment process and the need for an EREC G5 Stage 3 Compliance Report.

Requirements for the review of the EREC G5 Stage 3 Compliance Report are provided in Appendix J.

6.2.2.1 EREC G5 Stage 3 Harmonic Specification

The method for derivation of the EREC G5 Stage 3 Harmonic Specification is defined in EREC G5/5. It comprises of the following main steps:

- Set up harmonic model for given PCC

- Calculate harmonic transfer coefficients from PCC to remote nodes

- Collect/estimate Background Harmonic Distortion measurements for critical nodes

- Calculate harmonic limits for EREC G5 Stage 3 Harmonic Specification.

- Derive harmonic impedance loci/envelopes to represent the distribution network harmonic self-impedance for a range of credible outages.

Preparation of the EREC G5 Stage 3 Harmonic Specification may commence once the Customer has formally accepted the Connection Offer. It is prepared by WPD's appointed consultant.

6.2.2.1.1 Harmonic Model

The network model shall be set up for different load scenarios (e.g. Summer minimum and Winter maximum load) and generation scenarios. For the purposes of Summer minimum modelling a load level of 30% of Winter maximum is recommended in the absence of further information.

The network model shall be modified as necessary to include the new PCC and shall be imported into the harmonic modelling software. The harmonic model prepared by WPD's appointed consultant shall be configured to ensure the frequency dependent aspects are suitably represented:

- Use of frequency-dependent distributed parameter modelling of lines and cables and including skin-effect
- Use of frequency-dependent modelling of transformers and generators
- Use of aggregate equivalent RLC load model.

The harmonic model shall be used by WPD's appointed consultant to produce the harmonic self-impedance at the PCC and the harmonic transfer-impedance from the PCC to remote nodes for each harmonic order for each credible operating condition, including outages under EREC P2 and credible reactive compensation operating conditions.

6.2.2.1.2 Harmonic Transfer Coefficients

The harmonic self-impedance and harmonic transfer-impedance at the PCC shall be used by WPD's appointed consultant to calculate the harmonic transfer coefficients from the PCC to remote nodes. Note that to reflect practical limitations of the modelling it may be necessary to cap the transfer coefficients (e.g. to a maximum of 6) as per ETR 122- 2.

Remote nodes with harmonic transfer coefficients exceeding a specified value shall be used to determine critical remote notes that are considered in the limit-setting process. Typically, the harmonic transfer coefficient threshold for determining critical nodes shall be 1.6.

6.2.2.1.3 Background Harmonic Distortion Data

Background Harmonic Distortion measurements shall be determined for those nodes identified as critical above. Where reasonably practicable, these measurements performed under normal operating conditions and shall be used to determine the 95^{th}-percentile of seven contiguous days of measurement of 10-minute mean values.

Where it is necessary to estimate Background Harmonic Distortion data this shall be done using the harmonic load flow functionality of the harmonic model. Note that it is necessary to have measured data from at least one node.

For the purposes of providing Background Harmonic Distortion data for harmonics in the range above 2.5kHz and up to 5 kHz, where measurement is via a wound voltage transformer, it shall be assumed, in the absence of other information, that measured values are 10% of the EREC G5/5 planning levels.

6.2.2.1.4 Harmonic Limits

The method for derivation of the harmonic limits for the EREC G5 Stage 3 Harmonic Specification is defined in detail in EREC G5/5. The outcome from this analysis includes:

- Incremental Harmonic Voltage Limits for each harmonic order.
- Total Harmonic Voltage Limits for each harmonic order.

The EREC G5 Stage 3 Harmonic Specification comprises:

- 95th-percentile Background Harmonic Distortion at the PCC, pre-connection, for each harmonic order.
- Incremental Harmonic Voltage Limits for each harmonic order.
- Total Harmonic Voltage Limits for each harmonic order.
- Harmonic self-impedance of the network as seen from the PCC.

Once the harmonic limits have been derived these shall be communicated to the Customer. See Section 7.2 and Appendix B reference the Connection Agreement and format for the EREC G5 Stage 3 Harmonic Specification.

6.2.2.1.5 Concurrent Connections

There will be a delay between a Customer being issued with an EREC G5 Stage 3 Harmonic Specification and their connection to the network and their installation becoming fully operational. If a subsequent Customer with the same PCC or a PCC that is electrically close to them requires an EREC G5 Stage 3 Harmonic Specification before the first Customer has become fully operational then it is not possible to obtain Background Harmonic Distortion data by measurement that includes the first Customer. In this situation it is necessary to estimate values assuming the background based on the first Customer using their EREC G5 Stage 3 Harmonic Specification allowance fully. The required approach is defined in detail in EREC G5/5.

6.2.3 EREC G5 Stage 3 Compliance Report

The Customer is responsible for preparing the EREC G5 Stage 3 Compliance Report to demonstrate compliance with the limits in the EREC G5 Stage 3 Harmonic Specification issued by WPD.

The content of the EREC G5 Stage 3 Compliance Report must include:

- Presentation of the incremental harmonic voltage change values at the PCC (i.e. $V_{h\ Inc}$ as defined in EREC G5/5) due to the emission from the Relevant Customer Installation taking into account all operating conditions and configurations of the new installation, and presentation of the corresponding harmonic voltage change limit values (i.e. $V_{h\ Limit\ Resonant}$ as defined in EREC G5/5).

- Presentation of the total harmonic level at the PCC due to the Relevant Customer Installation (i.e. $V_{h\ Total}$ as defined in EREC G5/5), considering all operating conditions and configurations of the Relevant Customer Installation.

- Demonstration of compliance with the EREC G5 Stage 3 Harmonic Specification by showing compliance with the Incremental Harmonic Voltage Limits (i.e. $V_{h\ Limit\ \ Inc}$ as defined in EREC G5/5) and Total Harmonic Voltage Limits (i.e. $V_{h\ Limit\ Total}$ as defined in EREC G5/5) at the PCC. That is, $V_{h\ Inc} \leq V_{h\ Limit\ Inc}$ and $V_{h\ Total} \leq V_{h\ Limit\ Total}$.

- Equivalent Thévenin harmonic impedance of the proposed installation as seen from the PCC, with different values, as applicable, to cover the various operating conditions and configurations of the installation.

- Equivalent Thévenin voltage or Norton current source harmonic emission model at the PCC, with different values, as applicable, to cover the various operating conditions and configurations of the installation in relation to the corresponding abovementioned equivalent Thévenin harmonic impedance.

The PSD Engineer responsible for Power Quality shall review the EREC G5 Stage 3 Compliance Report in a timely manner and verify compliance with the EREC G5 Stage 3 Harmonic Specification or comment accordingly. Note that the EREC G5 Stage 3 Compliance Report may demonstrate the need for the Customer to employ mitigation, select different equipment etc, and this may conceivably delay the proposed connection.

Appendix D.2 provides a checklist for the review of the EREC G5 Stage 3 Compliance Report.

6.3 Connection Design – Unbalanced Installations

6.3.1 Need for Assessment - Circumstances where the Assessment may be Curtailed

EREC P29 defines the technical design requirements for connection of Customer Unbalanced Installations that may cause Voltage Unbalance. Examples of features of Relevant Customer Installations that cause Voltage Unbalance are given in Appendix A. On this basis, a new or modified connection with any capability to cause Voltage Unbalance is subject to assessment under EREC P29. However, in some cases the proposed equipment may be insufficient to make a material change. For example, where the ratio of the fault level at the PCC to the aggregate equipment rating is very high (e.g. ≥500); for example, with a 33kV fault level at the PCC of 250MVA this permits connection of an aggregate unbalanced equipment rating of 500kVA without detailed assessment.

Where the Customer installation will comprise a balanced three-phase load then it should be noted that this can still cause voltage unbalance due to system asymmetry (e.g. flat formation). As a guide, for such cases the mutual impedance is typically 0.029Ω/km. The balanced load in MVA required to produce voltage unbalance at the 'stage 2' level of 0.5% for a 33kV overhead circuit is given by 0.5% x 33^2/(0.029 x circuit length (km) x 100). On this basis, the balanced three phase 33kV load required to produce 0.5% voltage unbalance for flat formation construction is shown in Table 1. Where the voltage unbalance due to asymmetry is less than 0.5% then no further assessment is necessary.

Table 1 – Balanced Load for 0.5% Voltage for 33kV Overhead Circuit – Flat Formation

Circuit Length (km)	Balanced Load (MVA)
5	37.55
10	18.78
15	12.52
20	9.39
25	7.51
30	6.26

Table 2 and Table 3 give the balanced three phase load required to produce 0.5% voltage unbalance for flat formation construction 66kV and 132kV circuits respectively.

Table 2 – Balanced Load for 0.5% Voltage for 66kV Overhead Circuit – Flat Formation

Circuit Length (km)	Balanced Load (MVA)
5	150.21
10	75.10
15	50.07
20	37.55
25	30.04
30	25.03
35	21.46
40	18.78

Table 3 – Balanced Load for 0.5% Voltage for 132kV Overhead Circuit – Flat Formation

Circuit Length (km)	Balanced Load (MVA)
5	600.84
10	300.40
15	200.28
20	150.20
25	120.16
30	100.12
35	85.84
40	75.12
45	66.76
50	60.08
55	54.62
60	50.07

6.3.2 EREC P29 Assessment

The assessment process for Voltage Unbalance described in EREC P29 comprises of one stage. This is not ideal and EREC P29 is under review. For practical reasons it is necessary to introduce a simpler 'intermediate' assessment akin to the EREC P28 Stage 2 flicker assessment. For connections within the scope of this ST, where Voltage Unbalance assessment is required this is done with intermediate assessment initially which we refer to for the purposes of this document as 'Stage 2 Voltage Unbalance assessment'. If the assessment fails then alternative connection points and Voltage Unbalance reduction options are evaluated and, if the proposal still does not pass, then it is assessed under the full process defined in EREC P29 which we refer to as 'Stage 3 Voltage Unbalance assessment'.

6.3.2.1 Stage 2 Voltage Unbalance Assessment

Stage 2 Voltage Unbalance assessment predicts the incremental Voltage Unbalance at the PCC due to the Relevant Customer Installation, $V_{u\text{-}inc}$, and compares it against the Stage 2 limit, $V_{u\ Stage\ 2\ limit}$, of 0.5% based on the 95th-percentile 1 week 10-minute mean. It passes Stage 2 if the predicted value is no more than 0.5% (i.e. $V_{u\text{-}inc} \leq V_{u\ Stage\ 2\ limit}$) and fails if it exceeds this value (i.e. $V_{u\text{-}inc} > V_{u\ Stage\ 2\ limit}$). If it fails then alternative connection points and Voltage Unbalance reduction options are evaluated and, if it still does not pass Stage 2, then it is assessed under Stage 3. Note that Stage 2 considers the impedance/fault level at the PCC but does not consider the impact of existing Background Voltage Unbalance; at Stage 3 the existing Background Voltage Unbalance is also included in the assessment.

Note that a link to the 'WPD Connection Guide - Connections subject to ENA EREC P29 'stage 2' assessment' can be found in Appendix C. This can be used to explain the EREC P29 assessment process and the need for an EREC P29 Compliance Report.

6.3.2.1.1 Stage 2 Voltage Unbalance Analysis - EREC P29 Compliance Report

The Customer is responsible for preparing the Stage 2 Voltage Unbalance analysis and its presentation in the EREC P29 Compliance Report to demonstrate compliance with the Stage 2 limit in EREC P29.

The content of the EREC P29 Compliance Report in respect of Stage 2 Voltage Unbalance analysis must include:

- Presentation of the incremental Voltage Unbalance values at the PCC (i.e. $V_{u\text{-}inc}$) due solely to the emission from the Relevant Customer Installation for its worst credible operating condition taking into account the fault level and X/R ratio as advised by WPD.

- Demonstration of compliance with the EREC P29 Stage 2 limit by showing compliance at the PCC. That is, $V_{u\text{-}inc} \leq V_{u\ Stage\ 2\ limit}$ where $V_{u\ Stage\ 2\ limit} = 0.5\%$.

The PSD Engineer responsible for Power Quality shall review the EREC P29 Compliance Report in a timely manner and verify compliance with the Stage 2 limit of EREC P29 or comment accordingly. Note that the EREC P29 Compliance Report may demonstrate the need for the Customer to employ mitigation, select different equipment etc., and this may conceivably delay the proposed connection.

6.3.2.2 Stage 3 Voltage Unbalance Assessment

Planning levels for Voltage Unbalance are effectively defined in Section 4.3 of EREC P29.

EREC P29 assessment considers the Voltage Unbalance at the PCC. It involves evaluating the incremental Voltage Unbalance due to the Relevant Customer Installation and also the combined effect of that with the Background Voltage Unbalance. If the levels are in excess of the limits then it is necessary to evaluate alternative Customer connection options or Voltage Unbalance reduction options. If it still fails after those have been considered then connection is not permitted.

The assessment process splits into two distinct parts:

- Derivation of the EREC P29 Stage 3 Voltage Unbalance Specification by WPD for the Customer

- Preparation of the Voltage Unbalance analysis and its presentation in the EREC P29 Compliance Report by the Customer for submission to WPD for approval/comment.

Requirements for the review of the Voltage Unbalance analysis aspect of the EREC P29 Compliance Report are provided in Appendix D.

6.3.2.1 EREC P29 Stage 3 Voltage Unbalance Specification

The EREC P29 Stage 3 Voltage Unbalance Specification comprises four parts:

- Background Voltage Unbalance levels at the PCC, pre-connection, $V_{u\text{-}background}$

- Relevant planning levels, $V_{u\ planning\ level}$ at the PCC

- Incremental Voltage Unbalance Limits, $V_{u\text{-}inc\ limit}$

- Minimum credible fault level based on initial symmetrical short-circuit current of the network as seen from the PCC and associated X/R ratio.

Preparation of the EREC P29 Stage 3 Voltage Unbalance Specification may commence once the Customer has formally accepted the Connection Offer. The specification is prepared by WPD Primary System Design using the 'ERECP28_S3_Voltage_Unbalance_Specification.xlsx' spreadsheet.

Note that a link to the 'WPD Connection Guide - Connections subject to ENA EREC P29 'Stage 3' assessment' can be found in Appendix C. This can be used to explain the EREC P29 assessment process and the need for an EREC P29 Compliance Report.

6.3.2.1.1 Background Voltage Unbalance Data

Under EREC P29 it is necessary to determine the Background Voltage Unbalance by measurement at the PCC or nearest practical nodes. Where reasonably practicable, this measurement shall be performed under normal operating conditions and shall be used to determine the 100th-percentile of at least one day of measurement of 1-minute mean values and the 95th-percentile of one week of measurement of 10-minute mean values.

6.3.2.1.2 Interpretation of Voltage Unbalance Limits

Table 4 details the WPD interpretation of the EREC P29 voltage unbalance limits for connections with a PCC ≥33kV.

Table 4 – Interpretation of EREC P29 Voltage Unbalance Limits

EREC P29 Section	Limit	Interval	Percentile/Period	Interpretation
4.3(a)	2.0%	1-minute	100th/1 day	Planning level
4.3(b)	1.0%	10-minute	95th/1 week	Incremental limit
	2.0%[1]	10-minute	95th/1 week	Planning level

6.3.2.1.3 Incremental Voltage Unbalance Limits

This section describes how to calculate the 1-minute and 10-minute Incremental Voltage Unbalance Limits that form part of the EREC P29 Stage 3 Voltage Unbalance Specification.

The method of derivation of the Incremental Voltage Unbalance Limits for the 1-minute and 10-minute cases follows the same process and is as defined in detail below. The method involves two steps:

- Calculation of the Voltage Unbalance headroom
- Calculation of the Incremental Voltage Unbalance Limits.

Note that it is at WPD's discretion to either allocate the full headroom between background level and planning level or just a part of it to the Customer. In order to preserve some headroom for future connections, without being overly restrictive, our normal approach shall be to allocate 75% of the available headroom in defining the Incremental Voltage Unbalance Limits.

[1] The Voltage Unbalance based on 10-minute values cannot exceed that based on 1-minute values. Consequently, the planning level on a 10-minute basis must be ≤2.0% and has been set at 2.0%.

The Voltage Unbalance headroom is calculated as below:

$$V_{u-headroom} = \sqrt[\propto]{V_{u-planning\ level}{}^{\propto} - V_{u-background}{}^{\propto}} \quad (7)$$

where

- $V_{u\text{-}headroom}$ is the Voltage Unbalance headroom at the PCC
- $V_{u\text{-}planning\ level}$ is the Voltage Unbalance planning level at the PCC
- $V_{u\text{-}background}$ is the Voltage Unbalance background level at the PCC
- α is the summation exponent, taken as equal to 1.4.

The Incremental Voltage Unbalance Limits shall be calculated as below:

$$V_{u-inc\ limit} = MV_{u-headroom} \quad (8)$$

where

- $V_{u\text{-}inc\ limit}$ is the Incremental Voltage Unbalance Limit at the PCC
- M is the apportionment multiplier
- $V_{u\text{-}headroom}$ is the voltage unbalance headroom at the PCC.

The apportionment multiplier, M, shall normally be set at a default value of 0.75; however, other values may be used where this can be justified (e.g. a value of 0.5 where further Unbalanced Installations may be expected to seek connection).

Once the Incremental Voltage Unbalance Limits have been derived these shall be communicated to the Customer. See Section 7.3 and Appendix B reference the Connection Agreement and format for the EREC P29 Stage 3 Voltage Unbalance Specification.

6.3.2.2.1 Stage 3 Voltage Unbalance Analysis - EREC P29 Compliance Report

The Customer is responsible for preparing the Stage 3 Voltage Unbalance analysis and its presentation in the EREC P29 Compliance Report to demonstrate compliance with the limits in the EREC P29 Stage 3 Voltage Unbalance Specification issued by WPD. The method for the 1-minute and 10-minute cases follows the same process as defined in detail below.

The content of the EREC P29 Compliance Report must include:

- Presentation of the incremental Voltage Unbalance values at the PCC (i.e. $V_{u\text{-}inc}$) due solely to the emission from the Relevant Customer Installation for its worst credible operating condition taking into account the fault level and X/R ratio from the EREC P28 Stage 3 Voltage Unbalance Specification.
- Presentation of the combined Voltage Unbalance level at the PCC due to the Relevant Customer Installation and Background Voltage Unbalance level from the EREC P29 Stage 3 Voltage Unbalance Specification (i.e. $V_{u\text{-}inc}$ combined with $V_{u\text{-}background}$ giving $V_{u\text{-}combined}$).
- Demonstration of compliance with the EREC P29 Stage 3 Voltage Unbalance Specification by showing compliance with the Incremental Voltage Unbalance Limit (i.e. $V_{u\text{-}inc\ limit}$) at the PCC. That is, $V_{u\text{-}inc} \leq V_{u\text{-}inc\ limit}$.
- Demonstration of compliance with the EREC P29 planning levels at the PCC. That is, $V_{u\text{-}combined} \leq V_{u\text{-}planning\ level}$.

The combined Voltage Unbalance level at the PCC due to the Relevant Customer Installation and Background Voltage Unbalance level is calculated as below:

$$V_{u-combined} = \sqrt[\propto]{V_{u-inc}{}^{\propto} + V_{u-background}{}^{\propto}} \quad (9)$$

Where

- $V_{u\text{-}inc}$ is the incremental Voltage Unbalance at the PCC due solely to the emission from the Relevant Customer Installation
- $V_{u\text{-}background}$ is the Background Voltage Unbalance level at the PCC
- α is the summation exponent, taken as equal to 1.4.

The PSD Engineer responsible for Power Quality shall review the EREC P29 Compliance Report in a timely manner and verify compliance with the EREC P29 Stage 3 Voltage Unbalance Specification or comment accordingly. Note that the EREC P29 Compliance Report may demonstrate the need for the Customer to employ mitigation, select different equipment etc, and this may conceivably delay the proposed connection.

Appendix D provides a checklist for the review of the EREC P29 Compliance Report.

7.0 CONNECTION OFFERS & AGREEMENTS

Typically, Connection Offers, including Modification Offers, are made in advance of comprehensive assessment of the acceptability of the proposed connection or modification to Relevant Customer Installations. Given this, it is essential that such offers are made subject to specific requirements that control the level of disturbance to Voltage Quality created by connection of such Relevant Customer Installations. Consequently, it is necessary to include relevant clauses in the Connection Offer/Modification offer, as appropriate. See Appendix B.1.

Standard Connection Agreements call up the National Terms for Connection. This provides some protection for the Company against a Customer who operates equipment that adversely affects voltage regulation or the supply of electricity. See Appendix B.2.1.

Connection Agreements shall include suitable clauses to provide for enduring control of possible disturbance to Voltage Quality. See Appendix B.2.2.

In addition, where an EREC P28 Stage 3 Flicker Specification, EREC G5 Stage 3 Harmonic Specification and/or EREC P29 Stage 3 Voltage Unbalance Specification have been issued to the Customer then these shall be incorporated into the Connection Agreement. See sections 7.1-7.3.

7.1 EREC P28 Stage 3 Flicker Specification incorporation into Connection Agreement

The EREC P28 Stage 3 Flicker Specification forms part of the Connection Agreement.

Preparation of the EREC P28 Stage 3 Flicker Specification may commence once the Customer has formally accepted the Connection Offer. It is prepared by WPD Primary System Design.

The PSD Engineer responsible for the connection application is responsible for the incorporation of the EREC P28 Stage 3 Flicker Specification into the Connection Agreement. The format for presentation of Flicker limits that form part of the EREC G5 Stage 3 Flicker Specification is shown in Appendix B.3.

7.2 EREC G5 Stage 3 Harmonic Specification incorporation into Connection Agreement

The EREC G5 Stage 3 Harmonic Specification forms part of the Connection Agreement.

Preparation of the EREC G5 Stage 3 Harmonic Specification may commence once the Customer has formally accepted the Connection Offer. It is prepared by WPD Primary System Design.

Preparation of the EREC G5 Stage 3 Harmonic Specification involves extensive harmonic modelling of the WPD network, measurement of existing Voltage Distortion at critical nodes, calculation of harmonic headroom at these nodes, derivation of 'Incremental Harmonic Voltage Limits' and 'Total Harmonic Voltage Limits' at the PCC and the statement associated harmonic impedance of the network as seen from the PCC.

The PSD Engineer responsible for the connection application is responsible for the incorporation of the EREC G5 Stage 3 Harmonic Specification into the Connection Agreement. The format for presentation of harmonic limits that form part of the EREC G5 Stage 3 Harmonic Specification is shown in Appendix B.4.

7.3 EREC P29 Stage 3 Voltage Unbalance Specification incorporation into Connection Agreement

The EREC P29 Stage 3 Voltage Unbalance Specification forms part of the Connection Agreement.

Preparation of the EREC P29 Stage 3 Voltage Unbalance Specification may commence once the Customer has formally accepted the Connection Offer. It is prepared by WPD Primary System Design.

The PSD Engineer responsible for the connection application is responsible for the incorporation of the EREC P29 Stage 3 Voltage Unbalance Specification into the Connection Agreement. The format for presentation of Voltage Unbalance limits that form part of the EREC P29 Stage 3 Voltage Unbalance Specification is shown in Appendix B.5.

8.0 VERIFICATION OF COMPLIANCE

Compliance with the specified limits may be verified by measurements at the PCC. As detailed below, this can be problematic and of limited use. Given this, WPD will not normally seek to verify compliance by measurement post-connection although it reserves the right to do so.

8.1 Verification of Compliance with EREC P28 Stage 3 Flicker Specification by Measurement

Compliance with the EREC G5 Stage 3 Flicker Specification may be verified by Flicker measurements at the PCC. Post-connection, such measurements will relate to the new Background Flicker level at the PCC (i.e. $P_{\text{st-post-connection background}}$ and $P_{\text{lt-post-connection background}}$) due to the Relevant Customer Installation emission and Background Flicker for the specific operating conditions prevailing at the time of measurement; these measurements can be used to determine the incremental flicker due to the Relevant Customer Installation for comparison with the limits in the specification ($P_{\text{st-inc limit}}$ and $P_{\text{lt-inc limit}}$) to verify compliance. That is, measured $P_{\text{st-inc measured}} \leq P_{\text{st-inc limit}}$ and $P_{\text{lt-inc measured}} \leq P_{\text{lt-inc limit}}$ where:

$$P_{st-inc\ measured} = \sqrt[\propto]{P_{st-post-connection\ background}{}^{\propto} - P_{st-background}{}^{\propto}} \qquad (10)$$

$$P_{lt-inc\ measured} = \sqrt[\propto]{P_{lt-post-connection\ background}{}^{\propto} - P_{lt-background}{}^{\propto}} \qquad (11)$$

where

- $P_{st\text{-}inc\ measured}$ is the 'measured' incremental short-term flicker severity at the PCC due solely to the emission from the Relevant Customer Installation
- $P_{lt\text{-}inc\ measured}$ is the 'measured' incremental long-term flicker severity at the PCC due solely to the emission from the Relevant Customer Installation
- $P_{st\text{-}post\text{-}connection\ background}$ is the background short-term flicker severity at the PCC without the emission from the Relevant Customer Installation
- $P_{lt\text{-}post\text{-}connection\ background}$ is the background long-term flicker severity at the PCC without the emission from the Relevant Customer Installation
- $P_{st\text{-}background}$ is the background short-term flicker severity at the PCC without the emission from the Relevant Customer Installation
- $P_{lt\text{-}background}$ is the background long-term flicker severity at the PCC without the emission from the Relevant Customer Installation
- α is the summation exponent, taken as equal to 3.

It will not normally be practicable to perform measurements for the limiting operating condition used to derive the specified limits and there will be uncertainty over the actual summation exponent. Furthermore, the Background Flicker prevailing at the time of measurement may differ from that used in the specification. As such, this limits the usefulness of attempting verification by measurement. In view of these limitations, WPD will not normally seek to verify compliance by measurement post-connection although it reserves the right to do so. Note that an example of circumstances when verification by measurement may be warranted is when investigating a complaint by other customers or a situation that may give rise to such complaints.

8.2 Verification of Compliance with EREC G5 Stage 3 Harmonic Specification by Measurement

Compliance with the EREC G5 Stage 3 Harmonic Specification may be verified by harmonic measurements at the PCC. Post-connection, such measurements will relate to the measured total harmonic level at the PCC due to the Relevant Customer Installation (i.e. measured $V_{h\ Total}$) for the specific operating conditions prevailing at the time of measurement; these measurements would typically include the effect of the Customer emissions and the effect of amplification of Background Voltage Distortion due to the Customer's installation and should be compared with the specified Total Harmonic Voltage Limits (i.e. $V_{h\ Limit\ Total}$ as defined in the Connection Agreement) to verify compliance. That is, measured $V_{h\ Total} \leq V_{h\ Limit\ Total}$.

It will not normally be practicable to perform measurements for the limiting operating condition used to derive the specified Total Harmonic Voltage Limits. Furthermore, the Background Voltage Distortion prevailing at the time of measurement may differ from that used in the Harmonic Specification. As such, this limits the usefulness of attempting verification by measurement. In view of these limitations, WPD will not normally seek to verify compliance by measurement post-connection although it reserves the right to do so.

Note that an example of circumstances when verification by measurement may be warranted is when investigating a complaint by other customers or a situation that may give rise to such complaints.

8.3 Verification of Compliance with EREC P29 Stage 3 Voltage Unbalance Specification by Measurement

Compliance with the EREC P29 Stage 3 Voltage Unbalance Specification may be verified by Voltage Unbalance measurements at the PCC. Post-connection, such measurements will relate to the new Background Voltage Unbalance level at the PCC (i.e. $V_{u\text{-post-connection background}}$) due to the Relevant Customer Installation emission and Background Voltage Unbalance for the specific operating conditions prevailing at the time of measurement; these measurements can be used to determine the incremental voltage unbalance due to the Relevant Customer Installation for comparison with the limit in the specification ($V_{u\text{-inc limit}}$) to verify compliance. That is, measured $V_{u\text{-inc measured}} \leq V_{u\text{-inc limit}}$ where:

$$V_{u-inc\ measured} = \sqrt[\propto]{V_{u-post-connection\ background}{}^{\propto} - V_{u-background}{}^{\propto}} \qquad (12)$$

where

- $V_{u\text{-inc measured}}$ is the 'measured' incremental Voltage Unbalance at the PCC due solely to the emission from the Relevant Customer Installation
- $V_{u\text{-post-connection background}}$ is the Background Voltage Unbalance level at the PCC without the emission from the Relevant Customer Installation
- $V_{u\text{-background}}$ is the Background Voltage Unbalance level at the PCC without the emission from the Relevant Customer Installation
- α is the summation exponent, taken as equal to 1.4.

It will not normally be practicable to perform measurements for the limiting operating condition used to derive the specified limits and there will be uncertainty over the actual summation exponent. Furthermore, the Background Voltage Unbalance prevailing at the time of measurement may differ from that used in the specification. As such, this limits the usefulness of attempting verification by measurement. In view of these limitations, WPD will not normally seek to verify compliance by measurement post-connection although it reserves the right to do so. Note that an example of circumstances when verification by measurement may be warranted is when investigating a complaint by other customers or a situation that may give rise to such complaints.

9.0 LIST OF APPENDICES

APPENDIX	TITLE
A	Typical Voltage Quality disturbance by Relevant Customer Installation type
B	Connection terms and conditions
C	Connection guides for Customers
D	Review of Customer compliance reports
E	WPD interpretation of EREC P28 Step Voltage Change limits
F	WPD interpretation of EREC P28 Rapid Voltage Change limits
G	WPD interpretation of EREC P28 Flicker limits
H	WPD interpretation of EREC G5 Harmonic Voltage limits
I	WPD Interpretation of EREC P29 Voltage Unbalance Limits
J	Background – Legal and Regulatory Framework
K	Superseded Documentation
L	Ancillary Documentation
M	Keywords
N	Document Last Reviewed

APPENDIX A – TYPICAL VOLTAGE QUALITY DISTURBANCE BY RELEVANT CUSTOMER INSTALLATION TYPE

Table A.1 — Examples of Voltage Quality disturbances associated with various Relevant Customer Installation features

CUSTOMER INSTALLATION FEATURE	VOLTAGE QUALITY CHARACTERISTIC POTENTIALLY AFFECTED				
	Flicker	Rapid Voltage Change	Step Voltage Change	Voltage Distortion	Voltage Unbalance
Cables - Capacitance				○	
Capacitor				●	
Capacitor – Switching		●	●		
Furnace - Arc	●	●	●	●	
Furnace - Induction	●	●	●	●	○
Generator – no PE Converter	○	○	●	○	
Generator – with PE Converter	●		●	●	
Motor – no PE Converter	●	●	●	○	
Motor – with PE Converter	○		●	●	
Power Change ΔP, ΔQ	●	●	●		○
PE Converter	○		●	●	
Switching Operations	○	●	●		
Traction			●	●	●
Transformer Energisation		●			
Welding Machine	●	●		○	○
PE = Power Electronic ○ = Depends on installation/plant/equipment type					

APPENDIX B – CONNECTION TERMS AND CONDITIONS

B.1 Connection Offers – Standard Text

Standard text for use in Connection Offers, including Modification Offers, is reproduced below.

The Customer shall ensure that any voltage fluctuation, voltage unbalance, voltage harmonics or voltage interharmonics caused by any of its electrical equipment or apparatus at the Customer's Installation do not exceed the levels laid down in Engineering Recommendations EREC P28, EREC P29 and EREC G5 and, if appropriate, as specified by WPD where:

- EREC P28 covers 'Voltage fluctuations and the connection of disturbing equipment to transmission systems and distribution networks in the United Kingdom'
- EREC P29 covers 'Planning limits for voltage unbalance in the United Kingdom'
- EREC G5 covers 'Harmonic voltage distortion and the connection of harmonic sources and/or resonant plant to transmission systems and distribution networks in the United Kingdom '.'

The proposed Customer Installation shall be subject to assessment under EREC P28, EREC P29 and EREC G5 unless WPD advise otherwise. [Where such assessments are required and the Point of Common Coupling (PCC) is at LV, WPD will normally conduct these assessments unless we advise otherwise. Should it not be possible for WPD to do the necessary assessments (e.g. proposed equipment cannot be characterized using standard methods) then it may be necessary to engage a consultant and to make a cost-reflective charge.]

The short-term flicker severity, P_{st}, as defined in EREC P28, caused by the Customer's Installation shall be limited to the EREC P28 Stage 2 flicker planning level at the PCC. [Unless WPD advise otherwise, where the PCC is equal to or greater than 11kV, the Customer shall submit a report in accordance with EREC P28 to demonstrate compliance with this limit. If this limit cannot be met after considering reasonably practicable flicker reduction options then WPD may, at its discretion, allow assessment under Stage 3 of EREC P28 and provide a WPD flicker specification to the Customer after acceptance of the Connection Offer. The Customer shall then submit a report in accordance with EREC P28 to demonstrate compliance with this specification for approval. The Customer's Installation shall be designed such that it is possible, if so required, to introduce sequential switching to ensure a minimum period between each operation that causes voltage change consistent with the above flicker limit; examples include switching of each generator, switching of each transformer, switching of load etc.]

The step voltage change, as defined in EREC P28, caused by the Customer's Installation shall be limited to the planning level specified in EREC P28 [and, where the PCC is equal to or greater than 11kV WPD policy POL:SD2 and POL:SD3 at the PCC. Unless WPD advise otherwise, the Customer shall submit a report in accordance with EREC P28 to demonstrate compliance with this limit for approval.]

The rapid voltage change, as defined in EREC P28, caused by the Customer's Installation shall be limited to the planning levels specified in EREC P28 at the PCC. [Unless WPD advise otherwise, where the PCC is equal to or greater than 11kV, the Customer shall submit a report in accordance with EREC P28 to demonstrate compliance with these limits for approval.]

[Where the PCC is at LV or equal to or greater than 11KV, the Customer's Installation shall be assessed in accordance with EREC G5 Stage 1 and/or 2, as appropriate. Where assessment is under EREC G5 Stage 2C the harmonic voltage distortion caused by the Customer's Installation shall be limited to the planning levels specified in EREC G5 at the PCC. Unless WPD advise otherwise, the Customer shall submit a report to demonstrate compliance for approval. If compliance cannot be achieved after considering reasonably practicable mitigation options then the Customer's Installation shall be assessed in accordance with EREC G5 Stage 3.]

Where the PCC is equal to or greater than 33kV, the harmonic voltage distortion, as defined in EREC G5, caused by the Customer's Installation shall be limited to the levels defined in the WPD Stage 3 harmonic specification in accordance with EREC G5; this specification will be provided by WPD to the Customer after acceptance of the Connection Offer. The Customer shall submit a report to demonstrate compliance with this specification for approval.]

The voltage unbalance, as defined in EREC P29, caused by the Customer's Installation shall be limited to 0.5% at the PCC. [Unless WPD advise otherwise, where the PCC is equal to or greater than 11kV, the Customer shall submit a report to demonstrate compliance with this limit for approval. If this limit cannot be met after considering reasonably practicable unbalance reduction options then WPD may, at its discretion, allow assessment under Stage 3 of EREC P29 as defined in WPD Standard Technique ST:SD6F and provide a WPD voltage unbalance specification to the Customer after acceptance of the Connection Offer; the Customer shall then submit a report to demonstrate compliance with this specification for approval.]

WPD will not Energise the Customer's Installation until WPD is satisfied the requirements of EREC P28, EREC P29 and EREC G5 are met and any required mitigation put in place. The Customer's choice of equipment may influence the need for mitigation significantly (e.g. harmonic emissions produced by equipment with a similar function can vary substantially with some makes/models being 'cleaner' than others).

The Customer shall not connect any electrical equipment that may adversely affect the supply of electricity to others and/or cause disturbance outside of acceptable limits to the Distribution System without WPD's previous written consent, which will not be unreasonably delayed or withheld. Such equipment includes motors, welders, furnaces, high power appliances, convertors (e.g. rectifiers, switch mode power supplies, uninterruptible power supplies, battery chargers, high-frequency induction furnaces and variable speed drives), regulators (e.g. AC heating and lighting controls) and other equipment with non-linear voltage/current characteristics (e.g. arc welders and arc furnaces). Consent may be granted for equipment subject to specified operating restrictions required by WPD. WPD may base any consent upon estimation of the disturbance caused by the proposed equipment (which cannot be precisely determined in advance) and taking a risk-based approach to the likelihood of complaint. Given this, it may be that after the installation of any electrical equipment is complete the disturbance levels are determined to be unacceptable, and/or complaints are received that are attributable to the Customer's equipment. WPD may de-energise the Connection Point or curtail the Customer's import / export (including to zero) where the Customer's Installation and/or any other electrical equipment which the Customer connects adversely affects any other customer connected to the Distribution System and/or causes disturbance outside of acceptable limits and the Customer shall be responsible for the costs of any remedial action that may be required as a result of any electrical equipment which the Customer connects (including to the Customer's Installation and/or the Distribution System).

Where the Customer wishes to make a Modification to their Customer Installation, this shall be subject to the same requirements as described above. Where the Customer can demonstrate that the Modification will not materially change the EREC P28, P29 and EREC G5 assessments made in obtaining their existing Connection Agreement then full reassessment can be omitted.

B.2 Connection Agreements – Standard Text

B.2.1 National Terms of Connection

The standard text used in Connection Agreements invokes the National Terms of Connection.

This agreement and the schedules to it shall be referred to as the "Agreement" and the "Schedules" respectively. The Agreement, the Schedules, and the National Terms of Connection shall together be referred to as the "Connection Agreement". The Company and the Customer shall together be referred to as the "Parties", and each a "Party".

The National Terms of Connection are available to view on the website: **www.connectionterms.org.uk**. Alternatively the Customer may request a copy from the Company by written request to the address for notices given above. The Customer confirms that they have read, fully understand and accept the terms of the National Terms of Connection.

Subject to the express provisions of this Agreement, Section 1 and either Section 2 (if the Customer uses whole current metering), or Section 3 (if the Customer uses C.T. metering) of the National Terms of Connection will apply as if set out in this Agreement and references in the National Terms of Connection to "this agreement" or to "this Agreement" shall be interpreted as if references to this Connection Agreement. Expressions used in this Agreement and the Schedules shall have the same meanings as given to them in the National Terms of Connection

To the extent that there is any conflict between this Agreement and the provisions of the Schedules or the National Terms of Connection, the order of precedence shall be as follows:
(a) this Agreement;
(b) the schedules; and
(c) the National Terms of Connection

The Company agrees to the Connection of the Customer's Installation to the Company's Distribution System on the terms and conditions of this Connection Agreement and in consideration of the Company's agreement to do so the Customer agrees to be bound contractually by the terms and conditions of this Connection Agreement. Details of the Premises, the Connection Points, the technical characteristics of the Connection Points and other matters are set out in the Schedules.

B.2.2 Default Additional Text

Additional standard text is included in Connection Agreements to define further detailed requirements. Extracts of standard text used in Connection Agreements is reproduced below.

2. Curtailment and De-Energisation

2.1 Notwithstanding any other provision of this Connection Agreement, the Company may instruct the Customer to (at the Customer's own expense) immediately De-energise or implement an immediate reduction to the Maximum Import Capacity and/or the Maximum Export Capacity (including to zero), or the Connection Point may otherwise be de-energised (whether De-energised as defined or otherwise), or a Customer's Maximum Import Capacity and/or the Maximum Export Capacity reduced (including to zero) (any such reduced capacity under this paragraph being the "Revised Maximum Export Capacity" or the "Revised Maximum Import Capacity"), in the following scenarios:

(d) notwithstanding any consent that may be granted for any equipment (including any as set in this Connection Agreement below), and without prejudice to any other provision of this Connection Agreement, where the Customer's Installation and/or any other electrical equipment which the Customer connects adversely affects any other customer connected to the Distribution System and/or causes disturbance outside of acceptable limits to the Distribution System.

3. Disturbing Loads

3.1 The Customer shall not connect any electrical equipment that may adversely affect the supply of electricity to others and/or cause disturbances outside of acceptable limits to the Distribution System without the Company's previous written consent, which will not unreasonably be delayed or withheld. Such equipment includes motors, welders, furnaces, high power appliances, converters (e.g. rectifiers, switch mode power supplies, uninterruptible power supplies, battery chargers, high-frequency induction furnaces and variable speed drives), regulators (e.g. AC heating and lighting controls) and other equipment with non-linear voltage / current characteristics (e.g. arc welders and arc furnaces)). Any consent that is or may be granted is or will be based on estimated disturbance levels (which cannot be precisely determined in advance) and taking a risk-based approach to the likelihood of complaint, and is without prejudice to any other provision of this Connection Agreement.

3.2 Notwithstanding any other provision of this Connection Agreement, the Customer shall be liable for the costs of any remedial action required (including to the Customer's Installation and/or the Distribution System) as a result of any adverse interference caused by the Customer's Installation and/or any other electrical equipment which the Customer connects with any other customer connected to the Distribution System.

4. Compliance

4.1 The Customer shall ensure that any voltage fluctuation, voltage unbalance, voltage harmonics or voltage interharmonics caused by any of its electrical equipment or apparatus at the Customer's Installation do not exceed the levels laid down in Engineering Recommendations EREC P28, EREC P29 and EREC G5 and as specified by WPD in annexs to this Connection Agreement, where:

- EREC P28 covers 'Voltage fluctuations and the connection of disturbing equipment to transmission systems and distribution networks in the United Kingdom'
- EREC P29 covers 'Planning limits for voltage unbalance in the United Kingdom'
- EREC G5 covers 'Harmonic voltage distortion and the connection of harmonic sources and/or resonant plant to transmission systems and distribution networks in the United Kingdom '.

4.2 The short-term flicker severity, P_{st}, as defined in EREC P28, caused by the Customer's Installation shall be limited to 0.5 at the point of common coupling (PCC) except where WPD has issued an EREC P28 Stage 3 flicker specification and this forms an annex to this Connection Agreement. The Customer's Installation shall be such that it is possible, if so required, to introduce sequential switching to ensure a minimum period between each operation that causes voltage change consistent with the above flicker limit; examples include switching of each generator, switching of each transformer, switching of load etc. Where remedial action is required, whether it be to the Customer's Installation or the Company's Distribution System, the Customer shall be liable for all reasonable costs incurred.

4.3 Where WPD has issued an EREC P28 Stage 3 flicker specification and this forms an annex to this Connection Agreement the flicker caused by the Customer's Installation shall be limited to the levels defined therein.

4.4 The step voltage change, as defined in EREC P28, caused by the Customer's Installation shall be limited to the planning level specified in EREC P28 and WPD policy POL:SD2 and POL:SD3, as appropriate, at the PCC.

4.5 The rapid voltage change, as defined in EREC P28, caused by the Customer's Installation shall be limited to the planning levels specified in EREC P28 at the PCC.

4.6 The harmonic voltage distortion, as defined in EREC G5, caused by the Customer's Installation shall be limited to the levels defined in the WPD EREC G5 Stage 3 harmonic specification where this forms an annex to this Connection Agreement.

4.7 The voltage unbalance, as defined in EREC P29, caused by the Customer's Installation shall be limited to 0.5% at the point of common coupling except where WPD has issued an EREC P29 Stage 3 voltage unbalance specification and this forms an annex to this Connection Agreement. Where WPD has issued an EREC P29 Stage 3 voltage unbalance specification and this forms an annex to this Connection Agreement the voltage unbalance caused by the Customer's Installation shall be limited to the levels defined therein.

4.8 Generator plant and equipment shall comply with the requirements of the EREC G99 'Recommendations for the connection of generating plant to the distribution systems of licensed distribution network operators' or its replacement, or other reasonable provisions as may, from time to time, be required by the Company.

B.3 EREC P28 STAGE 3 FLICKER SPECIFICATION - FORMAT FOR CONNECTION AGREEMENT

The EREC P28 Stage 3 Flicker Specification comprises four parts:

- 95th-percentile Background Flicker levels at the PCC, pre-connection, $P_{st\text{-}background}$ and $P_{lt\text{-}background}$.
- Incremental Flicker Limits for short- and long-term flicker severity, $P_{st\text{-}inc\ limit}$ and $P_{lt\text{-}inc\ limit}$
- Relevant planning levels, $P_{st\ planning\ level}$ and $P_{lt\ planning\ level}$, at the PCC
- Minimum credible fault level and X/R ratio based on initial symmetrical short-circuit current of the network as seen from the PCC.

The format for presentation of EREC P28 Stage 3 Flicker Specification is shown in Table B.3.

Table B.3 — Format of limits forming part of EREC P28 Stage 3 Flicker Specification

	Background level at PCC [1)]	**Incremental limit at PCC** [2)]	**Planning level at PCC**
Short-term Flicker Severity	...	...	...
Long-term Flicker Severity	...	...	...
Minimum credible fault level (MVA)	...		
X/R ratio	...		
NOTE: All values apply at the PCC.			
[1)] Prior to connection of the Relevant Customer Installation. [2)] Due to flicker emission of the Relevant Customer Installation.			

B.4 EREC G5 STAGE 3 HARMONIC SPECIFICATION - FORMAT FOR CONNECTION AGREEMENT

The EREC G5 Stage 3 Harmonic Specification comprises:

- 95th-percentile Background Harmonic Distortion at the PCC, pre-connection, for each harmonic order.
- Incremental Harmonic Voltage Limits for each harmonic order.
- Total Harmonic Voltage Limits for each harmonic order.
- Harmonic self-impedance of the network as seen from the PCC.

The format for presentation of harmonic limits that form part of the EREC G5 Stage 3 Harmonic Specification is shown in Table B.3. WPD specify limits from the 2nd harmonic to the 100th harmonic as a percentage of the fundamental frequency voltage of 50Hz (i.e. h=1).

Table B.4 — Format of limits forming part of EREC G5 Stage 3 Harmonic Specification

Harmonic order (*h*)	**Background Harmonic Distortion [1)] *% h=1***	**Incremental Harmonic Voltage Limit [2)] *% h=1***	**Total Harmonic Voltage Limit *% h=1***
2	...	...	...
3	...	...	...
4	...	...	...
...	...	...	...
100	...	...	...
NOTE: All values apply at the PCC.			
[1)] Prior to connection of the Relevant Customer Installation. [2)] Due to harmonic emission of the Relevant Customer Installation.			

Incremental Harmonic Voltage Limits are used to manage the impact of injection of harmonics by the Customer's equipment upon the PCC and remote nodes. In contrast, Total Harmonic Voltage Limits are used to manage amplification/attenuation of background Voltage Distortion caused by the Customer's installation at the PCC only.

In addition to the table of limits, WPD also provide the harmonic impedance of the Distribution System as seen from the PCC.

B.5 EREC P29 STAGE 3 VOLTAGE UNBALANCE SPECIFICATION - FORMAT FOR CONNECTION AGREEMENT

The EREC P29 Stage 3 Voltage Unbalance Specification comprises four parts:

- Background Voltage Unbalance levels at the PCC, pre-connection, $V_{u\text{-}background}$
- Incremental Voltage Unbalance Limit, $V_{u\text{-}inc\ limit}$
- Relevant planning level, $V_{u\ planning\ level}$ at the PCC
- Minimum credible fault level based on initial symmetrical short-circuit current of the network as seen from the PCC and associated X/R ratio.

The format for presentation of EREC P29 Stage 3 Voltage Unbalance Specification is shown in Table B.5.

Table B.5 — Format of limits forming part of EREC P29 Stage 3 Voltage Unbalance Specification

	Background level at PCC [1)]	**Incremental limit at PCC** [2)]	**Planning level at PCC**
Voltage Unbalance (1-minute)	...	...	...
Voltage Unbalance (10-minute)	...	...	...
Minimum credible fault level (MVA)	...		
X/R ratio	...		
NOTE: All values apply at the PCC.			
[1)] Prior to connection of the Relevant Customer Installation. [2)] Due to voltage unbalance emission of the Relevant Customer Installation.			

APPENDIX C – CONNECTION GUIDES FOR CUSTOMERS

Three Connection Guides for Customers have been prepared covering connections subject to:

- EREC P28/2 Stage 2
- EREC P28/2 Stage 3
- EREC G5/5 Stage 3
- EREC P29 ‘Stage 2’
- EREC P29 ‘Stage 3’.

See links in Table C.1.

Table C.1 — Links to Connection Guides

Connection Guide
WPD Connection Guide - Connections subject to ENA EREC P28/2 stage 2 assessment
WPD Connection Guide - Connections subject to ENA EREC P28/2 stage 3 assessment
WPD Connection Guide - Connections subject to ENA EREC G5/5 stage 3 assessment
WPD Connection Guide - Connections subject to ENA EREC P29 ‘stage 2’ assessment
WPD Connection Guide - Connections subject to ENA EREC P29 ‘Stage 3’ assessment

APPENDIX D – REVIEW OF CUSTOMER COMPLIANCE REPORTS

As part of the connection design process the Customer will have to submit compliance reports as necessary covering:

- Compliance with EREC P28
  - Step Voltage Change analysis
  - RVC analysis
  - Stage 2 Flicker analysis
  - Stage 3 Flicker analysis
- Compliance with EREC G5
  - Stage 3 Harmonic Voltage analysis
- Compliance with EREC P29
  - Stage 2 Voltage Unbalance analysis
  - Stage 3 Voltage Unbalance analysis.

Sections D.1-D.3 provide checklists to use when reviewing and commenting on the submitted report(s). Appendices E-I provide further guidance on interpretation of the various limits.

D.1 EREC P28 Compliance Report Review Checklist

Step Voltage Change Analysis Review - Checklist	✓
Step voltage change values at the PCC (i.e. V_{step})	
$V_{step} \leq V_{step\text{-}planning\ level}$	

RVC Analysis Review - Checklist	✓
Maximum and steady-state voltage change values at the PCC (i.e. V_{max})	
Steady-state voltage change values at the PCC (i.e. $V_{steadystate}$)	
$V_{max} \leq V_{max\text{-}planning\ level}$	
$V_{steadystate} \leq V_{steadystate\text{-}planning\ level}$	

Stage 2 Flicker Analysis review - Checklist	✓
Incremental short-term flicker severity values at the PCC (i.e. $P_{st\text{-}inc}$)	
$P_{st\text{-}inc} \leq 0.5$	

Stage 3 Flicker Analysis Review - Checklist	✓
Incremental short-term flicker severity values at the PCC (i.e. $P_{st\text{-}inc}$)	
Incremental long-term flicker severity values at the PCC (i.e. $P_{lt\text{-}inc}$)	
Combined short-term flicker severity values at the PCC (i.e. $P_{st\text{-}combined}$)	
Combined long-term flicker severity value at the PCC (i.e. $P_{lt\text{-}combined}$)	
$P_{st\text{-}combined} \leq P_{st\text{-}planning\ level}$	
$P_{lt\text{-}combined} \leq P_{lt\text{-}planning\ level}$	

D.2 EREC G5 Stage 3 Compliance Report Review Checklist

Checklist	✓
Incremental harmonic voltage change, $V_{h\ Inc}$	
Harmonic voltage change limit, $V_{h\ Limit\ Resonant}$	
Total harmonic level, $V_{h\ Total}$	
Incremental harmonic voltage change, $V_{h\ Inc}$ ≤ Incremental Harmonic Voltage Limit, $V_{h\ Limit\ Inc}$	
Total harmonic level, $V_{h\ Total}$ ≤ Total Harmonic Voltage Limits, $V_{h\ Limit\ Total}$.	
Equivalent Thévenin harmonic impedance of the proposed installation	
Equivalent Thévenin voltage or Norton current source harmonic emission model of the proposed installation	

D.3 EREC P29 Report Review Checklist

Stage 2 Voltage Unbalance Analysis review - Checklist	✓
Incremental voltage unbalance severity values at the PCC (i.e. $V_{u\text{-}inc}$)	
$V_{u\text{-}inc} \leq V_{u\ Stage\ 2\ limit}$ where $V_{u\ Stage\ 2\ limit} = 0.5\%$	

Stage 3 Voltage Unbalance Analysis Review - Checklist	✓
Incremental voltage unbalance values at the PCC (i.e. $V_{u\text{-}inc}$)	
Combined voltage unbalance values at the PCC (i.e. $V_{u\text{-}combined}$)	
$V_{u\text{-}combined} \leq V_{u\text{-}planning\ level}$	

APPENDIX E - WPD INTERPRETATION OF EREC P28 STEP VOLTAGE CHANGE LIMITS

Reserved for future use.

APPENDIX F - WPD INTERPRETATION OF EREC P28 RAPID VOLTAGE CHANGE LIMITS

Reserved for future use.

APPENDIX G - WPD INTERPRETATION OF EREC P28 FLICKER LIMITS

Reserved for future use.

APPENDIX H - WPD INTERPRETATION OF EREC G5 HARMONIC VOLTAGE LIMITS

Reserved for future use.

APPENDIX I - WPD INTERPRETATION OF EREC P29 VOLTAGE UNBALANCE LIMITS

Reserved for future use.

APPENDIX J – BACKGROUND – LEGAL AND REGULATORY FRAMEWORK

J.1 Key Documents

Connection design requirements for potentially disturbing Relevant Customer Installations arise from the following key documents:

- ESQC Regulations 2002
- Distribution Code
- ENA Engineering Recommendations EREC P28, G5 and P29
- Connection Agreement
- National Terms of Connection.

J.2 ESQC Regulations 2002

Regulation 26 of the ESQC Regulations 2002 (as amended) empowers WPD to challenge Customers in circumstances where their existing installations are causing or their proposed installation/ modification would cause unacceptable electrical interference on the network. This regulation requires that, in the first instance, WPD issue instructions to Customers to carry out remedial works within a reasonable period. If after the expiry of the specified period the interference has not been rectified, WPD may disconnect the supply to the installation or refuse to connect the supply until the problem is rectified.

J.3 Distribution Code

The Distribution Code is a code arising from the Distribution Licence. The technical and design criteria applied in the planning and development of the DNO Distribution System are listed in Annex 1 of the Distribution Code. Annex 1 documents are subject to approval by the regulatory authority.

J.4 Engineering Recommendations

Engineering Recommendations are published under the authority of the ENA Engineering Policy and Standards Manager and are approved by the GB Distribution Code Review Panel. Engineering Recommendations which are listed in Annex 1 of the Distribution Code form technical and design criteria of the Distribution Code. Annex 1 Engineering Recommendations which cover connection design for Relevant Customer Installations with potential to adversely affect Voltage Quality are as follows:

- EREC P28 – Voltage Fluctuations and Flicker
- EREC G5 – Voltage Distortion
- EREC P29 – Voltage Unbalance.

J.5 Connection Agreements

In the context of this document, a Connection Agreement is an agreement between WPD and a Customer setting out the terms and conditions under which the Customer's installation may be connected (and remain connected) to WPD's Distribution System.

The Connection Agreement will either be provided on WPD's behalf by the Customer's chosen Supplier as part of their application for a supply of electricity or in some cases for larger connections, or where non-standard conditions exist, WPD will provide a site-specific Connection Agreement, which replaces any Connection Agreement put in place via the Supplier, as part of the connection process. This particular Connection Agreement will only take effect upon completion of the connection and will set out, in more detail, the rights and obligations to one another. Additionally, it may contain the technical detail of the installation being connected to the Distribution System and will require the Customer to comply with the provisions of the Distribution Code.

Site-specific Connection Agreements refer to the National Terms of Connection and, in doing so to the Distribution Code. They also refer specifically to EREC P28, EREC G5 and EREC P29.

J.6 National Terms of Connection

National Terms of Connection are used to define the terms under which Customers will be, and will remain, connected to a DNO Distribution System in the absence of a site-specific Connection Agreement. The Supplier is appointed as the agent of the DNO to obtain a Connection Agreement with the Customer under the National Terms of Connection.

In cases where a site-specific Connection Agreement applies, the National Terms of Connection form part of that agreement.

The National Terms of Connection includes clauses on interference with the Distribution System, de-energisation and on modification.

APPENDIX K

SUPERSEDED DOCUMENTATION

This document supersedes ST: SD6F/1 dated December 2012 which has now been withdrawn.

APPENDIX L

ANCILLARY DOCUMENTATION

NUMBER	TITLE
POL:SD2	132kV Network Design
POL:SD3	66kV and 33kV Network Design
ST:SD5G Part 1	Connection of Low Carbon Technology (Electric Vehicle Charge Points and Heat Pumps) with a Capacity < 32A per phase
ST:SD5G Part 2	Relating to the Connection of Low Carbon Technology (Electric Vehicle Charge Points and Heat Pumps) with a Capacity > 32A per phase
ST:SD6J	Determination process for the connection of potentially disturbing electrical equipment

APPENDIX M

KEYWORDS

Design; Distortion; Disturbing; Flicker; Fluctuating; Fluctuation; Step; Unbalance.

APPENDIX N

DOCUMENT LAST REVIEWED

08/11/2012.

APPENDIX O

RECORD OF COMMENT DURING CONSULTATION

No comments received.