nationalgrid

Stage 02: Workgroup Report

Grid Code

What stage is this document at?

01	Modification Report
02	**Workgroup Report**
03	Code Admin Consultation
04	Draft Final Modification Report
05	Report to the Authority

GC0118:

Mod Title: Modification to the Grid Code to accommodate the recent Distribution Code modification to Engineering Recommendation P28 –*Voltage fluctuations and the connection of disturbing equipment to transmission systems and distribution networks in the United Kingdom.*

Purpose of Modification: The purpose of this modification is to ensure the Grid Code implements the proposed changes as set out in the revised Engineering Recommendation P28 Issue 2 (2018) (subsequently referred to as EREC P28 Issue 2).

This document contains the discussion of the Workgroup which formed in September 2018 to develop and assess the proposal, the voting of the Workgroup held on 31 October 2018 and the Workgroup's final conclusions.

High Impact: None

Medium Impact: It applies to any new customer connection that can impose voltage disturbances on a system either demand or generation.

New developers of transmission connected generation installations, and existing users that make changes to existing installations with significant number of transformers that cause rapid voltage changes (RVCs) when energised, who are required to design their installations in accordance with the requirements and planning levels for RVCs in EREC P28 Issue 2.

Any User connected to or seeking connection with the National Electricity Transmission System

Low Impact: The modifications are intended not to unduly impact on or cause interference to existing Users of public electricity systems/networks.

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Any Questions?

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On behalf of the Distribution Network Licensees

Timetable

A timetable was approved by the Grid Code Panel once the governance route is decided at the Panel meeting on **18 July 2018.**

Workgroup Meeting 1	5 September 2018
Workgroup Report presented to Panel	22 November 2018
Code Administration Consultation Report issued to the Industry	03 December 2018
Draft Final Modification Report presented to Panel	30 January 2018
Modification Panel decision	30 January 2018
Final Modification Report issued the Authority	11 February 2018
Decision implemented in Grid Code	18 March 2018

About this document

This document is the Workgroup Report that contains the discussion of the Workgroup which formed in September 2018 to develop and assess the proposal, the voting of the Workgroup held on 31 October 2018.

GC0118 was proposed by Energy Networks Association and was submitted to the Grid Code Review Panel for its consideration on 18 July 2018. The Panel decided to send the Proposal to a Workgroup to be developed and assessed against the applicable Grid Code Objectives.

Workgroup Conclusions

At the final Workgroup meeting, Workgroup members voted on the Original proposal. The Workgroup unanimously voted that the Original better facilitates the Grid Code Objectives.

1.Summary

Defect

Engineering Recommendation (EREC) P28 Issue 1 was first published in 1989 to provide recommended planning limits for voltage fluctuations for connection of equipment to public electricity supply systems in the UK. EREC P28 Issue 1 was primarily concerned with assessment of voltage fluctuations and associated flicker produced by traditional domestic, commercial and industrial loads.

Since EREC P28 Issue 1 was first published, the factors affecting development of transmission systems and distribution networks, and equipment connected to them have changed significantly. There has been a shift towards connection of distributed/embedded generation equipment powered by renewable energies and other low carbon technology equipment. These types of modern equipment are capable of causing voltage fluctuations.

Significant developments in Electromagnetic Compatibility (EMC) requirements have also taken place, which are captured in the International Electro-technical Commission (IEC) 61000 series of Standards and technical reports. United Kingdom implementation of these Standards is captured in the various parts of BS EN 61000.

Engineering Recommendation P28 is referenced in both the Grid Code and Distribution Code. A joint Grid Code and Distribution Code Working Group was established to oversee the revision of Engineering Recommendation P28 Issue 1 and associated modification to requirements for voltage fluctuation. Following the transition to Open Governance of the Grid Code, the Working Group became a Distribution Code Review Panel Working Group, although NGET continued to remain a member of the Working Group. The working group has produced a revised version of Engineering Recommendation P28 i.e. EREC P28 Issue 2 which was submitted to the Authority for approval on 17 May 2018. The DCRP/MP/18/01 FMR was subsequently sent back as the Authority considered that there had not been sufficient industry consideration of the impact of DCRP/MP/18/01 on other industry codes i.e Grid Code. Specifically, the Authority did not consider that the impact on the Grid Code had been properly considered. The Authority noted that Engineering Recommendation P28 is referenced multiple times within the Grid Code. The changes proposed under DCRP/MP/18/01, which have a direct impact on the requirements for parties connecting to the electricity networks, could result in consequential changes to Grid Code requirements that have not been assessed and which may be relevant to inform their decision. The Authority expect distribution licensees and the Grid Code Review Panel ('GCRP') to work together and submit any proposed Distribution and Grid Code changes to them as a package.

What

There are a ten specific references relating to Engineering Recommendation P28 in the Grid Code that need to be considered and revised and they are as follows:

- GLOSSARY AND DEFINITIONS
  - Flicker Severity
- PLANNING CODE
  - PC.A.4.7 General Demand Data - PC.A.4.7.1 (f)
  - Appendix C Technical Design Criteria Part 1 PC.C.3 SHETLs Technical Design Criteria (Item4)
  - Appendix E – Offshore Transmission System and OTSDUW Plant and Apparatus Technical Design Criteria – PC.E.2 (Table)
- CONNECTION CONDITIONS
  - CC.6 Technical, Design and Operational Criteria
Voltage Fluctuations CC6.1.7
- EUROPEAN CONNECTION CONDITIONS
  - ECC.6 Technical, Design and Operational Criteria
  - Voltage Fluctuations ECC.6.1.7
- OPERATING CODES
  - OC5.5.4 Test And Monitoring Assessment (Test Criteria)
- DATA REGISTRATION CODE
  - Schedule 7 - Load Characteristics at Grid Supply Points

All of the proposed changes bar revision to CC 6.1.7 and ECC 6.1.7 are editorial and relate to modifying the Grid Code so that the Code references EREC P28 Issue 2. Modifications to CC 6.1.7 and ECC 6.1.7 are is required to align the technical requirementsbetween in the Grid Code and those set out in the new EREC P28 Issue 2.

Why

The changes are required to align the Grid Code with the new technical requirements set out in P28 and those new requirements are compared to the equivalent ones in the Grid Code and the Grid Code should considered whether they should be adopted.

How

The solution (draft legal text) proposed is documented in Appendices A.

2.Governance

Justification for normal governance procedures

In its decision letter Ofgem (see Appendix B) considered that there was not sufficient industry consideration of the impact of DCRP/PC/18/01/FMR on other industry codes. Specifically, they did not consider that the impact on the Grid Code had been properly considered. Ofgem noted that Engineering Recommendation P28 is referenced multiple times within the Grid Code. The changes proposed under DCRP/PC/18/01/FMR, which have a direct impact on the requirements for parties connecting to the distribution networks, could result in consequential changes to Grid Code requirements that have not been assessed and which may be relevant to inform their decision.

Ofgem therefore expect distribution licensees and the Grid Code Review Panel (‘GCRP’) to work together and submit any proposed Distribution and Grid Code changes as a package, which should include co-ordinated implementation timetables. Ofgem expects the GCRP to discuss the issues set out in their decision letter and DCRP/MP/18/01 at the next GCRP meeting.

It is therefore recommended that the requirements of CC.6.1.7 and ECC 6.1.7 of the Grid Code are aligned with those in EREC P28 Issue 2 and the references in the Grid Code to Engineering Recommendation P28 is replaced with reference to Engineering Recommendation P28 Issue 2 (see Appendix C).

A Distribution Code public consultation which included Grid Code stakeholders was held from the 8th January 2018 to 31st January 2018. Full details of the response are contained in the aforementioned Report to Authority DCRP/PC/18/01/FMR.

Requested Next Steps

This modification should:

- be subject to normal governance procedures.

It is expected that the workgroup should hold no more than one meeting to consider and agree to the recommendations contained in this modification proposal.

The workgroup should then prepare a short report to the Panel. With Panel agreement a final Report to Authority should be submitted in conjunction with the DRCP Report recommending that the modification proposal should be approved.

3.Why Change?

The need for the change and the modification proposal is to align the Grid Code with the new Engineering Recommendation P28. Those changes are set out in section 1 of this report.

If the change is not addressed in the Grid Code then the Authority will not be able to approve the modification to Engineering Recommendation P28 Issue 2. Please note the recent Authority decision letter on DCRP/PC/18/01/RtA (see appendix D).

The following parties will be impacted with regards to complying with the new Engineering Recommendation P28 Issue 2:

- Transmission System Operators will need to comply with CC6.1.7 and ECC 6.1.7
- Generators and demand customers connected to the transmission System
- New developers of transmission connected generation installations, demand customers, and existing users that make changes to existing installations with significant number of transformers;
- Any User connected to or seeking connection with the National Electricity Transmission System:
- Users that propose to connect disturbing equipment/fluctuating installations to the system, which could result in flicker.

For additional background and context please also refer to the Distribution Code Final Modification Report DCRP/PC/18/01/FMR (see appendix B) which sets out the recommendation that modifications should be made to the Distribution Code and Engineering Recommendation P28, in relation to voltage fluctuations resulting from the connection of disturbing equipment to transmission systems and distribution networks in the United Kingdom.

ER P28 Issue 2 now:
a) Introduces requirements and planning levels for Rapid Voltage Changes (RVCs).
b) Improves definition and clarity of ‘worst case operating conditions’ to be used in the assessment of voltage fluctuations.
c) Includes an intermediate planning level and associated flicker severity limits for supply systems to improve co-ordination of flicker severity from higher to lower voltage supply systems.
d) Improves the definition of voltage step change.
e) Clarifies information requirements for assessment and responsibilities for provision of information.
f) Includes the application of transfer coefficients for determining voltage fluctuation contributions from different nodes.
g) Assesses voltage fluctuations caused by renewable energy and low carbon technologies.

4.Code Specific Matters

Technical Skillsets

A skill set and understanding in Power Quality standards and the actual application of Engineering Recommendation P28 would be helpful.

Reference Documents

- Grid Code
- Distribution Code
- Security and Quality of Supply Standard
- Engineering Recommendation P28 Issue 2 (2018)

5.Solution

Please refer to appendices A

6.Impacts and Other Considerations

The Distribution Code and the Grid Code are both impacted by the proposed modification to Engineering Recommendation P28 Issue 2 but this is mainly editorial, where the Codes signpost users to Engineering Recommendation P28 Issue 2.

The most significant impact is to the requirements for Rapid Voltage Changes (RVC)in CC.6.1.7 and ECC 6.1.7 of the Grid Code, in particular Tables CC.6.1.7 and ECC 6.1.7. The limits for RVCs proposed in EREC P28 Issue 2 take into account those in the GC0076 modification to the Grid Code. The key differences between the requirements in EREC P28 Issue 2 and those in the Grid Code are as follows noting that the intention is to align the requirements in the Grid Code with those in EREC P28 Issue 2, so as to provide greater flexibility for customer connections and to be less onerous for customers to comply with and for NGET in terms of operation of the transmission system.

- Allowable voltage changes are expressed as a percentage of nominal voltage (V_n) in P28 Issue 2 as opposed to a percentage of the initial voltage (V_o) in the Grid Code. The intention being to align with the approach taken in National and International Standards.
- For increases in voltage:
    - EREC P28 Issue 2 proposes a limit on the maximum voltage change between two steady state conditions of $\Delta V_{max} \leq 6\%$ for a maximum duration of 0.8 s from the initiation of a voltage change.
    - The Grid Code has a limit of $\Delta V_{max} \leq 5\%$ for a maximum duration of 0.5 s.
- For decreases in voltage:
    - EREC P28 Issue 2 proposes a time limit of 100 ms from initiation of a voltage change during which the maximum voltage change permitted
(-12% for ‘very infrequent events’ and -10% for ‘infrequent events’) can persist.

- The Grid Code has a time limit of 80 ms from initiation of a voltage change during which the maximum permitted voltage change is -12%.

- For increases and decreases in voltage, EREC P28 Issue 2 permits a greater maximum number of occurrences for Category 3 ‘very infrequent’ events:
    - EREC P28 Issue 2 proposes to permit up to a maximum of 4 RVCs in one day (irrespective of type of operational event causing the RVC) not more frequent than once every 3 months.
    - The Grid Code permits up to a maximum of 4 RVCs in one day (for commissioning, maintenance and fault restoration) typically not planned more than once per year on average over the lifetime of the connection.
- EREC P28 Issue 2 introduces an intermediate category of RVC (Category 2) for ‘infrequent events’, where up to a maximum of 4 RVCs in one day are permitted not more frequent than 4 times per month providing the $\Delta V_{max} \leq -10\%$ for ≤ 100 ms then reducing to ≤ 6% for up to 2 s after initiation of the event. There is no equivalent existing Grid Code requirement.

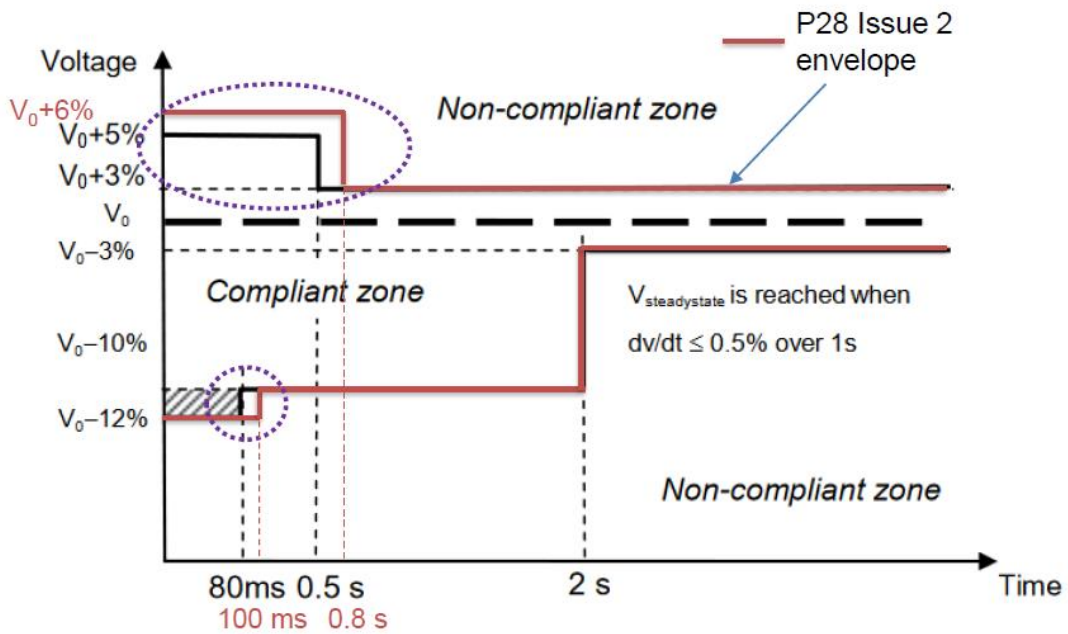


Figure CC.6.1.7 -
Time and magnitude limits for a category 3 Rapid Voltage Change

The difference between the voltage envelope for Rapid Voltage Changes in Figure CC.6.1.7 of the Grid Code and Table 4 of EREC P28/2 Issue 2 for Very Infrequent RVCs are shown in the above figure. The P28 Working Group has proposed limits for RVC in EREC P28 Issue 2 that:

- generally align with those in Figure CC.6.1.7 for reductions in voltage.
- are absolute and compatible with EREC G59 and grid connected protection as well as TGN 288 for overvoltage.
- are compatible with immunity levels for customer equipment.
- should not result in unacceptable disturbance provided:-
    - events are sufficiently spaced apart.
    - multiple RVCs are completed within a small time window.

- there is no damage to or tripping of customer equipment.

The impacts of the proposals for RVC limits in EREC P28 Issue 2 can be summarised as follows:

- There could be potentially a greater number of RVCs at any given Point Common Coupling over a calendar year. The P28 WG believe the potentially greater number of RVCs permitted at a given PCC will not cause unacceptable disturbance to other customers.
- The changes to the RVC limits permit a greater number of transformer to be energised at the same time providing greater flexibility for design of user connections and for operation of the transmission system.
- There is no material impact on ΔV_{max} for decreases in voltage.

The proposed RVC limits in EREC P28 Issue 2 (and associated differences with the requirements in the Grid Code) reflect the:

- further work carried out by the Working Group and the experience of NGET in applying RVC limits since the GC0076 modification was implemented in the Grid Code. NGET's representative on the P28 Working Group oversaw the GC0076 modification the Grid Code and chaired the P28 RVC sub-group.
- limits for RVCs in Category 2 and Category 3 of Table 4 taking into account differences in the perceptibility of RVC compared with flicker associated with continuously fluctuating loads.

Please also note that the Security and Quality of Supply Standard (SQSS) Figure 6.1 references ER P28 (Issue 1) Figure 4. Figure 4 in ER P28 Issue 1 has been replaced by a slightly different Figure B.1.2 in EREC P28 Issue 2. This will be subject to a separate modification proposal submitted to the SQSS Panel.

There are no practices affected and no systems impacted.

This modification does not impact on any Significant Code Review (SCR) or any other significant industry change project.

There are no consumer impacts as a result of this modification proposal.

7.Workgroup Discussions

The Workgroup convened once to discuss the issue, detail the scope of the proposed defect, devise potential solutions and assess the proposal in terms of the applicable Grid Code Objectives.

The Proposer presented the defect that they had identified in the GC0118 Proposal and highlighted that the defect related to updates to P28 from the proposal to update P28 there was a requirement to ensure harmonisation across the Distribution Code and the Grid Code.

The discussions and views of the Workgroup are outlined below.

The Proposer explained that the requirements contained in P28 (issue 2) have been relaxed but are still sufficiently robust. The Grid Code Workgroup believes that the changes made will have no impact on existing or new users of the system. P28 (issue 1) had some ambiguity in terms of interpretation. P28 (issue 2) provides clarity around the definitions used and the document provides detail about what is required and when.

The Workgroup discussed the practical implications of the proposed modification. The NGET representative provided an explanation of the changes and how these will work.

Reconnection Following a System Fault

The Workgroup discussed the number of switching events allowed on the system and fault clearing. The Grid Code specifies four event occurrences can occur per day. P28 Issue 2 is more flexible as it applies to each customer rather than a set number of maximum occurrences.

A Workgroup member explained that they had concerns related to a situation where a system fault or other unplanned event, out with their control trips their equipment off and whether they can reconnect to the system again or could they be left waiting for up to 3 months. Members of the Grid Code Workgroup indicated that this equipment could be reconnected as this was the result of a fault and was excluded from P28 Issue 2 in section 5.3.3 Emission limits which has the following text excluding fault conditions:-

"The requirement to prevent co-incident RVCs exceeding the limits in Table 4 at the PCC does not apply to: a) fault clearance operations; or b) immediate operations in response to fault conditions."

The Workgroup member queried how this exclusion allowed reconnection following a fault. The Grid Code workgroup members indicated that they considered post fault system restoration was included within the exclusion. The key issues relates to the definitions of 'fault clearance' and "immediate operations in response to fault conditions". Further discussion agreed that "fault clearance" was the opening of circuit breakers to disconnect a fault from the system and did not cover post fault system restoration. Similarly, it was agreed that "immediate operations in response to fault conditions" were actions to deal with an ongoing system issue and did not cover post fault system restoration.

The NGET representative stated that there is an assumption that tripping the system would not occur four times a day, every day for a single customer.

Retrospective Application

A Workgroup member queried whether P28 (issue 2) would be retrospective. Another Workgroup member stated that if you complied with P28 (issue 1) you would automatically comply with P28 (issue 2) as this was less onerous.

Inclusion of P28 Values or Only References in Grid Code

The Workgroup discussed whether the values contained within the P28 tables should be copied and pasted into the Grid Code or whether the Grid Code should simply reference the P28 document. The key issue relates to whom P28 applies to and whom Grid Code sections CC.6.1.7 and ECC.6.1.7 applies to, specifically P28 excludes licensed transmission and distribution operators whereas CC.6.1.7 & ECC.6.1.7 does apply to these parties. The Workgroup agreed that in order to retain control over changes to the Grid Code and choose the least invasive option, the best solution was for the relevant parts of P28 to be replicated in the Grid Code. Therefore, there would not be an automatic update of Grid Code requirements should EREC P28 be updated in the future and any future changes made to P28 would need to be considered separately.

Implementation & Terms of Reference

In terms of an implementation date, a Workgroup member stated that the date needs to have a suitable lead in time to allow the necessary changes to be made.

The Workgroup agreed the Terms of Reference had been met for this modification.

8.Workgroup Vote

The Workgroup believe that the Terms of Reference have been fulfilled and GC0118 has been fully considered.

The Workgroup met on 31 October 2018 and voted on whether the Original would better facilitate the Applicable Grid Code Objectives than the baseline and what option was best overall.

The Workgroup agreed unanimously that the Original was better than the baseline. The voting record is detailed below.

Vote 1 – *Does the original facilitate the objectives better than the Baseline?*

Vote recording guidelines:
"Y" = Yes
"N" = No
"-" = Neutral

Objective:	i	ii	iii	iv	v	Overall
David Spillett:						
	Y	Y	Y	-	-	Y
Voting Statement: *The original aligns the Grid Code with the requirements set out in Engineering Recommendation P28 Issue 2.*						
Alastair Frew						
	Y	-	Y	-	-	Y
Voting Statement: *This allows the P28 implementation and has been improved from the draft version of P28 issue 2 by the addition of a third point to sections CC.6.1.7c and ECC.6.1.7c (which is not in P28 section 5.3.3) which makes it clear to parties can re-energise after system faults which are out with their control without having restrictions.*						

Isaac Gutierrez						
	Y	-	Y	-	-	Y
Voting Statement: *The original proposed modification by NGESO is acceptable and it is in line with the requirements of Engineering recommendation P28 v 2*						
Mark Horrocks						
	-	Y	Y	-	Y	Y
Voting Statement: *I'm happy that the new codes accurately, is fair for both operator and user*						
Steve Mould						
	Y	Y	-	Y	Y	Y
Voting Statement: *P28 v2 provides more clarity to users of the document. It facilitates more efficient access to the network whilst continuing to ensure that the network remains within acceptable limits. Alignment of the Grid Code with P28 v2 ensures the majority of the five objectives which the work group were set are met.*						
Greg Heavens						
	-	Y	Y	Y	-	Y
Voting Statement: *Aligns the grid code with the update of P28 issue 2.*						

Vote 2 – ***Which option is the best?***

Workgroup Member	BEST Option?
David Spillett	**Original**
Alastair Frew	**Original**
Isaac Gutierrez	**Original**
Mark Horrocks	**Original**
Steve Mould	**Original**
Greg Heavens	**Original**

9. GC0118 Relevant Objectives

Impact of the modification on the Relevant Objectives:	
Relevant Objective	**Identified impact**
To permit the development, maintenance and operation of an efficient, coordinated and economical system for the transmission of electricity	**Positive**
To facilitate competition in the generation and supply of electricity (and without limiting the foregoing, to facilitate the national electricity transmission system being made available to persons authorised to supply or generate electricity on terms which neither prevent nor restrict competition in the supply or generation of electricity)	**Positive**

Subject to sub-paragraphs (i) and (ii), to promote the security and efficiency of the electricity generation, transmission and distribution systems in the national electricity transmission system operator area taken as a whole	**Positive**
To efficiently discharge the obligations imposed upon the licensee by this license and to comply with the Electricity Regulation and any relevant legally binding decisions of the European Commission and/or the Agency; and	**Neutral**
To promote efficiency in the implementation and administration of the Grid Code arrangements	**Neutral**

10.Implementation

Proposers initial view:

This modification proposal should be implemented no later than 30 January 2019 or as soon as reasonably practicable to avoid any further delay of the approval of the Distribution Code modification currently awaiting approval of the Authority. There should be no costs attributed to any stakeholder in delivering and implementing this modification. This needs to be in agreement with the DCRP and possibly the SQSS Panel.

11.Legal Text

Legal text is included with this modification proposal. Please refer to Appendix A

12.Recommendations

The GCRP Panel have:

Agreed that this modification proposal should be subject to normal governance procedures and

Agreed the Terms of Reference for the Grid Code Workgroup

13.Workgroup Terms of Reference

The Terms of Reference for this Workgroup can be accessed here: https://www.nationalgrideso.com/codes/grid-code/modifications/gc0118-modification-grid-code-accommodate-recent-distribution-code

Appendices

Appendix A Legal Text
Appendix B - DCRP/18/01/FMR Decision Letter
Appendix C - DCRP_FMR_EREC P28 Issue 2_v0.4.1_Issued
Appendix D – DCRP/PC/18/01/RtA
Appendix E – Attendance Register

Appendix A – Legal Text

Voltage Fluctuations

CC.6.1.7

CC.6.17 Voltage changes at a **Point of Common Coupling** on the **Onshore Transmission System** shall not exceed:

(a) The limits specified in Table CC.6.1.7(a) with the stated frequency of occurrence, where:

(i)

$$\%\Delta V_{steadystate} = \left| 100 \times \frac{\Delta V_{steadystate}}{Vn} \right|$$

and

$$\%\Delta V_{max} = 100 \times \frac{\Delta V_{max}}{V_n} ;$$

(ii) V_n is the nominal system voltage;

(iii) $V_{steadystate}$ is the voltage at the end of a period of 1 s during which the rate of change of system voltage over time is ≤ 0.5%;

(iv) $\Delta V_{steadystate}$ is the difference in voltage between the initial steady state voltage prior to the RVC (V_0) and the final steady state voltage after the RVC ($V_{0'}$);

(v) ΔV_{max} is the absolute change in the system voltage relative to the initial steady state system voltage (V_0);

(vi) All voltages are the r.m.s. of the voltage measured over one cycle refreshed every half a cycle as per BS EN 61000-4-30; and

(vii) The applications in the 'Example Applicability' column are examples only and are not definitive.

Category	Title	Maximum number of occurrence	Limits $\%\Delta V_{max}$ & $\%\Delta V_{steadystate}$	Example Applicability
1	Frequent events	(see NOTE 1)	As per Figure CC.6.1.7 (1)	Any single or repetitive RVC that falls inside Figure CC.6.1.7 (1)
2	Infrequent events	4 events in 1 calendar month (see NOTE 2)	As per Figure CC.6.1.7 (2) $\lvert \%\Delta V_{steadystate} \rvert \leq 3\%$ For decrease in voltage: $\lvert \%\Delta V_{max} \rvert \leq 10\%$ (see NOTE 3) For increase in voltage: $\lvert \%\Delta V_{max} \rvert \leq 6\%$ (see NOTE 4)	Infrequent motor starting, transformer energisation, re-energisation (see NOTE 7)
3	Very infrequent events	1 event in 3 calendar months (see NOTE 2)	As per Figure CC.6.1.7 (3) $\lvert \%\Delta V_{steadystate} \rvert \leq 3\%$ For decrease in voltage: $\lvert \%\Delta V_{max} \rvert \leq 12\%$ (see NOTE 5) For increase in voltage: $\lvert \%\Delta V_{max} \rvert \leq 6\%$ (see NOTE 6)	Commissioning, maintenance & post fault switching (see NOTE 7)

NOTE 1: ±6% is permissible for 100 ms reduced to ±3% thereafter as per Figure CC.6.1.7 (1) . If the profile of repetitive voltage change(s) falls within the envelope given in Figure CC.6.1.7 (1) , the assessment of such voltage change(s) shall be undertaken according to the recommendations for assessment of flicker and shall conform to the planning levels provided for flicker. If any part of the voltage change(s) falls outside the envelope given in Figure CC.6.1.7(1), the assessment of such voltage changes, repetitive or not, shall be done according to the guidance and limits for RVCs.

NOTE 2: No more than 1 event is permitted per day, consisting of up to 4 RVCs, each separated by at least 10 minutes with all switching completed within a two-hour window.

NOTE 3: −10% is permissible for 100 ms reduced to -6% until 2 s then reduced to -3% thereafter as per Figure CC.6.1.7 (1).

NOTE 4: +6% is permissible for 0.8 s from the instant the event begins then reduced to +3% thereafter as per Figure CC.6.1.7 (2).

NOTE 5: −12% is permissible for 100 ms reduced to −10% until 2 s then reduced to -3% thereafter as per Figure CC.6.1.7 (3).

NOTE 6: +6% is permissible for 0.8 s from the instant the event begins then reduced to +3% thereafter as per Figure CC.6.1.7 (3).

NOTE 7: These are examples only. The Limits of another category providing the frequency of occurrence is not expected to exceed the ‘Maximum number of occurrence’ for the chosen category. Where the measured emission level exceeds the expected emission level, paragraph 4 of Clause 6.1.4 applies.

Table CC.6.1.7 (a) – Planning levels for RVC

(b) The voltage change limit is the absolute maximum allowed of either the phase-to-earth voltage change or the phase-to-phase voltage change, whichever is the highest. The limits do not apply to single phasor equivalent voltages, e.g. positive phase sequence (PPS) voltages. For high impedance earthed systems, the maximum phase-to-phase, i.e. line voltage, should be used for assessment.

(c) The RVCs in Category 2 and 3 should not exceed the limits depicted in the time dependent characteristic shown in Figure CC.6.1.7 (2) and Figure CC.6.1.7 (3) respectively. These limits do not apply to: 1) fault clearance operations; or 2) immediate operations in response to fault conditions; or 3) operations relating to post fault system restoration~~.~~ (for the avoidance of doubt this third exception pertains to a fault that is external to the users plant and apparatus).

(d) Any RVCs permitted in Category 2 and Category 3 should be at least 10 minutes apart.

(e) The value of $V_{steadystate}$ should be established immediately prior to the start of a RVC. Following a RVC, the voltage should remain within the relevant envelope, as shown in Figures CC.6.1.7 (1), CC.6.1.7 (2), CC.6.1.7 (3), until a $V_{steadystate}$ condition has been satisfied.

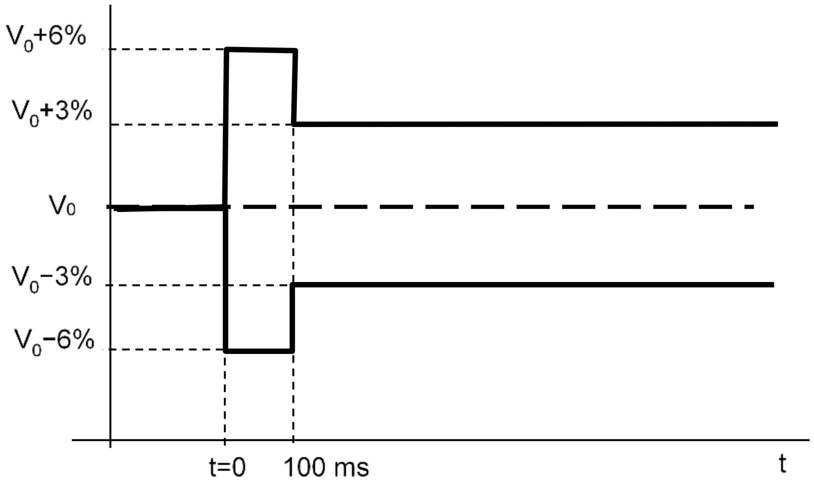


Figure CC.6.1.7 (1) — Voltage characteristic for frequent events

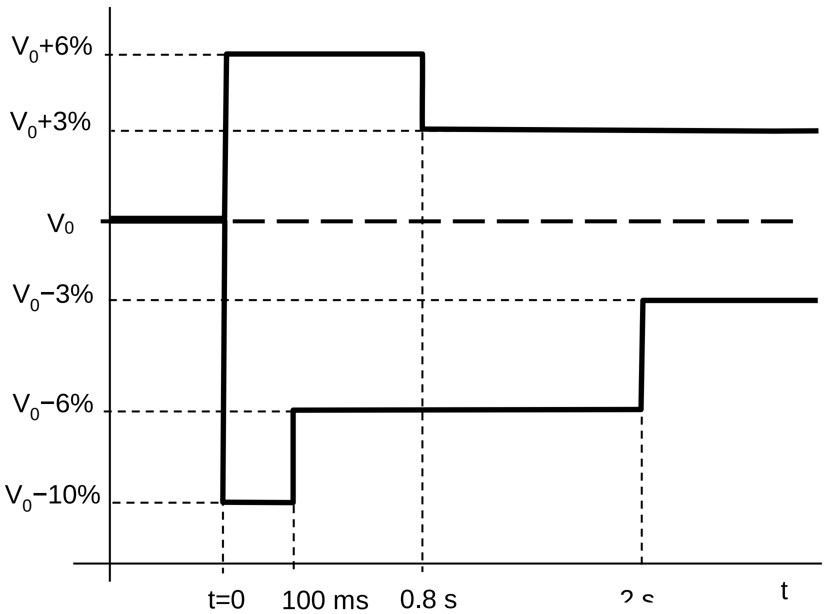


Figure CC.6.1.7 (2) — Voltage characteristic for infrequent events

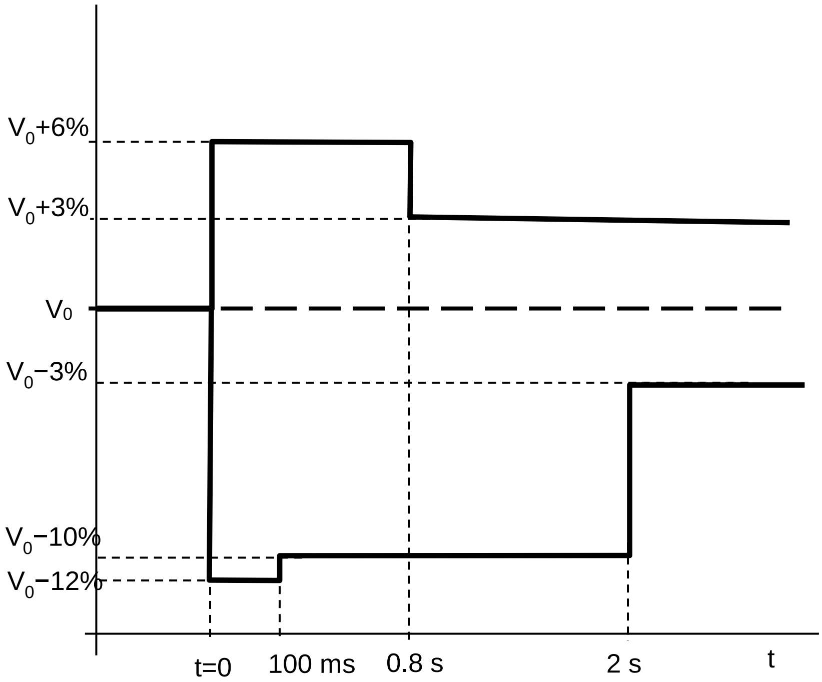


Figure CC.6.1.7 (3) — Voltage characteristic for very infrequent events

(f) The voltage change between two steady state voltage conditions should not exceed 3%. (The limit is based on 3% of the nominal voltage of the system (V_n) as measured at the PCC. The step voltage change as measured at the customer's supply terminals or equipment terminals could be greater. For example: The step voltage change limit stated in BS EN 61000-3-3 and BS EN 61000-3-11 is 3.3% when measured at the equipment terminals.)

(g) The limits apply to voltage changes measured at the **Point of Common Coupling**.

(h) Category 3 events that are planned should be notified to the Company in advance.

(i) For connections with a **Completion Date** after 1st September 2015 and where voltage changes would constitute a risk to the **National Electricity Transmission System** or, in **The Company's** view, the **System** of any **GB Code User**, **Bilateral Agreements** may include provision for **The Company** to reasonably limit the number of voltage changes in Category 2 or 3 to a lower number than specified in Table CC.6.1.7(a) to ensure that the total number of voltage changes at the **Point of Common Coupling** across multiple **Users** remains within the limits of Table CC.6.1.7(a).

(j) The planning levels applicable to Flicker Severity (Short Term) (Pst) and Flicker Severity (Long Term) (Plt) are set out in Table CC.6.1.7(b).

Supply system Nominal voltage	Planning level	
	Flicker Severity Short Term (Pst)	Flicker Severity Long Term (Plt)
3.3 kV, 6.6 kV, 11 kV, 20 kV, 33 kV	0.9	0.7
66 kV, 110 kV, 132 kV, 150 kV, 200 kV, 220 kV, 275 kV, 400 kV	0.8	0.6
NOTE 1: The magnitude of P_{st} is linear with respect to the magnitude of the voltage changes giving rise to it. NOTE 2: Extreme caution is advised in allowing any excursions of P_{st} and P_{lt} above the planning level.		

Table CC.6.7.1(b) — Planning levels for flicker

The values and figures referred to in this paragraph CC.6.1.7 are derived from Engineering Recommendation P28 Issue 2.

~~Voltage changes at a **Point of Common Coupling** on the **Onshore Transmission System** shall not exceed:~~

~~The limits specified in Table CC.6.1.7 with the stated frequency of occurrence, where:~~

~~(i)~~

$$\cancel{\%\Delta V_{steadystate} = \left| 100 \times \frac{\Delta V_{steadystate}}{V_0} \right|}$$ ~~and~~

$$\cancel{\%\Delta V_{max} = 100 \times \frac{\Delta V_{max}}{V_0}};$$

~~(ii) V_0 is the initial steady state system voltage;~~

~~(iii) $V_{steadystate}$ is the system voltage reached when the rate of change of system voltage over time is less than or equal to 0.5% over 1 second and $\Delta V_{steadystate}$ is the absolute value of the difference between $V_{steadystate}$ and V_0;~~

~~(iv) ΔV_{max} is the absolute value of the maximum change in the system voltage relative to the initial steady state system voltage of V_0;~~

~~(v) All voltages are the root mean square of the voltage measured over one cycle refreshed every half a cycle as per IEC 61000-4-30;~~

~~(vi) The voltage changes specified are the absolute maximum allowed, applied to phase to ground or phase to phase voltages whichever is the highest change;~~

~~(vii) Voltage changes in category 3 do not exceed the limits depicted in the time dependant characteristic shown in Figure CC.6.1.7;~~

~~(viii) Voltage changes in category 3 only occur infrequently, typically not planned more than once per year on average over the lifetime of a connection, and in circumstances notified to **The Company,** such as for example commissioning in accordance with a commissioning programme, implementation of a planned outage notified in accordance with **OC2** or an **Operation** or **Event** notified in accordance with **OC7**; and~~

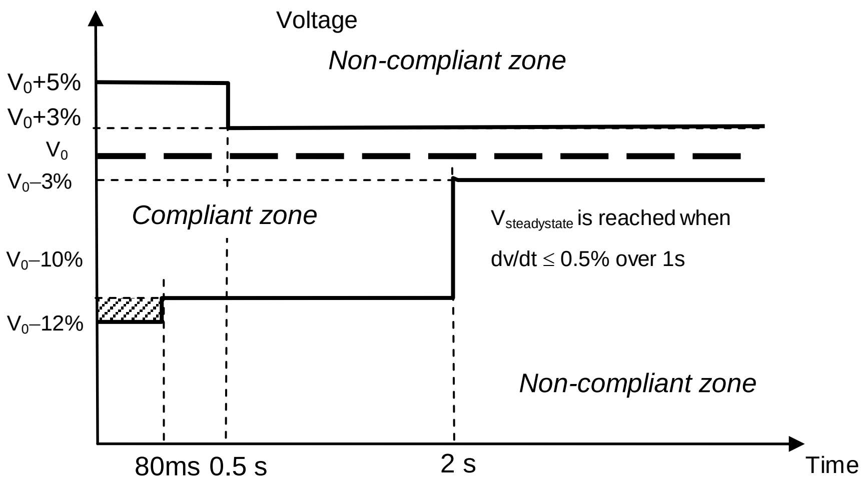
~~(ix) For connections with a **Completion Date** after 1st September 2015 and where voltage changes would constitute a risk to the **National Electricity Transmission System** or, in **The Company's** view, the **System** of any **GB Code User**, **Bilateral Agreements** may include provision for **The Company** to reasonably limit the number of voltage changes in category 2 or 3 to a lower number than specified in Table CC.6.1.7 to ensure that the total number of voltage changes at the **Point of Common Coupling** across multiple **Users** remains within the limits of Table CC.6.1.7.~~

~~Category~~	~~Maximum number of Occurrences~~	~~$\%\Delta V_{max}$ & $\%\Delta V_{steadystate}$~~
~~1~~	~~No Limit~~	~~$\lvert\%\Delta V_{max}\rvert \leq 1\%$ & $\lvert\%\Delta V_{steadystate}\rvert \leq 1\%$~~
~~2~~	~~$\dfrac{3600}{\sqrt[0.304]{2.5 \times \%\Delta V_{max}}}$ occurrences per hour with events evenly distributed~~	~~$1\% < \lvert\%\Delta V_{max}\rvert \leq 3\%$ & $\lvert\%\Delta V_{steadystate}\rvert \leq 3\%$~~
~~3~~	~~No more than 4 per day for Commissioning, Maintenance and Fault Restoration~~	~~For decreases in voltage:~~ ~~$\%\Delta V_{max} \leq 12\%$[1] &~~ ~~$\%\Delta V_{steadystate} \leq 3\%$~~ ~~For increases in voltage:~~ ~~$\%\Delta V_{max} \leq 5\%$[2] &~~ ~~$\%\Delta V_{steadystate} \leq 3\%$~~ ~~(see Figure CC6.1.7)~~

~~Table CC.6.1.7 - Limits for Rapid Voltage Changes~~

~~[1] A decrease in voltage of up to 12% is permissible for up to 80ms, as highlighted in the shaded area in Figure CC.6.1.7, reducing to up to 10% after 80ms and to up to 3% after 2 seconds.~~

~~[2] An increase in voltage of up to 5% is permissible if it is reduced to up to 3% after 0.5 seconds.~~



~~Figure CC.6.1.7 -~~

~~Time and magnitude limits for a category 3 Rapid Voltage Change~~

~~(b)~~ ~~For voltages above 132kV,~~ ~~**Flicker Severity (Short Term)**~~ ~~of 0.8 Unit and a~~ ~~**Flicker Severity (Long Term)**~~ ~~of 0.6 Unit, for voltages 132kV and below,~~ ~~**Flicker Severity (Short Term)**~~ ~~of 1.0 Unit and a~~ ~~**Flicker Severity (Long Term)**~~ ~~of 0.8 Unit, as set out in~~ ~~**Engineering Recommendation**~~ ~~P28 as current at the~~ ~~**Transfer Date**.~~

Voltage Fluctuations

ECC.6.1.7 Voltage changes at a **Point of Common Coupling** on the **Onshore Transmission System** shall not exceed:

(a) The limits specified in Table ECC.6.1.7(a) with the stated frequency of occurrence, where:

(i)

$$\%\Delta V_{steadystate} = \left| 100 \times \frac{\Delta V_{steadystate}}{Vn} \right|$$ and

$$\%\Delta V_{max} = 100 \times \frac{\Delta V_{max}}{V_n};$$

(ii) V_n is the nominal system voltage;

(iii) $V_{steadystate}$ is the voltage at the end of a period of 1 s during which the rate of change of system voltage over time is ≤ 0.5%;

(iv) $\Delta V_{steadystate}$ is the difference in voltage between the initial steady state voltage prior to the RVC (V_0) and the final steady state voltage after the RVC ($V_{0'}$);

(v) ΔV_{max} is the absolute change in the system voltage relative to the initial steady state system voltage (V_0);

(vi) All voltages are the r.m.s. of the voltage measured over one cycle refreshed every half a cycle as per BS EN 61000-4-30; and

(vii) The applications in the 'Example Applicability' column are examples only and are not definitive.

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Category	Title	Maximum number of occurrence	Limits $\%\Delta V_{max}$ & $\%\Delta V_{steadystate}$	Example Applicability
1	Frequent events	(see NOTE 1)	As per Figure ECC.6.1.7 (1)	Any single or repetitive RVC that falls inside Figure ECC.6.1.7 (1)
2	Infrequent events	4 events in 1 calendar month (see NOTE 2)	As per Figure ECC.6.1.7 (2) $\lvert \%\Delta V_{steadystate} \rvert \leq 3\%$ For decrease in voltage: $\lvert \%\Delta V_{max} \rvert \leq 10\%$ (see NOTE 3) For increase in voltage: $\lvert \%\Delta V_{max} \rvert \leq 6\%$ (see NOTE 4)	Infrequent motor starting, transformer energisation, re-energisation (see NOTE 7)
3	Very infrequent events	1 event in 3 calendar months (see NOTE 2)	As per Figure ECC.6.1.7 (3) $\lvert \%\Delta V_{steadystate} \rvert \leq 3\%$ For decrease in voltage: $\lvert \%\Delta V_{max} \rvert \leq 12\%$ (see NOTE 5) For increase in voltage: $\lvert \%\Delta V_{max} \rvert \leq 6\%$ (see NOTE 6)	Commissioning, maintenance & post fault switching (see NOTE 7)

NOTE 1: ±6% is permissible for 100 ms reduced to ±3% thereafter as per Figure ECC.6.1.7 (1) .
If the profile of repetitive voltage change(s) falls within the envelope given in Figure ECC.6.1.7 (1) , the assessment of such voltage change(s) shall be undertaken according to the recommendations for assessment of flicker and shall conform to the planning levels provided for flicker.
If any part of the voltage change(s) falls outside the envelope given in Figure ECC.6.1.7(1), the assessment of such voltage changes, repetitive or not, shall be done according to the guidance and limits for RVCs.

NOTE 2: No more than 1 event is permitted per day, consisting of up to 4 RVCs, each separated by at least 10 minutes with all switching completed within a two-hour window.

NOTE 3: −10% is permissible for 100 ms reduced to -6% until 2 s then reduced to -3% thereafter as per Figure ECC.6.1.7 (1).

NOTE 4: +6% is permissible for 0.8 s from the instant the event begins then reduced to +3% thereafter as per Figure ECC.6.1.7 (2).

NOTE 5: −12% is permissible for 100 ms reduced to −10% until 2 s then reduced to -3% thereafter as per Figure ECC.6.1.7 (3).

NOTE 6: +6% is permissible for 0.8 s from the instant the event begins then reduced to +3% thereafter as per Figure ECC.6.1.7 (3).

NOTE 7: These are examples only. The Limits of another category providing the frequency of occurrence is not expected to exceed the 'Maximum number of occurrence' for the chosen category. Where the measured emission level exceeds the expected emission level, paragraph 4 of Clause 6.1.4 applies.

Table ECC.6.1.7 (a) – Planning levels for RVC

(b) The voltage change limit is the absolute maximum allowed of either the phase-to-earth voltage change or the phase-to-phase voltage change, whichever is the highest. The limits do not apply to single phasor equivalent voltages, e.g. positive phase sequence (PPS) voltages. For high impedance earthed systems, the maximum phase-to-phase, i.e. line voltage, should be used for assessment.

(c) The RVCs in Category 2 and 3 should not exceed the limits depicted in the time dependent characteristic shown in Figure ECC.6.1.7 (2) and Figure ECC.6.1.7 (3) respectively. These limits do not apply to: 1) fault clearance operations; or 2) immediate operations in response to fault conditions; or 3) operations relating to post fault system restoration (for the avoidance of doubt this third exception pertains to a fault that is external to the users plant and apparatus).

(d) Any RVCs permitted in Category 2 and Category 3 should be at least 10 minutes apart.

(e) The value of $V_{steadystate}$ should be established immediately prior to the start of a RVC. Following a RVC, the voltage should remain within the relevant envelope, as shown in Figures ECC.6.1.7 (1), ECC.6.1.7 (2), ECC.6.1.7 (3), until a $V_{steadystate}$ condition has been satisfied.

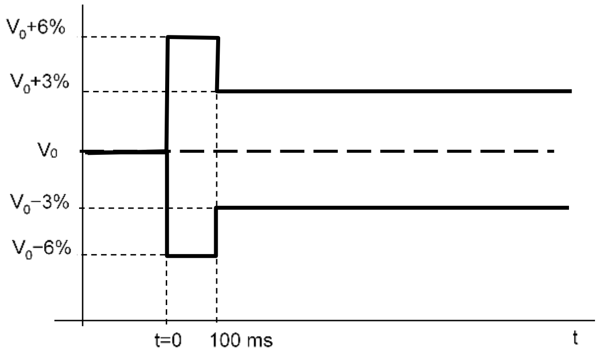


Figure ECC.6.1.7 (1) — Voltage characteristic for frequent events

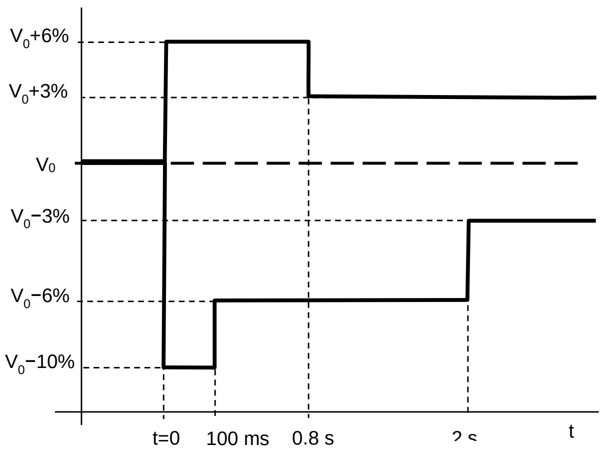


Figure ECC.6.1.7 (2) — Voltage characteristic for infrequent events

Field Code Changed

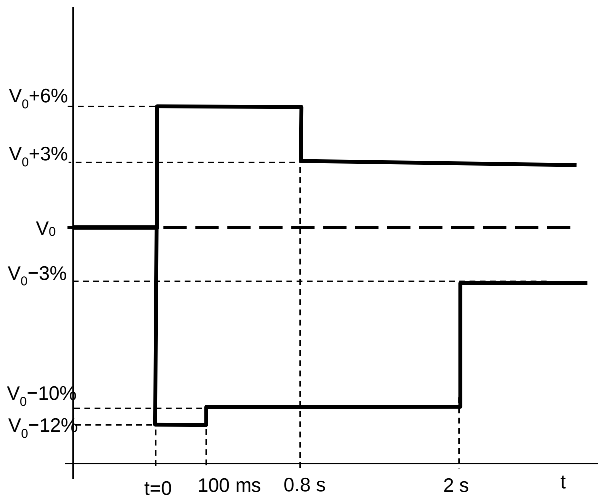


Figure ECC.6.1.7 (3) — Voltage characteristic for very infrequent events

(f) The voltage change between two steady state voltage conditions should not exceed 3%. (The limit is based on 3% of the nominal voltage of the system (V_n) as measured at the PCC. The step voltage change as measured at the customer's supply terminals or equipment terminals could be greater. For example: The step voltage change limit stated in BS EN 61000-3-3 and BS EN 61000-3-11 is 3.3% when measured at the equipment terminals.)

(g) The limits apply to voltage changes measured at the **Point of Common Coupling**.

(h) Category 3 events that are planned should be notified to the Company in advance.

(i) For connections where voltage changes would constitute a risk to the **National Electricity Transmission System** or, in **The Company's** view, the **System** of any **GB Code User**, **Bilateral Agreements** may include provision for **The Company** to reasonably limit the number of voltage changes in Category 2 or 3 to a lower number than specified in Table ECC.6.1.7(a) to ensure that the total number of voltage changes at the **Point of Common Coupling** across multiple **Users** remains within the limits of Table ECC.6.1.7(a).

(j) The planning levels applicable to Flicker Severity Short Term (Pst) and Flicker Severity Long Term (Plt) are set out in Table ECC.6.1.7(b).

Supply system Nominal voltage	**Planning level**

	Flicker Severity Short Term (Pst)	Flicker Severity Long Term (Plt)
3.3 kV, 6.6 kV, 11 kV, 20 kV, 33 kV	0.9	0.7
66 kV, 110 kV, 132 kV, 150 kV, 200 kV, 220 kV, 275 kV, 400 kV	0.8	0.6
NOTE 1: The magnitude of P_{st} is linear with respect to the magnitude of the voltage changes giving rise to it. NOTE 2: Extreme caution is advised in allowing any excursions of P_{st} and P_{lt} above the planning level.		

Table ECC.6.7.1(b) — Planning levels for flicker

The values and figures referred to in this paragraph ECC.6.1.7 are derived from Engineering Recommendation P28 Issue 2.

~~ECC.6.1.7 Voltage changes at a **Point of Common Coupling** on the **Onshore Transmission System** shall not exceed:~~

~~(a) The limits specified in Table ECC.6.1.7 with the stated frequency of occurrence, where:~~

~~(i)~~

$$\cancel{\%\Delta V_{steadystate} = \left| 100 \times \frac{\Delta V_{steadystate}}{V_0} \right|}$$

~~and~~

$$\cancel{\%\Delta V_{max} = 100 \times \frac{\Delta V_{max}}{V_0}};$$

~~(ii) V_0 is the initial steady state system voltage;~~

~~(iii) $V_{steadystate}$ is the system voltage reached when the rate of change of system voltage over time is less than or equal to 0.5% over 1 second and $\Delta V_{steadystate}$ is the absolute value of the difference between $V_{steadystate}$ and V_0;~~

~~(iv) ΔV_{max} is the absolute value of the maximum change in the system voltage relative to the initial steady state system voltage of V_0;~~

~~(v) All voltages are the root mean square of the voltage measured over one cycle refreshed every half a cycle as per IEC 61000-4-30;~~

~~(vi) The voltage changes specified are the absolute maximum allowed, applied to phase to ground or phase to phase voltages whichever is the highest change;~~

~~(vii) Voltage changes in category 3 do not exceed the limits depicted in the time dependent characteristic shown in Figure ECC.6.1.7;~~

~~(viii) Voltage changes in category 3 only occur infrequently, typically not planned more than once per year on average over the lifetime of a connection, and in circumstances notified to **The Company**, such as for example commissioning in accordance with a commissioning programme, implementation of a planned outage notified in accordance with **OC2** or an **Operation** or **Event** notified in accordance with **OC7**; and~~

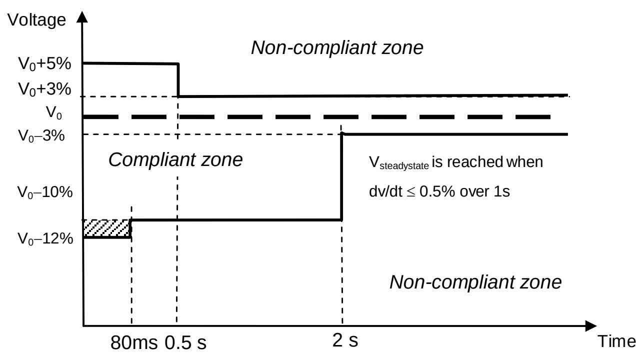
~~(ix) For connections where voltage changes would constitute a risk to the **National Electricity Transmission System** or, in **The Company's** view, the **System** of any **User**, **Bilateral Agreements** may include provision for **The Company** to reasonably limit the number of voltage changes in category 2 or 3 to a lower number than specified in Table ECC.6.1.7 to ensure that the total number of voltage changes at the **Point of Common Coupling** across multiple **Users** remains within the limits of Table ECC.6.1.7.~~

~~Category~~	~~Maximum number of Occurrences~~	~~$\%\Delta V_{max}$ & $\%\Delta V_{steadystate}$~~
~~1~~	~~No Limit~~	~~$\lvert\%\Delta V_{max}\rvert \leq 1\%$ & $\lvert\%\Delta V_{steadystate}\rvert \leq 1\%$~~
~~2~~	~~$\dfrac{3600}{\sqrt[0.304]{2.5 \times \%\Delta V_{max}}}$ occurrences per hour with events evenly distributed~~	~~$1\% < \lvert\%\Delta V_{max}\rvert \leq 3\%$ & $\lvert\%\Delta V_{steadystate}\rvert \leq 3\%$~~
~~3~~	~~No more than 4 per day for Commissioning, Maintenance and Fault Restoration~~	~~For decreases in voltage:~~ ~~$\%\Delta V_{max} \leq 12\%^{1}$ & $\%\Delta V_{steadystate} \leq 3\%$~~ ~~For increases in voltage:~~ ~~$\%\Delta V_{max} \leq 5\%^{2}$ & $\%\Delta V_{steadystate} \leq 3\%$~~ ~~(see Figure ECC6.1.7)~~

~~Table ECC.6.1.7 - Limits for Rapid Voltage Changes~~

~~[1] A decrease in voltage of up to 12% is permissible for up to 80ms, as highlighted in the shaded area in Figure ECC.6.1.7, reducing to up to 10% after 80ms and to up to 3% after 2 seconds.~~

~~[2] An increase in voltage of up to 5% is permissible if it is reduced to up to 3% after 0.5 seconds.~~



~~Figure ECC.6.1.7 -~~
~~Time and magnitude limits for a category 3 Rapid Voltage Change~~

~~(b) For voltages above 132kV, **Flicker Severity (Short Term)** of 0.8 Unit and a **Flicker Severity (Long Term)** of 0.6 Unit, for voltages 132kV and below, **Flicker Severity (Short Term)** of 1.0 Unit and a **Flicker Severity (Long Term)** of 0.8 Unit, as set out in **Engineering Recommendation** P28 as current at the **Transfer Date**.~~

Flicker Severity ~~(~~**Long Term**~~)~~ **(Plt)**	Has the meaning set out in **Engineering Recommendation** P28 Issue 2. ~~A value derived from 12 successive measurements of **Flicker Severity** (**Short Term**) (over a two hour period) and a calculation of the cube root of the mean sum of the cubes of 12 individual measurements, as further set out in **Engineering Recommendation** P28 as current at the **Transfer Date**.~~
Flicker Severity ~~(~~**Short Term**~~)~~ **(Pst)**	Has the meaning set out in **Engineering Recommendation** P28 Issue 2. ~~A measure of the visual severity of flicker derived from the time series output of a flickermeter over a 10 minute period and as such provides an indication of the risk of **Customer** complaints.~~

	Parameter to be Tested	Criteria against which the test results will be assessed by The Company.
	Rapid Voltage Change ~~Fluctuation~~	CC.6.1.7(i~~a~~) or ECC.6.1.7(i~~a~~) ~~In England and Wales, measured voltage fluctuations at the **Point of Common Coupling** shall not exceed 1% of the voltage level for step changes. Measured voltage excursions other than step changes may be allowed up to a level of 3%. In Scotland,~~ The measured Rapid V~~v~~oltage Change ~~fluctuations~~ at the~~a~~ **Point of Common Coupling** shall not exceed the Planning Levels specified in CC.6.1.7(i) or ECC 6.1.7.(i)l~~imits set out in **Engineering Recommendation** P28.~~
	Flicker Severity	CC.6.1.7(j~~b~~) or ECC.6.1.7(j~~b~~) The m~~M~~easured Flicker Severity ~~voltage fluctuations~~ at the ~~a~~ **Point of Common Coupling** shall not exceed~~,~~ the limits specified in the table of CC.6.1.7(j) or ECC 6.1.7(j). ~~for voltages above 132kV, **Flicker Severity (Short Term)** of 0.8 Unit and **Flicker Severity (Long Term)** of 0.6 Unit, and, for voltages at 132kV and below, shall not exceed **Flicker Severity (Short Term)** of 1.0 Unit and **Flicker Severity (Long Term)** of 0.8 Unit, as set out in **Engineering Recommendation** P28 as current at the **Transfer Date**~~.

PC.A.4.7 General Demand Data

PC.A.4.7.1 The following information is infrequently required and should be supplied (wherever possible) when requested by **The Company**:

(a) details of any individual loads which have characteristics significantly different from the typical range of Domestic, Commercial or Industrial loads supplied;

(b) the sensitivity of the **Demand** (**Active and Reactive Power**) to variations in voltage and **Frequency** on the **National Electricity Transmission System** at the time of the peak **Demand** (**Active Power**). The sensitivity factors quoted for the **Demand** (**Reactive Power**) should relate to that given under PC.A.4.3.1 and, therefore, include any **User's System** series reactive losses but exclude any reactive compensation equipment specified in PC.A.2.4 and exclude any network susceptance specified in PC.A.2.3;

(c) details of any traction loads, e.g. connection phase pairs and continuous load variation with time;

(d) the average and maximum phase unbalance, in magnitude and phase angle, which the **User** would expect its **Demand** to impose on the **National Electricity Transmission System**;

(e) the maximum harmonic content which the **User** would expect its **Demand** to impose on the **National Electricity Transmission System**;

(f) details of all loads which may cause **Demand** fluctuations greater than those permitted under **Engineering Recommendation** P28 Issue 2, Stage 1 at a **Point of Common Coupling** including the **Flicker Severity** (**Short Term**) and the **Flicker Severity** (**Long Term**).

APPENDIX C - TECHNICAL AND DESIGN CRITERIA

PC.C.1 Planning and design of the **SPT** and **SHETL Transmission Systems** is based generally, but not totally, on criteria which evolved from joint consultation among various **Transmission Licensees** responsible for design of the **National Electricity Transmission System**.

PC.C.2 The above criteria are set down within the standards, memoranda, recommendations and reports and are provided as a guide to system planning. It should be noted that each scheme for reinforcement or modification of the **Transmission System** is individually designed in the light of economic and technical factors associated with the particular system limitations under consideration.

PC.C.3 The tables below identify the literature referred to above, together with the main topics considered within each document.

PART 1 – SHETL's TECHNICAL AND DESIGN CRITERIA

ITEM No.	DOCUMENT	REFERENCE No.
1	National Electricity Transmission System Security and Quality of Supply Standard	Version [ ]
2	System Phasing	TPS 13/4
3	Not used	
4	Voltage fluctuations and the connection of disturbing equipment to transmission systems and distribution networks in the United Kingdom ~~Planning Limits for Voltage Fluctuations Caused by Industrial, Commercial and Domestic Equipment in the United Kingdom~~	EREC P28 Issue 2 ~~ER P28~~
5	EHV or HV Supplies to Induction Furnaces Voltage unbalance limits. Harmonic current limits.	ER P16 (Supported by ACE Report No.48)
6	Planning Levels for Harmonic Voltage Distortion and the Connection of Non-Linear Loads to Transmission Systems and Public Electricity Supply Systems in the United Kingdom Harmonic distortion (waveform). Harmonic voltage distortion. Harmonic current distortion. Stage 1 limits. Stage 2 limits. Stage 3 Limits Addition of Harmonics Short Duration Harmonics Site Measurements	ER G5/4 (Supported by ACE Report No.73)
7	AC Traction Supplies to British Rail Type of supply point to railway system. Estimation of traction loads. Nature of traction current. System disturbance estimation. Earthing arrangements.	ER P24

ITEM No.	DOCUMENT	REFERENCE No.
8	Operational Memoranda	(SOM)
	Main System operating procedure.	SOM 1
	Operational standards of security.	SOM 3
	Voltage and reactive control on main system.	SOM 4
	System warnings and procedures for instructed load reduction.	SOM 7
	Continuous tape recording of system control telephone messages and instructions.	SOM 10
	Emergency action in the event of an exceptionally serious breakdown of the main system.	SOM 15
9	Planning Limits for Voltage Unbalance in the United Kingdom.	ER P29

PART 2 - SPT's TECHNICAL AND DESIGN CRITERIA

ITEM No.	DOCUMENT	REFERENCE No.
1	National Electricity Transmission System Security and Quality of Supply Standard	Version [ ]
2	System Phasing	TDM 13/10,002 Issue 4
3	Not used	
4	Voltage fluctuations and the connection of disturbing equipment to transmission systems and distribution networks in the United Kingdom~~Planning Limits for Voltage Fluctuations Caused by Industrial, Commercial and Domestic Equipment in the United Kingdom~~	EREC P28 Issue 2~~ER P28~~
5	EHV or HV Supplies to Induction Furnaces Voltage Unbalance limits. Harmonic current limits.	ER P16 (Supported by ACE Report No.48)
6	Planning Levels for Harmonic Voltage Distortion and the Connection of Non-Linear Loads to Transmission Systems and Public Electricity Supply Systems in the United Kingdom Harmonic distortion (waveform). Harmonic voltage distortion. Harmonic current distortion. Stage 1 limits. Stage 2 limits. Stage 3 Limits Addition of Harmonics Short Duration Harmonics Site Measurements	ER G5/4 (Supported by ACE Report No.73)
7	AC Traction Supplies to British Rail Type of supply point to railway system. Estimation of traction loads. Nature of traction current. System disturbance estimation. Earthing arrangements.	ER P24

APPENDIX E - OFFSHORE TRANSMISSION SYSTEM AND OTSDUW PLANT AND APPARATUS TECHNICAL AND DESIGN CRITERIA

PC.E.1 In the absence of any relevant **Electrical Standards**, **Offshore Transmission Licensees** and **Generators** undertaking **OTSDUW** are required to ensure that all equipment used in the construction of their network is:

(i) Fully compliant and suitably designed to any relevant **Technical Specification**;

(ii) Suitable for use and operation in an **Offshore** environment, where such parts of the **Offshore Transmission System** and **OTSDUW Plant and Apparatus** are located in **Offshore Waters** and are not installed in an area that is protected from that **Offshore** environment, and

(iii) Compatible with any relevant **Electrical Standards** or **Technical Specifications** at the **Offshore Grid Entry Point** and **Interface Point**.

PC.E.2 The table below identifies the technical and design criteria that will be used in the design and development of an **Offshore Transmission System** and **OTSDUW Plant and Apparatus**.

ITEM No.	DOCUMENT	REFERENCE No.
1	National Electricity Transmission System Security and Quality of Supply Standard	Version [ ]
2*	Voltage fluctuations and the connection of disturbing equipment to transmission systems and distribution networks in the United Kingdom~~Planning Limits for Voltage Fluctuations Caused by Industrial, Commercial and Domestic Equipment in the United Kingdom~~	~~ER P28~~P28 Issue 2
3*	Planning Levels for Harmonic Voltage Distortion and the Connection of Non-Linear Loads to Transmission Systems and Public Electricity Supply Systems in the United Kingdom	ER G5/4
4*	Planning Limits for Voltage Unbalance in the United Kingdom	ER P29

* Note:- Items 2, 3 and 4 above shall only apply at the **Interface Point**.

Appendix B – DCRP/18/01/FMR Decision Letter

Electricity Distribution Licensees,
Distribution Code Review Panel
(DCRP), Grid Code Review Panel
Chair, GCRP, and other
interested parties

Email: peter.bingham@ofgem.gov.uk

Date: 22 June 2018

Dear Electricity Distribution Licensees and GCRP chair,

Our decision to send back modification proposal DCRP/MP/18/01 'Revision to Engineering Recommendation P28 (Voltage fluctuations and the connection of disturbing equipment to transmission systems and distribution networks in the United Kingdom)' (DCRP/MP/18/01)

On 17 May 2018, the electricity distribution licensees submitted a Final Modification Report (FMR) for Distribution Code modification proposal DCRP/MP/18/01 to us. We have decided that we cannot form an opinion on this modification proposal based on the FMR as submitted. We are therefore sending the FMR back to industry for further work.

We consider that there has not been sufficient industry consideration of the impact of DCRP/MP/18/01 on other industry codes. Specifically, we do not consider that the impact on the Grid Code has been properly considered. We note that Engineering Recommendation P28[1] is referenced multiple times within the Grid Code. The changes proposed under DCRP/MP/18/01, which have a direct impact on the requirements for parties connecting to the electricity networks, could result in consequential changes to Grid Code requirements that have not been assessed and which may be relevant to inform our decision.

We expect distribution licensees and the Grid Code Review Panel ('GCRP') to work together and submit any proposed Distribution and Grid Code changes to us as a package, which should include co-ordinated implementation timetables. We expect the GCRP to discuss the issues set out in this letter and DCRP/MP/18/01 at the next GCRP meeting, on 28 June 2018.

We therefore direct that the FMR be sent back to the electricity distribution licensees to be reviewed once work to assess the impact of DCRP/MP/18/01 on the Grid Code is complete. To achieve this, we expect the relevant Code Administrators (CA) to follow Principle 13[2] of the CA Code of Practice. [3]

This should be carried out as soon as practicable.

Yours faithfully,

[1] Planning limits for voltage fluctuations caused by industrial, commercial and domestic equipment in the United Kingdom, please see http://www.dcode.org.uk/assets/uploads/ENA_ER_P28_Issue_1___1989_.pdf
[2] CA will ensure cross code coordination to progress changes efficiently where modifications impact multiple codes.
[3] https://www.ofgem.gov.uk/publications-and-updates/code-administration-code-practice-version-4

Peter Bingham
Chief Engineer
Signed on behalf of the Authority and authorised for that purpose

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Appendix C – DCRP_FMR_EREC P28 Issue 2_v0.4.1_Issued

PRODUCED BY THE OPERATIONS DIRECTORATE OF ENERGY NETWORKS ASSOCIATION

Engineering Recommendation P28

Issue 2 2018

Voltage fluctuations and the connection of disturbing equipment to transmission systems and distribution networks in the United Kingdom

PUBLISHING AND COPYRIGHT INFORMATION

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Foreword

This Engineering Recommendation (EREC) is published by the Energy Networks Association (ENA) and comes into effect from date of publication. The approved abbreviated title of this Engineering Recommendation is "EREC P28", which replaces the previously used abbreviation "ER P28".

Revision of this EREC has been prepared under the authority of the Grid Code and Distribution Code Review Panels of Great Britain – being a qualifying standard and licence standard under these respective codes. The review and subsequent revision of EREC P28 has been overseen by the ENA P28 Working Group. Approval for publication has been granted by Ofgem.

This EREC supersedes ENA Engineering Recommendation P28 Issue 1 1989.

This EREC has been fully updated with reference to the United Kingdom implementation of the IEC 61000 series of Standards so far as they relate to voltage fluctuations and disturbance.

Harmonic voltage distortion and voltage unbalance aspects associated with the connection of disturbing equipment to transmission systems and distribution networks are covered in ENA Engineering Recommendation G5 and Engineering Recommendation P29 respectively.

This document constitutes a full technical revision of EREC P28 Issue 1. This issue [Issue 2] of EREC P28 has been extended to cover assessment and limits for rapid voltage changes (RVCs).

This EREC is intended to be read as a standalone document; references to other publications are intended to direct users to additional supporting information that could be useful but not essential to understanding requirements.

Engineering Report P28 [8] provides background, information and examples that support the requirements in this EREC.

This EREC should be used by those who propose to connect disturbing equipment with the potential for voltage fluctuation, being flicker and/or RVC, to public electricity supply systems. The document should also be used by those who carry out assessments concerning the suitability of connecting such equipment to these systems.

This document is not intended to replace or override requirements in BS EN 50160 for ensuring acceptable voltage quality.

The terms 'this Engineering Recommendation' and 'this EREC' refer to Engineering Recommendation P28 Issue 2 2018, as amended.

In this document, the term 'shall' relates to a statutory or mandatory requirement. The term 'should' expresses a recommendation and the term 'may' indicates a permission.

Commentary, explanation and general informative material is presented in smaller *italic* type, and does not constitute a normative element.

The term ‘system/network operator’ in this EREC is intended to apply to owners and operators of transmission systems and distribution networks, in so far as the requirements are applicable to their statutory and regulatory duties and responsibilities.

The term ‘disturbing equipment’ is intended to refer to individual items of disturbing equipment, whereas the term ‘fluctuating installation’ is intended to refer to multiple items of disturbing equipment contained within an installation connected to the supply system.

The convention used for cross-referencing clauses within this EREC is the omission of the term ‘clause’ before the clause number and the placing within parenthesis. For example: “(see 5.3)” denotes a cross-reference to Clause 5.3 in this document.

Abbreviations used throughout this document are stated in ‘Terms and definitions’ (see 3).

Introduction

Repetitive voltage fluctuations of sufficient frequency and/or magnitude in the supply system can cause the luminance of incandescent lamps, e.g. traditional tungsten filament light bulbs, to fluctuate with time. This creates an impression of unsteadiness of visual sensation in humans, who observe these fluctuations. This effect is known as flicker. If the flicker is of sufficient severity then this can be annoying to observers and can result in them complaining to the system/network operator.

Fast changes in supply system voltages can result from energising/de-energising certain types of electrical equipment. These are known as rapid voltage changes (RVCs) which, if of sufficient magnitude, duration and frequency, can cause maloperation of and damage to equipment and similar annoyance, as flicker, to those that observe changes in luminance of electric lighting. The process for assessment of RVCs is described in Clause 5.3.

EREC P28 was first published in 1989 to provide recommended planning limits for voltage fluctuations for connection of equipment to public electricity supply systems in the UK. Issue 1 was primarily concerned with assessment of voltage fluctuations and associated flicker produced by traditional domestic, commercial and industrial loads. Since EREC P28 was first published, the factors affecting development of transmission systems and distribution networks, and equipment connected to them have changed significantly. There has been a shift towards connection of distributed/embedded generation equipment powered by renewable energies and other low carbon technology equipment. These types of modern equipment are capable of causing flicker. As such, the impact of connecting modern equipment has been reviewed and EREC P28 has been updated accordingly.

Significant developments in Electromagnetic Compatibility (EMC) requirements have taken place, which are captured in the International Electrotechnical Commission (IEC) 61000 series of Standards and technical reports. United Kingdom implementation of these Standards is captured in the various parts of BS EN 61000. Consequently, EREC P28 Issue 2 has been revised in line with the requirements of these Standards, so far as they apply to the limitation of voltage fluctuations in public electricity supply systems and resultant flicker. Relevant considerations in IEC technical reports have been reviewed and, where appropriate, have been adopted.

The flickermeter algorithm is based on the perceived visual effects from traditional incandescent light bulbs, which are being phased out and replaced by new technology lamps including:

- halogen;
- compact fluorescent lamps (CFL);
- light emitting diodes (LED).

Whilst most new technology lamps are less sensitive to applied voltage fluctuations, some are more sensitive at higher frequencies [of voltage fluctuation] than the traditional 60 W incandescent lamp, which is the reference lamp for the flicker curve[1].

For example: some types of high pressure discharge lighting might produce marginally higher levels of flicker severity than tungsten filament lamps at higher frequencies of the voltage fluctuation spectrum, however operating experience over many years has not found this to be problematic. The requirements in this EREC will need to be kept under review given on-going developments in lighting technology.

International Standards continue to use the existing flicker curve [P_{st} = 1 in Figure 2 of BS EN 61000-3-3] for assessing the disturbance to lighting and all other equipment connected to public electricity supply systems caused by voltage fluctuation. The limits for voltage fluctuation in EREC P28 Issue 2 are compatible with the existing flicker curve.

This EREC defines good engineering practice, which is applicable to the connection of customers' disturbing equipment and fluctuating installations, with respect to limiting voltage fluctuations on transmission systems and distribution networks in the United Kingdom.

The intention is that planning levels stated in this EREC will ensure emissions from new connections of customers' disturbing equipment and fluctuating installations are sufficiently below immunity levels of equipment connected to the system so as not to cause unacceptable disturbance to other customers and system users. Disturbance includes the effect of voltage fluctuations on flicker severity and/or the capability of equipment connected to the system to function correctly. The planning levels in this document should not be considered as targets and all reasonable steps should be taken to minimise voltage fluctuations.

A key principle in this EREC is that the visual discomfort due to light flicker is the most frequent reason to limit voltage changes due to fluctuating installations. Flicker, if particularly severe, can adversely affect the health of those people exposed. This is why minimising flicker, where possible, is important. System/network operators have to maintain the voltage magnitude within narrow limits and individual customers should not produce significant voltage fluctuations even if they are tolerable from a flicker perspective.

A three-stage approach is presented for assessing the acceptability of the connection of proposed disturbing equipment and/or fluctuating installations, in terms of flicker, to supply systems.

a) Stage 1

The intention is that individual equipment that conforms to relevant product standards can be connected to the system without further assessment under Stage 1 (see 6.3.2).

---

[1] The term 'flicker curve' relates to the curve for P_{st} = 1 for rectangular equidistant voltage changes as illustrated in Figure 2 of BS EN 61000-3-3. The flicker curve is used to determine the amplitude of rectangular voltage changes that correspond to a flicker severity of P_{st} = 1 for a particular rate of repetition.

b) Stage 2

Disturbing equipment that does not conform to Stage 1 requirements but conforms to limits and requirements in Stage 2 can be connected without detailed assessment or consideration of flicker background level (see 6.3.3).

c) Stage 3

All other disturbing equipment that does not conform to limits and requirements in Stage 2 will need detailed assessment against Stage 3 limits and requirements before it can be connected (see 6.3.4).

The characteristic of flicker means disturbances from independent sources are not directly additive. In practice, additional disturbing equipment/fluctuating installations can generally be connected to the electricity supply system even when the existing flicker background level is approaching the planning level[2]. The coincidence of RVCs from independent sources is considered to present a low enough probability that no summation laws are taken into account when assessing RVCs. Whilst it is recognised that particular network designs could result in coincident RVCs under certain circumstances, e.g. restoration of systems/networks following a G59 trip event, conformance to the limits in this EREC is still required.

Therefore, flicker from disturbing equipment/fluctuating installations should not be unnecessarily constrained by system/network operators, to allow for future unspecified emissions, subject to good engineering practice being followed in the design and installation of disturbing equipment.

If disturbing equipment fails to meet the stage limits following assessment, in exceptional circumstances the system operator or network operator may permit the connection of disturbing equipment even though flicker levels are likely to exceed planning levels. The final decision as to whether or not disturbing equipment exceeding the limits in this EREC may be connected to the public electricity supply system is at the discretion of the relevant system/network operator – subject to any other recourse that could be available to customers[3].

1 Scope

This EREC defines planning levels and compatibility levels for the assessment of voltage fluctuations from customer disturbing equipment and fluctuating installations to be connected to transmission systems and distribution networks in the United Kingdom.

This EREC only applies to the proposed connection of customer disturbing equipment and fluctuating installations. It is not intended to apply to the connection of equipment or installations operated by licensed distribution network operators or licensed transmission system operators.

---

[2] A review of flicker background levels in the UK public electricity supply system has not found any evidence to support apportioning of remaining capacity to prevent planning levels being exceeded in future. See ENA Engineering Report P28 [8].

[3] Such as Regulation 26 of The Electricity Safety, Quality & Continuity Regulations 2002 [6] (as amended) for GB and Regulation 27 The Electricity Safety, Quality and Continuity Regulations (Northern Ireland) 2012 [7] (as amended) for Northern Ireland.

The scope of voltage fluctuations in this EREC applies to flicker or RVCs emitted onto the public electricity supply system by customer equipment, i.e. customer owned demand, generation, energy storage[4], or other types of disturbing equipment that may be connected.

This EREC is not intended to be applied retrospectively to existing connections that have been previously assessed under Issue 1 of EREC P28.

However, it is intended to be applied in the event of any change(s) to existing customer disturbing equipment/fluctuating installations that affect voltage fluctuation and to new connections.

This EREC neither replaces nor negates the United Kingdom implementation of EMC Standards, including relevant harmonised equipment Standards that are applicable to particular equipment, under the terms of the Electromagnetic Compatibility Regulations 2016 [1]. The intention is to assist customers to meet their obligations under these Regulations and to prevent interference.

The provisions in this EREC only apply to voltage fluctuations and connection of disturbing equipment. Other criteria, not stated in this document, apply to meeting current ratings, statutory voltage limits, harmonic distortion limits etc. such that, even if voltage fluctuation aspects are satisfied, the connection of disturbing equipment will be conditional on meeting other criteria.

Specific aspects not considered in this EREC include radiated interference, which might affect communications systems, and specific methods for mitigation of disturbances.

2 Normative references

The following referenced documents, in whole or part, are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

Standards publications

IEC 60050, *International Electrotechnical Vocabulary*

IEC TR 61000-2-1, *Electromagnetic compatibility (EMC) - Part 2: Environment - Section 1: Description of the environment - Electromagnetic environment for low-frequency conducted disturbances and signalling in public power supply systems*

IEC 61851-21-1, *Electric vehicle conductive charging system - Part 21-1: Electric vehicle on-board charger EMC requirements for conductive connection to an AC/DC supply*

BS EN 61000-2-2, *Electromagnetic compatibility (EMC). Environment. Compatibility levels for low-frequency conducted disturbances and signalling in public low-voltage power supply systems*

[4] Energy storage installations can operate flexibly as load or generation.

BS EN 61000-3-3, *Electromagnetic compatibility (EMC). Limits. Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current ≤ 16 A per phase and not subject to conditional connection*

BS EN 61000-3-11, *Electromagnetic compatibility (EMC). Limits. Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems. Equipment with rated voltage current ≤ 75 A and subject to conditional connection*

BS EN 61000-4-15, *Electromagnetic compatibility (EMC). Testing and measurement techniques. Flickermeter. Functional and design specifications*

BS EN 61000-6-3, *Electromagnetic compatibility (EMC). Generic standards. Emission standard for residential, commercial and light-industrial environments*

BS EN 61000-6-4, *Electromagnetic compatibility (EMC). Generic standards. Emission standard for industrial environments*

BS EN 61000-4-30, *Electromagnetic compatibility (EMC). Testing and measurement techniques. Power quality measurement methods*

BS EN 61400-21, *Wind turbines. Measurement and assessment of power quality characteristics of grid connected wind turbines*

BS 7671:2008+A3:2015, *Requirements for Electrical Installations. IET Wiring Regulations*

Other publications

[N1] ENA Engineering Recommendation G83, *Recommendations for the connection of type tested small-scale embedded generators (up to 16 A per phase) in parallel with low-voltage distribution systems*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
compatibility level
specified electromagnetic disturbance level used as a reference level in a specified environment for coordination in the setting of emission and immunity limits

NOTE: By convention, the compatibility level is chosen so that there is only a small probability, for example 5%, that it will be exceeded by the actual disturbance level.

[Equivalent to definition in Clause 3.6 of PD IEC/TR 61000-3-7:2008]

3.2
conditional connection
connection of equipment requiring the customer's supply at the connection point to have an impedance lower than the reference impedance Z_{ref} in order that the equipment emissions conform to the limits in BS EN 61000-3-3

NOTE 1: Meeting the voltage change limits might not be the only condition for connection; emission limits for other phenomena such as harmonics, might also have to be satisfied.

NOTE 2: The symbol Z_{ref} relates to the reference impedance referred to in BS EN 61000-3-3 and BS EN 61000-3-11.

3.3
customer
entity who is or is entitled to either supply or be supplied with electricity at any premises within the United Kingdom excepting the licensed transmission system operator or licensed network operator

NOTE 1: The definition of "customer" broadly aligns with the GB Distribution Code [2] but includes customer own generation by virtue of: "…to either supply or be supplied electricity…".

3.4
distribution network
part of a public electricity supply system that requires the owner or operator to hold a Distribution Licence in the United Kingdom

3.5
disturbance
electromagnetic phenomenon which, by being present in the electromagnetic environment, can cause electrical equipment to depart from its intended performance

3.6
disturbing equipment
equipment that when connected to the public electricity supply system has the potential to cause disturbance from voltage fluctuations

3.7
electricity supply system
lines, switchgear and transformers operating at various voltages which make up the transmission systems and distribution networks to which customers' installations are connected

NOTE 1: Sometimes abbreviated to "supply system" or "system".

NOTE 2: When preceded by the term "public", the wider use of the system is intended.

3.8
electromagnetic compatibility (EMC)
ability of equipment or a system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment

NOTE 1: Electromagnetic compatibility is a condition of the electromagnetic environment such that, for every phenomenon, the disturbance emission level is sufficiently low and immunity levels are sufficiently high so that all devices, equipment and systems operate as intended.

NOTE 2: Electromagnetic compatibility is achieved only if emission and immunity levels are controlled such that the immunity levels of the devices, equipment and systems at any location are not exceeded by the disturbance level at that location resulting from the cumulative emissions of all sources and other factors such as circuit impedances. Conventionally, compatibility is said to exist if the probability of the departure from intended performance is sufficiently low. See Clause 4 of BS EN 61000-2-1.

NOTE 3: Where the context requires it, compatibility could be understood to refer to a single disturbance or class of disturbances.

NOTE 4 Electromagnetic compatibility is a term used also to describe the field of study of the adverse electromagnetic effects which devices, equipment and systems undergo from each other or from electromagnetic phenomena.

3.9
emission
source of electromagnetic disturbance

3.10
emission level
level of a given electromagnetic disturbance emitted from a particular device, equipment, system or fluctuating installation as a whole, assessed and measured in a specified manner

3.11
emission limit
maximum emission level specified for a particular device, equipment, system or disturbing installation as a whole

3.12
ENA
Energy Networks Association

NOTE: ENA have responsibility for the review, publication and maintenance of EREC P28.

3.13
equipment
single apparatus or set of devices or apparatuses, or the set of main devices of an installation, or all devices necessary to perform a specific task

3.14
EREC
Engineering Recommendation

3.15
flicker
impression of unsteadiness of visual sensation induced by a light stimulus whose luminance or spectral distribution fluctuates with time

NOTE: Flicker is the effect on certain types of electric lamps, in particular incandescent lamps, while the electromagnetic phenomenon causing it is referred as voltage fluctuations.

[Equivalent to definition in Clause 3.6 of PD IEC/TR 61000-3-10:2008].

3.16
fluctuating installation
electrical installation as a whole, i.e. including disturbing equipment and non-disturbing equipment, 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 electricity supply system to which it is connected

3.17
fundamental frequency
frequency in the spectrum obtained from a Fourier transform of a time function, to which all the frequencies of the spectrum are referred.

NOTE: For the purpose of this EREC, the fundamental frequency is the same as the power supply frequency.

[Same as definition in PD IEC/TR 61000-3-7:2008].

3.18
high voltage (HV)
voltage exceeding 1 kV

NOTE: Equivalent to definition in the GB Distribution Code [2].

3.19
IEC
International Electrotechnical Commission

3.20
immunity level
maximum level of a given electromagnetic disturbance on a particular device, equipment or system for which it remains capable of operating with a declared degree of performance

3.21
interference
overlap of system disturbance levels and equipment immunity levels resulting in unwanted effects such as visual discomfort, degradation or maloperation of equipment

3.22
long-term flicker severity (P_{lt})
measure of the visual severity of flicker for a specified period derived from the summation of P_{st} values in accordance with the general formula stated in Clause 4 of PD IEC/TR 61000-3-7

NOTE: A 2 h period is specified in this EREC.

3.23
low voltage (LV)
in relation to alternating current, a voltage exceeding 50 V but not exceeding 1 kV

NOTE: Equivalent to definition in the GB Distribution Code [2].

3.24
network operator
owner or operator of a distribution network

NOTE: The term ‘network operator’ primarily applies to licensed Distribution Network Operators (DNOs) and Independent DNOs in the United Kingdom.

3.25
normal operating conditions
variation of generation/demand, the energisation/de-energisation of plant and equipment as a consequence of temporal, seasonal and operational variability, including credible outages, under which the supply system is designed to operate

NOTE: See Clause 6.1.6.

3.26
planning level
level of a particular disturbance in a particular environment, adopted as a reference value for the limits to be set for the emissions from the installations in a particular system, in order to coordinate those limits with all the limits adopted for equipment and installations intended to be connected to the electricity supply system

[Equivalent to definition in Clause 3.19 of PD IEC/TR 61000-3-7:2008]

3.27
point of common coupling (PCC)
point in the public electricity supply system which is electrically closest to the installation concerned and to which other customers are or might be connected

NOTE: The PCC is generally upstream from the installation concerned.

3.28
protective multiple earthing (PME)
TN-C-S LV supply system

NOTE: The term 'TN-C-S' is defined in BS 7671.

3.29
rapid voltage change (RVC)
change in root mean square (r.m.s.) voltage over several cycles

NOTE 1: Rapid voltage changes can also be in the form of cyclic changes.

NOTE 2: See Clause 5.2.

[Similar to definition in PD IEC/TR 61000-3-7:2008].

3.30
service current capacity
the current per phase which can be taken continuously by the customer at their supply terminals without exceeding the plant ratings used by the system/network operator in the design of its system

NOTE: Each part of the LV service equipment that provides the customer connection has a rating, i.e. service cable, cut-out, meter and meter tails. The environment that service equipment is located within affects this rating. In the case of a looped service, the rating is also determined by the service equipment at the adjacent premise(s). Whichever part of the service equipment has the lowest rating defines the service current capacity. It is necessary to consult the network operator to establish the service current capacity. In cases where the network operator declares supply capacities in volt-amperes, the current per phase can be deduced for: single-phase supplies by dividing the volt-amperes by the declared phase-neutral voltage, and three-phase supplies by dividing the volt-amperes by √3 multiplied by the declared phase-phase voltage.

3.31
short-term flicker severity (P_{st})
measure of the visual severity of flicker derived from the time series output of a flickermeter over a 10-minute period

NOTE 1: P_{st} provides an indication of the risk of customer complaints arising from voltage fluctuations.

NOTE 2: P_{st} = 1 for any point on the curve in Figure 2 of BS EN 61000-3-3 (replicated in Annex B) for repetitive and periodic step voltage changes in the form of a square waveform.

NOTE 3: The term 'flickermeter' refers to apparatus for measuring flicker conforming to the requirements of BS EN 61000-4-15.

3.32
step voltage change
change from the initial voltage level to the resulting voltage level after all generating unit automatic voltage regulator (AVR) and static VAR compensator (SVC) actions and transient decay (typically 5 seconds after the fault clearance or system switching) have taken place, but before any other automatic or manual tap-changing and switching actions have commenced

NOTE 1: Automatic voltage regulator also applies to other similar fast acting voltage control responses, e.g. associated with power park modules, HVDC voltage control responses.

NOTE 2: For the purposes of this EREC, percentage step voltage change is the value of step voltage change in volts expressed as percentage change of the nominal system voltage (V_n).

NOTE 3: Step voltage change can be equivalent to the steady state voltage change ($\Delta V_{steadystate}$) (see 4.6).

NOTE 4: By virtue of this definition, a ramped voltage change can be a form of step voltage change and subject to the limit in Clause 5.4.

NOTE 5: Step voltage changes can occur as a result of switching on the system, a fault or operation of disturbing equipment that produces an instantaneous change in steady state voltage.

[Similar to definition in DPC4.2.3.3 of the GB Distribution Code [2]].

3.33
system operator
owner or operator of a transmission system

3.34
transfer coefficient
relative level of disturbance that can be transferred between two busbars or two parts of an electricity supply system for various operating conditions

NOTE: Identical to Clause 3.28 of PD IEC/TR 61000-3-7.

3.35
transmission system
part of a public electricity supply system that requires the owner or operator to hold a Transmission Licence in the United Kingdom

3.36
voltage change
single variation of the r.m.s. value or the peak value of the supply voltage unspecified with respect to form and duration

3.37
voltage dip
temporary reduction of the r.m.s. voltage at a point in the electricity supply system below a specified start threshold

NOTE: Identical to Clause 3.23 of BS EN 50160: 2010+A1: 2015.

3.38
voltage fluctuation
series of voltage changes that can be regular or irregular

NOTE: Types of voltage fluctuation include: repetitive voltage change associated with flicker, rapid voltage change, step voltage change, etc.

3.39
voltage swell
temporary increase of the r.m.s. voltage at a point in the electricity supply system above a specified start threshold

NOTE: Identical to Clause 3.23 of BS EN 50160: 2010+A1: 2015.

3.40
worst case normal operating condition
the condition that results in the maximum short-circuit impedance when measured at the PCC for the various normal operating conditions considered

4 Basic EMC concepts related to voltage fluctuations

4.1 General

Fluctuations in the supply system voltage can result in excessive flicker and can adversely affect the performance, or even damage, electrical equipment. This can result in complaints from customers to the system/network operator.

To minimise the risk of equipment damage and complaints it is necessary to ensure that:

a) customer installations and associated equipment have a level of immunity to voltage fluctuations; and

b) the magnitude and frequency of voltage fluctuations in the supply system do not exceed recommended compatibility and/or planning levels.

EMC is achieved when the supply system disturbance level/emission level is sufficiently low and the equipment immunity level is sufficiently high to prevent interference.

System operators/network operators are responsible for overall coordination of permitted voltage fluctuations to ensure EMC in the supply system. Consequently, this EREC recommends:

a) planning levels for assessing disturbances and emissions from customer disturbing equipment and fluctuating installations to be connected to public electricity supply systems;

b) emission limits for customers' disturbing equipment and fluctuating installations that are or are proposed to be connected to public electricity supply systems.

Compatibility levels for LV public electricity supply systems in the UK are defined in BS EN 61000-2-2.

Equipment immunity levels are specified in relevant Standards[5] or agreed upon between equipment manufacturers and customers; as such no recommendations are made in this document.

4.2 Compatibility levels

Compatibility levels are the reference level in the supply system for setting of emission and immunity limits to ensure the EMC in the whole system (including system and connected equipment).

Compatibility levels are specified for entire supply systems so that there is only a small probability, typically 5%[6], that actual disturbance levels in the entire system will exceed the specified compatibility level. Similarly, there is only a small probability that actual equipment immunity levels will be below the compatibility level.

Compatibility levels for representative transmission systems and distribution networks in the UK are specified in Clause 5.

4.3 Planning levels

Planning levels are used for determining emission limits for individual fluctuating installations and take into consideration emissions from other fluctuating installations, i.e. flicker background levels.

Planning levels are specified at each system voltage level and allow coordination of voltage fluctuations between voltage levels[7].

Planning levels for different voltage levels in transmission systems and distribution networks in the UK are specified in Clause 5.

The nature of planning levels means that voltage fluctuations in parts of the electricity supply system could be higher than these levels.

4.4 Emission limits

Emission limits are maximum emission levels determined for either particular disturbing equipment or fluctuating installations that need to be met as a whole. Emission limits for disturbing equipment connected to LV public electricity supply systems are defined in the BS EN 61000 series of product standards. Emission limits that need to be met as a whole are determined from planning levels specified for the system concerned.

Emission levels are assessed against specified emission limits at a defined point (see 6.1.2). The intention is that under normal operating conditions emission levels do not exceed emission limits at any time.

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5 Immunity levels for products and equipment are specified in individual product standards or in BS EN 61000 Part 3 Standards insofar as they do not fall under the responsibility of product committees.

6 5% is a typical probability value, which may differ in real supply systems.

7 Different planning levels are necessary to take into account transfer of flicker from higher to lower voltage systems/networks.

Emission limits are specified in accordance with the approach in Clause 6 for assessing the connection of disturbing equipment and fluctuating installations to transmission systems and distribution networks.

4.5 Illustration of EMC concepts

Figure 1 and Figure 2[8] illustrate the concept of compatibility levels, planning levels and emission limits and how EMC, relating to voltage fluctuations in the supply system, is achieved.

Figure 1 shows how EMC is achieved on a supply system wide basis.

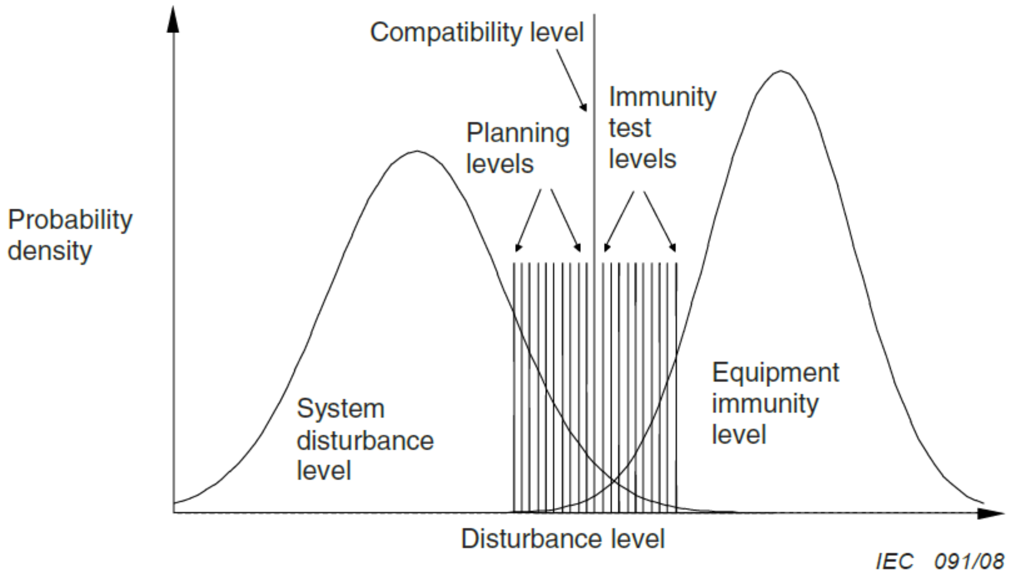

Figure 1 — Illustration of EMC concepts relevant to system

Figure 1 shows that there is a chance that interference might occur at certain times or certain locations in the system. This is recognition that the system operator/network operator cannot control all points of the system at all times.

8 Figure 1 and Figure 2 are reproduced from PD IEC/TR 61000-3-7.

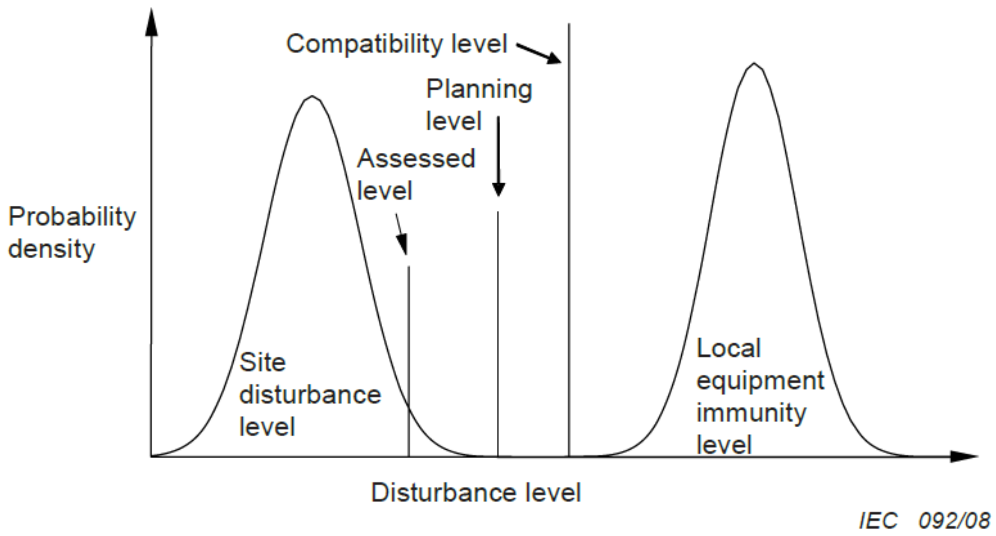

Figure 2 — Illustration of EMC concepts relevant to local site

Figure 2 shows conceptually that, on a local site basis, specifying suitable planning levels should ensure there is no overlap of disturbance and immunity levels.

4.6 Flicker

Flicker is the result of repetitive voltage fluctuations, caused by disturbing equipment, in the supply system, which can be observed by changes in luminance of incandescent lamps.

The severity of flicker is dependent upon the magnitude and the frequency of the voltage fluctuations. High powered process type equipment which does not have a steady power demand and can draw frequently changing current is typically associated with flicker related voltage fluctuations.

The severity of flicker is quantified using flicker severity levels, P_{st} and P_{lt}, where P_{st} is the short-term flicker severity measured over a 10-minute interval and P_{lt} is long-term flicker severity measured over a 2-hour interval, typically. Values of P_{st} and P_{lt} are determined from voltage fluctuation data using a flickermeter algorithm which conforms to the requirements of BS EN 61000-4-15 (see 6.3.1).

4.7 Rapid Voltage Change (RVC)

RVC is a fast change in the r.m.s.[9] voltage between two steady state voltage conditions.

RVCs are generally caused by equipment start-up and shutdown including:

- motor starting/stopping;

[9] RMS is measured over one cycle refreshed every half-cycle in accordance with the method in BS EN 61000-4-30.

- energising transformers;
- switching capacitors/inductors, e.g. capacitor banks and reactors;
- switching in/out of large electrical loads;
- tap-changer operation;
- tripping of load/generation.

RVCs generally relate to infrequent or very infrequent events that can occur randomly on the system/network or events that need to be separated by time periods, which exceed the minimum intervals stated in this EREC.

The characteristics of a voltage dip and a voltage swell are shown in Figure 3 and Figure 4 respectively.

Limits for RVCs are shown in Table 4.

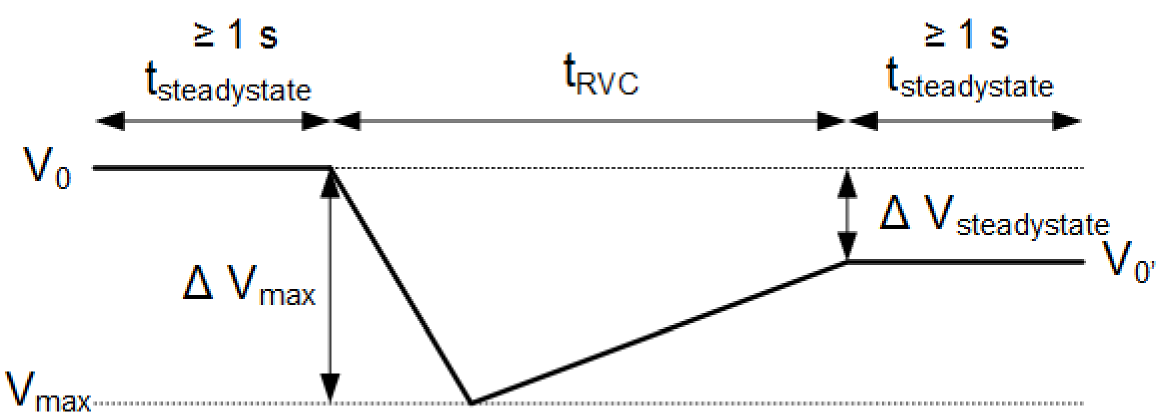

Figure 3 — Illustration of RVC characteristic for voltage dip

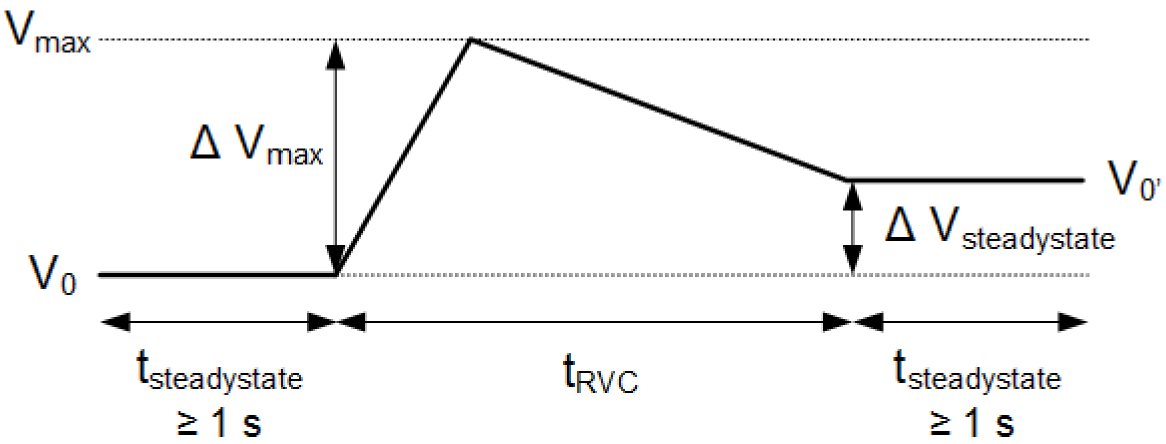

Figure 4 — Illustration of RVC characteristic for voltage swell

Where:

t_{RVC}	is the time duration of the RVC between steady state conditions
V_{max}	is the maximum voltage magnitude between two steady state voltage conditions
V_0	is the initial steady state voltage prior to the RVC
$V_{0'}$	is the final steady state voltage after the RVC
$V_{steadystate}$	is the voltage at the end of a period of 1 s during which the rate of change of system voltage over time is ≤ 0.5%.
ΔV_{max}	is the absolute value of the maximum change in the system voltage (V_{max}) relative to V_0
$\Delta V_{steadystate}$	is the difference in voltage between the initial steady state voltage prior to the RVC (V_0) and the final steady state voltage after the RVC ($V_{0'}$)
$\%\Delta V_{max}$	$= 100 \times \frac{\Delta V_{max}}{V_n}$
$\%\Delta V_{steadystate}$	$= 100 \times \frac{\Delta V_{steadystate}}{V_n}$
V_n	is the nominal system voltage

All voltages are the r.m.s. voltage measured over one cycle refreshed every half cycle in accordance with BS EN 61000-4-30.

For RVCs, $\Delta V_{steadystate}$ equates to the value of step voltage change.

5 Compatibility levels, planning level and emission limits

5.1 General

Separate compatibility levels, planning levels and emission limits apply to different types of voltage fluctuations, i.e. flicker and RVC. Levels/limits for flicker and RVC are stated in Clause 5.2 and 5.3 respectively. Limits for step voltage change are stated in Clause 5.4.

5.2 Flicker

5.2.1 Compatibility levels

The following compatibility levels for flicker in Table 1 are specified for LV supply systems[10].

Table 1 — Compatibility levels for flicker in LV supply systems

Compatibility level	
P_{st}	P_{lt}
1.0	0.8

Compatibility levels are such that there is a 5% probability that measured disturbance in the wider area system could exceed the specified levels based on a statistical distribution of measurements varying in both time and location [on the supply system].

The magnitude of any frequently occurring voltage change should not exceed the limits of the voltage characteristic shown in Figure 5, other than for RVCs (see 4.6)[11].

Compatibility levels should only be used for evaluating system-wide disturbance by system/network operators; planning levels should be used for evaluating the acceptability of disturbance levels at a local site or specific location.

5.2.2 Planning levels

Planning levels for distribution networks and transmission systems in the United Kingdom are dependent upon the nominal voltage of the system.

Planning levels for flicker are specified in Table 2.

Planning levels specified in Table 2 should be used to derive flicker limits for disturbing equipment and fluctuating installations according to the staged approach outlined in Clause 6.3. In principle, disturbing equipment and fluctuating installations that do not meet the criteria for unconditional connection under Stage 1 are required to meet the flicker limit allocated under the Stage 2 assessment. Under special circumstances, remaining headroom may be allocated to the customer, on a ‘first come first served’ basis, under the Stage 3 assessment process for flicker (see 6.3.1).

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[10] Compatibility levels for supply systems with nominal voltages greater than LV are not currently specified.

[11] When measured at the PCC (see 6.1.2).

The planning levels in Table 2 are absolute values and should not be exceeded given the real risk of customer complaints occurring.

The planning levels in Table 2 allow for coordination of voltage fluctuations based on typical transfer coefficients for flicker that have been determined for transmission systems and distribution networks in the United Kingdom such that the likelihood of visual nuisance to LV customers is minimised. In some non-typical parts of a network[12], specific consideration may be required to ensure that flicker at higher voltage levels are co-ordinated to prevent interference.

Table 2 — Planning levels for flicker

Supply system Nominal voltage	Planning level	
	P_{st}	P_{lt}
LV	1.0	0.8
3.3 kV, 6.6 kV, 11 kV, 20 kV, 33 kV	0.9	0.7
66 kV, 110 kV, 132 kV, 150 kV, 200 kV, 220 kV, 275 kV, 400 kV	0.8	0.6
NOTE 1: Planning levels for LV connections are equal to compatibility levels. NOTE 2: The magnitude of P_{st} is linear with respect to the magnitude of the voltage changes giving rise to it. NOTE 3: Extreme caution is advised in allowing any excursions of P_{st} and P_{lt} above the planning level.		

Table 3 — Typical transfer coefficients

System voltage level	T_{Pst} T_{Plt} [1]
400/275 kV to 132/110 kV	0.85
400/275 kV to 66 kV	0.85
400/275 kV to 33/22 kV	0.80
400/275 kV to 20/11/6.6 kV	0.70
132/110 kV to 66 kV	0.95
132/110 kV to 33/22 kV	0.90
132/110 kV to 20/11/6.6 kV	0.75
66 kV to 33/22 kV	0.95
66 kV to 20/11/6.6 kV	0.90
33/22 kV to 20/11/6/6 kV	0.90
11 kV to LV	1.0

[12] For example: Where there are higher than standard impedances between voltage levels, or particularly weak supply systems/networks with long feeders and limited current capacities, which could have higher transfer coefficients.

NOTE 1: Transfer coefficients are typical of those measured in UK transmission systems / distribution networks. NOTE 2: The transfer coefficients are based on the results of data and modelling by National Grid for the GB supply system. NOTE 3: Transfer coefficients equally apply to assessment of RVC as well as flicker.
[1] The transfer coefficients apply to both P_{st} and P_{lt}.

The typical transfer coefficients in Table 3 should be used unless specific flicker propagation data exists (see 7.2.2).

In the absence of specific flicker propagation data or where flicker at the PCC needs to be specifically assessed, it should be assumed that flicker is not transferred from lower voltage systems to higher voltage systems due to the associated increase in short-circuit power.

5.2.3 Emission limits

Emission limits from a fluctuating installation should be such so as to ensure planning levels at the PCC (see 6.1.2) are not exceeded taking into account flicker background levels.

5.3 Rapid voltage changes

5.3.1 Compatibility levels

Compatibility levels for RVC are common across transmission systems and distribution networks in the United Kingdom irrespective of the nominal voltage of the system.

Compatibility levels for RVC are the same as the planning levels specified in Table 4[13].

RVCs emanating from fluctuating installations that are thought likely to be coincident should be specifically assessed to ensure that the combined effect will not result in RVCs exceeding the compatibility level.

5.3.2 Planning levels

Planning levels for RVC are specified in Table 4.

The planning levels in Table 4 define absolute limits of maximum voltage change (ΔV_{max}) and steady state voltage change ($\Delta V_{steadystate}$) for RVCs according to the maximum number of occurrences expected within a specified time period.

These planning levels take into account the need to minimise disturbance to other customers connected to the system, associated with RVCs, whilst recognising that the visual disturbance caused by RVCs is not as severe or frequent as for flicker. The planning levels in Table 4 have been determined so as to avoid maloperation of electrical equipment connected to the system at the maximum voltage change permitted for RVCs.

[13] The assumption being that, in practice, there is no coincidence between RVCs in transmission systems or distribution networks.

Table 4 — Planning levels for RVC

Category	Title	Maximum number of occurrence	Limits $\%\Delta V_{max}$ & $\%\Delta V_{steadystate}$	Example Applicability
1	Frequent events	(see NOTE 1)	As per Figure 5	Any single or repetitive RVC that falls inside Figure 5
2	Infrequent events	4 events in 1 calendar month (see NOTE 2)	As per Figure 6 $\lvert\%\Delta V_{steadystate}\rvert \le 3\%$ For decrease in voltage: $\lvert\%\Delta V_{max}\rvert \le 10\%$ (see NOTE 3) For increase in voltage: $\lvert\%\Delta V_{max}\rvert \le 6\%$ (see NOTE 4)	Infrequent motor starting, transformer energisation, G59 [4] re-energisation (see NOTE 7)
3	Very infrequent events	1 event in 3 calendar months (see NOTE 2)	As per Figure 7 $\lvert\%\Delta V_{steadystate}\rvert \le 3\%$ For decrease in voltage: $\lvert\%\Delta V_{max}\rvert \le 12\%$ (see NOTE 5) For increase in voltage: $\lvert\%\Delta V_{max}\rvert \le 6\%$ (see NOTE 6)	Commissioning, maintenance & post fault switching (see NOTE 7)

NOTE 1: ±6% is permissible for 100 ms reduced to ±3% thereafter as per Figure 5.
If the profile of repetitive voltage change(s) falls within the envelope given in Figure 5, the assessment of such voltage change(s) shall be undertaken according to the recommendations for assessment of flicker and shall conform to the planning levels provided for flicker.
If any part of the voltage change(s) falls outside the envelope given in Figure 5, the assessment of such voltage changes, repetitive or not, shall be done according to the guidance and limits for RVCs.

NOTE 2: No more than 1 event is permitted per day, consisting of up to 4 RVCs, each separated by at least 10 minutes with all switching completed within a two-hour window.

NOTE 3: −10% is permissible for 100 ms reduced to -6% until 2 s then reduced to -3% thereafter as per Figure 6.

NOTE 4: +6% is permissible for 0.8 s from the instant the event begins then reduced to +3% thereafter as per Figure 6.

NOTE 5: −12% is permissible for 100 ms reduced to −10% until 2 s then reduced to -3% thereafter as per Figure 7.

NOTE 6: +6% is permissible for 0.8 s from the instant the event begins then reduced to +3% thereafter as per Figure 7.

NOTE 7: These are examples only. Customers may opt to conform to the limits of another category providing the frequency of occurrence is not expected to exceed the 'Maximum frequency of occurrence' for the chosen category. Where the measured emission level exceeds the expected emission level, paragraph 4 of Clause 6.1.4 applies.

Where:

a) $\%\Delta V_{steadystate} = 100 \times \frac{\Delta V_{steadystate}}{V_n}$ and

$\%\Delta V_{max} = 100 \times \frac{\Delta V_{max}}{V_n}$

b) V_n is the nominal system voltage.

c) $V_{steadystate}$ is the voltage at the end of a period of 1 s during which the rate of change of system voltage over time is ≤ 0.5%.

d) $\Delta V_{steadystate}$ is the difference in voltage between the initial steady state voltage prior to the RVC (V_0) and the final steady state voltage after the RVC ($V_{0'}$).

e) ΔV_{max} is the absolute change in the system voltage relative to the initial steady state system voltage (V_0).

f) All voltages are the r.m.s. of the voltage measured over one cycle refreshed every half a cycle as per BS EN 61000-4-30.

g) The applications in the 'Example Applicability' column are examples only and are not definitive.

The limits for RVCs in Category 2 and Category 3 of Table 4 take into account differences in the perceptibility of RVC compared with flicker associated with continuously fluctuating loads. As such, conformance to flicker limits in Clause 5.1, although desirable, is not a requirement for RVCs in Category 2 and Category 3.

The voltage change limit is the absolute maximum allowed of either the phase-to-earth voltage change or the phase-to-phase voltage change, whichever is the highest. The limits do not apply to single phasor equivalent voltages, e.g. positive phase sequence (PPS) voltages. For high impedance earthed systems, the maximum phase-to-phase, i.e. line voltage, should be used for assessment.

Voltage changes in Category 1 should not only fall within the envelope in Figure 5 but should also meet the flicker limits as determined from assessment of flicker (see 6.3).

RVCs in Category 2 and 3 should not exceed the limits depicted in the time dependant characteristic shown in Figure 6 and Figure 7 respectively.

Any RVCs permitted in Category 2 and Category 3 should be at least 10 minutes apart.

The value of $V_{steadystate}$ should be established immediately prior to the start of a RVC. Following a RVC, the voltage should remain within the relevant envelope, as shown in Figures 5, Figure 6 or Figure 7, until a $V_{steadystate}$ condition has been satisfied.

The voltage change between two steady state voltage conditions should not exceed 3%[14].

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[14] The limit is based on 3% of the nominal voltage of the system (V_n) as measured at the PCC. The step voltage change as measured at the customer's supply terminals or equipment terminals could be greater. For

The limits apply to voltage changes measured at the PCC (see 6.1.2).

At transmission system voltage levels, Category 3 events that are planned should be notified to the relevant Transmission System Operator in advance. At distribution network voltage levels, the requirement to notify planned Category 3 events is at the discretion of the relevant Distribution Network Operator.

Category 2 events do not need to be notified to the system/network operator.

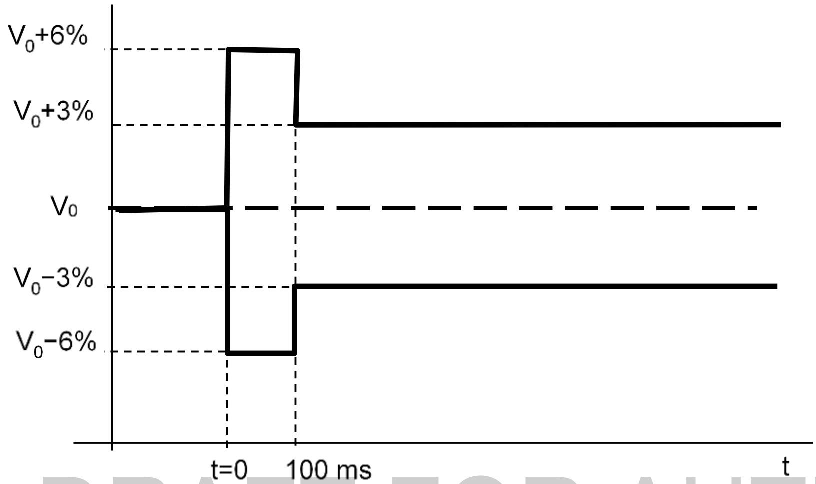
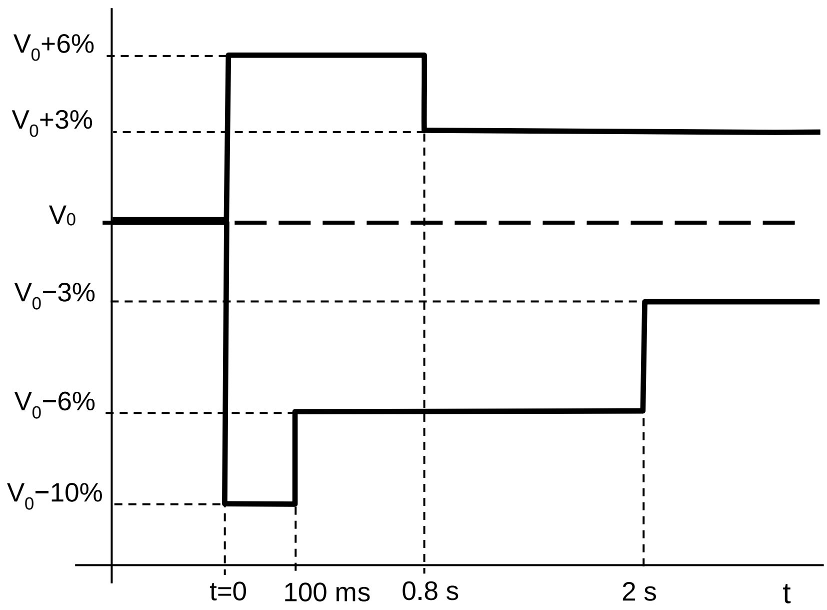


Figure 5 — Voltage characteristic for frequent events



example: The step voltage change limit stated in BS EN 61000-3-3 and BS EN 61000-3-11 is 3.3% when measured at the equipment terminals.

Figure 6 — Voltage characteristic for infrequent events

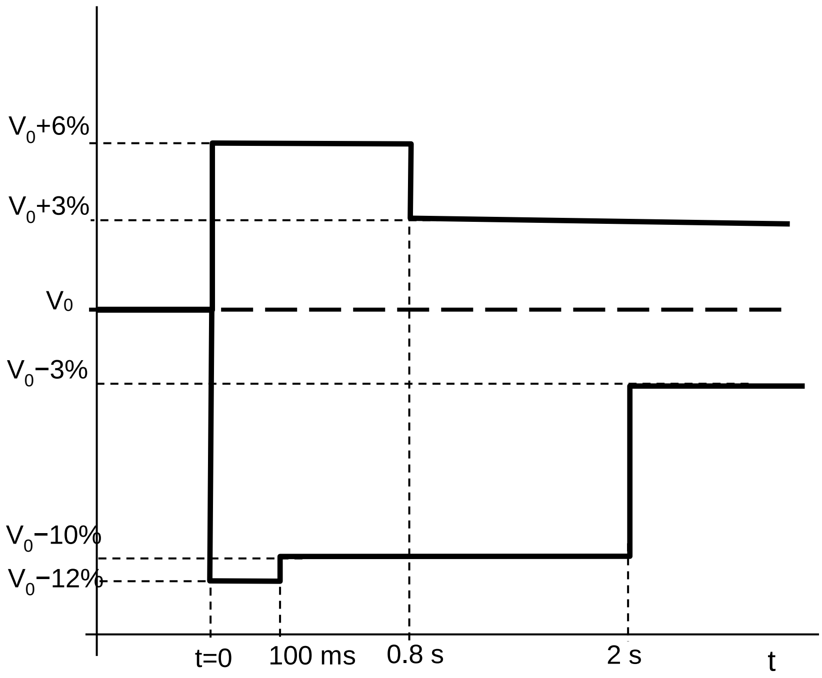


Figure 7 — Voltage characteristic for very infrequent events[15]

5.3.3 Emission limits

RVCs from individual fluctuating installations should not exceed the relevant planning level(s) in Table 4.

Limits for individual fluctuating installations may need to be lower than those in Table 4 where there is likely to be co-incident RVCs from different installations, such that the combined effect of co-incident RVCs from fluctuating installations are within the limits set out in Table 4. Measures should be taken to prevent co-incident RVCs at the PCC, where reasonably practicable. This requires knowledge to be obtained about the potential for RVCs from existing fluctuating installations to coincide with those for proposed connections.

The requirement to prevent co-incident RVCs exceeding the limits in Table 4 at the PCC does not apply to: a) fault clearance operations; or b) immediate operations in response to fault conditions.

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[15] In Northern Ireland, lesser limits than those in Figure 7 apply for as long as Engineering Recommendation G59/1/NI is applied.

5.4 Step voltage change limit

A 3% general limit applies to the magnitude of percentage step voltage changes regardless of frequency of occurrence.

NOTE: For the purposes of this EREC, percentage step voltage change is the value of step voltage change in volts expressed as percentage change of the nominal system voltage (V_n).

6 Assessment of disturbing equipment and fluctuating installations

6.1 General guidelines for assessment

6.1.1 Assessment procedure

Assessment of step voltage change should follow the procedure in Clause 6.2.

Assessment of flicker should follow the procedure in Clause 6.3.

Assessment of RVCs should follow the procedure in Clause 6.4.

The flowchart in Figure 8 summarises the high-level assessment procedure to be followed.

Disturbing equipment and fluctuating installations that can be characterised as producing RVCs but could also result in flicker should be assessed for RVC (see 6.4) and flicker (see 6.3).

NOTE: The relevant clauses in this EREC are identified in parentheses.

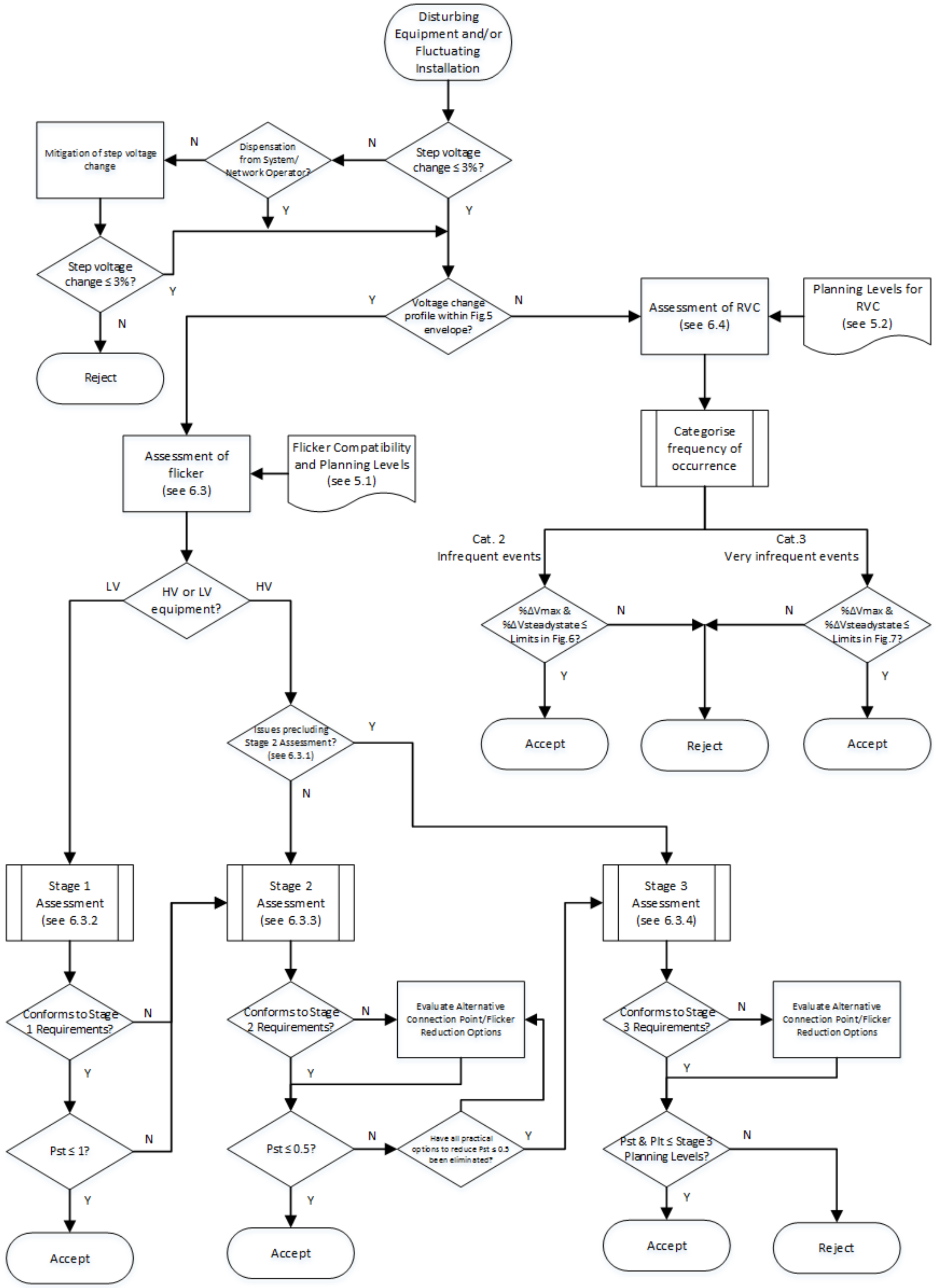

Figure 8 — Flowchart assessment procedure

6.1.2 Point of evaluation

The assessment of voltage fluctuation should be at the PCC unless otherwise specified by the system/network operator when evaluation at the PCC is not appropriate (see 6.3.4).

6.1.3 Capability of equipment to function correctly

Assessment in accordance with this EREC considers the effect of voltage fluctuations from disturbing equipment/fluctuating installations on the capability of other equipment connected to the public electricity supply system to function correctly.

6.1.4 Information requirements and responsibilities

The information to be provided and the responsibilities of the customer and system/network operator in the assessment process should be as those in Table 5.

The system/network operator shall declare maximum values of supply system impedance for networks with a nominal voltage greater than LV in accordance with the provisions of Clause 6.1.5 and Clause 6.1.6.

Details of disturbing equipment should be: provided in a timely manner; sufficiently detailed; and in a format that enables the system/network operator to accurately model it.

Where measured emission levels are found to exceed predicted emission levels in the compliance report and this has a material effect, the system/network operator may:

a) require the customer to take mitigating action, where such action is reasonable;

b) require the customer to disconnect the disturbing equipment until mitigating action can be taken;

c) consider the need to disconnect the fluctuating installation.

Where reasonably practicable, direct measurement of flicker severity should be carried out following connection of the disturbing equipment/fluctuating installation to validate the results of calculation and modelling.

Table 5 — Information requirements and responsibilities *(1 of 2)*

Information	**Requirement**	**Assessment Stage**	**Responsibility**
Supply system impedance - LV only	For single-phase: Measurement of supply phase to neutral loop impedance at the customer supply terminals (see NOTE 1) or Calculation of supply phase to neutral loop impedance at the customer supply terminals for normal supply arrangement (see NOTE 2) For three-phase: Measurement of supply phase to phase supply impedance at the customer supply terminals (see NOTE 1) or Calculation of supply phase to phase impedance at the customer supply terminals for normal supply arrangement (see NOTE 2)	Stage 1	Customer Network Operator (on request) Customer Network Operator (on request)
Service current capacity	Check against Connection Agreement Check service records and/or inspection of cut-out (see NOTE 3)	Stage 1	Customer Network Operator (on request)
Disturbing equipment details:	Type of equipment Rated voltage, current, power Single-phase or three-phase connection Single-phase or three-phase impedance Starting/stopping current characteristics Operating cycle (periods of operation) Statement of EMC compliance with relevant product standards, e.g. BS EN 61000-3-3 (see NOTE 4)	Stage 1,2 & 3	Customer

Table 5 — Information requirements and responsibilities *(2 of 2)*

Information	Requirement	Assessment Stage	Responsibility
P28 compliance assessment	Assess flicker/RVC emission against compatibility/planning levels in P28 Issue 2. Provide compliance report for Network Operator	Stage 2 & 3	Customer (see NOTE 5)
	Assess compliance report from customer for acceptability		System/Network Operator
Emission measurements and validation	Measurement of customer's emission levels and validation against predicted levels in P28 compliance report	Stage 2 & 3	Customer & System/Network Operator (see NOTE 6)
Supply system impedance - except LV (see 6.1.5)	Declaration of maximum supply system impedance at the PCC	Stage 1, 2 & 3	System/Network Operator
Known future connections/ alterations (see 6.1.6)	Provide system/network information in Long Term Development Statements, where available, and similar documents	Stage 1, 2 & 3	System/Network Operator
	Consider known future alterations to the supply system in supply system impedance information (see NOTE 7)		System/Network Operator
	Consider known future connection/alterations (supply system and disturbing equipment/fluctuating installation) in emissions assessment		Customer
Flicker background level (see 7)	Measurement of existing flicker background level (pre-connection)	Stage 3	System/Network Operator

NOTE 1: This check is required to be carried out by a competent person/organisation to ensure the supply impedance is equal to or less than the manufacturer declared maximum supply impedance for the equipment to be installed. For further information see BS EN 61000-3-3 and BS EN 61000-3-11.

NOTE 2: The source impedance upstream of the distribution transformer can be excluded where it is insignificant compared to the impedance of the distribution transformer.

NOTE 3: There is a requirement under BS 7671 (IET Wiring Regulations), to assess supply adequacy. It is important to note that the current rating of the cut-out fuse holder by itself is not indicative of the service current capacity.

NOTE 4: The System/Network Operator may provide assumed data, where data is not provided by the customer and will advise the customer accordingly. The costs could be chargeable to the customer according to the Network Operator's charging statements and methodologies.

NOTE 5: The System/Network Operator may elect to carry out the assessment on behalf of the customer. In this case a summary of the assessment and any relevant data should be provided to the customer on request and subject to meeting any confidentiality requirements.

NOTE 6: Depending upon the extent of studies carried out and the results provided, the system/network operator may decide not to measure customer emission levels for Stage 2 assessments. Notwithstanding, it is incumbent on the customer to ensure that actual emission levels post connection conform to emission limits.

NOTE 7: The onus is on the system/network operator to determine what system developments are known and reasonably foreseeable and to advise these for the assessment of disturbing equipment/fluctuating installations.

6.1.5 Supply system impedance

Where knowledge of supply system impedance is required for calculating the magnitude of voltage fluctuations, then credible maximum values should be used. These values should generally coincide with the worst case normal operating conditions (see 6.1.6). Where operation of disturbing equipment/fluctuating installations is seasonal then supply system impedances at coincident time(s) of year may be used.

When assessing the voltage fluctuation, which would be imposed on the supply to other customers, then only the supply system impedance up to the PCC should be taken into account. The effect on supply system impedance from customer owned local generation that can be relied upon to be in operation may be considered.

Information provided by the system/network operator regarding planned alterations to the public electricity supply system, which would increase or decrease the supply system impedance, should be taken into account[16].

Any local conditions that could increase the supply system impedance at the PCC should be considered (see 6.1.6).

The effects of embedded generation on the supply system impedance should be ignored unless there is a long-term guarantee that this generation would be operating at the same time as the disturbing equipment and/or fluctuating installation. In this case, planned outages of such embedded generation should be considered.

In the absence of seasonal data, the supply system impedance in summer, with minimum generating plant[17] in operation and credible planned outages, should be used.

At LV, the source impedance upstream of HV/LV distribution transformers may be ignored where it is insignificant compared with the impedance of the distribution transformer. The source impedance upstream of 11 000/230 V pole mounted transformers with small rated powers should not be ignored.

For assessing voltage fluctuation caused by three-phase connected equipment, the initial symmetrical short-circuit impedance of the supply system, Z_k'' (R_k'' and X_k''), should be used.

NOTE: The short-circuit impedance Z_k'' corresponds to the initial symmetrical short-circuit current, I_k''.

Where the initial symmetrical short-circuit impedance of the supply system, Z_k'' is not available then the symmetrical short-circuit breaking current I_b may be used to calculate the short-circuit impedance of the supply system.

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16 Planned system alterations and associated changes to fault levels can be obtained from Long Term Development Statements, where available, and similar documents prepared by system/network operators, noting that the fault levels in Long Term Development Statements are maximum fault levels.

17 'Minimum generation plant' equates to the expected minimum aggregated power output of generation connected to the system in any year, which is consistent with the lowest contribution from generation to system fault levels.

As the symmetrical short-circuit breaking current I_b is normally smaller than the initial symmetrical short-circuit current I_k'', using I_b instead of I_k'' for assessing voltage fluctuation would normally produce a more pessimistic result[18].

For assessing voltage fluctuation caused by single-phase connected equipment, the short-circuit loop impedance between the source and load should be used, whether that is between the phase and neutral or between two phases of the supply system.

For assessing RVC the appropriate subtransient reactance of the disturbing equipment should be used, where this information is available.

6.1.6 Normal operating conditions

Voltage fluctuations should be assessed under the worst case normal operating condition(s) unless specified otherwise by the system/network operator.

Normal operating conditions for the supply system include those operating conditions in Table 6, where the system/network is designed to remain within acceptable/statutory limits.

Voltage fluctuations during credible outage conditions should be considered, including planned and/or fault outages consistent with those where there is a requirement to secure demand as required by security of supply standards, i.e. ENA Engineering Recommendation P2 for HV distribution networks[19] and National Electricity Transmission System Security and Quality of Supply Standards (NETS SQSS) for transmission systems[20]. For generation, the most onerous condition(s) the generator(s) will be expected to normally operate should be considered.

For an arrangement where there are two transformers in a system/network operator's substation that are normally operated in parallel, a planned outage of one transformer would generally result in the worst case normal operating condition.

Considerations of outages in the electricity supply system may be disregarded for assessment of LV disturbing equipment/fluctuating installations.

Voltage fluctuations are not expected to conform to planning levels under the following conditions.

a) Temporary/abnormal conditions or whilst steps are taken to maintain/restore supplies to customers, where otherwise supplies would be interrupted[21].

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18 Further information on short-circuit currents can be found in BS EN 60909-0.

19 For HV distribution networks, a first circuit outage condition generally only needs to be considered, where a 'first circuit outage' condition refers to a single outage (planned or fault) of a circuit or item of plant.

20 For transmission systems, a second circuit outage condition generally needs to be considered, where a 'second circuit outage' condition refers to a first circuit outage (planned or fault) with the additional consideration of a fault outage on a second circuit or item of plant within the same load group as the first.

21 For example: Most 6.6 kV, 11 kV, 20 kV and 33 kV networks are not designed to operate within acceptable limits for a second circuit outage condition.

b) Emergency conditions.

Particular care should be taken when considering the effect of local system outages given the following.

a) An outage of a local circuit might not give rise to the worst case normal operating condition.

b) An outage of a local circuit needs to be considered together with wider system outage scenarios so minimum acceptable security of supply standards are still met.

Table 6 — System/network conditions - Normal operating conditions

System/network operating condition	Description
Normal network configuration	Normal running arrangement with normal open point(s). No network assets out-of-service for construction, maintenance or faults
Alternative network configuration(s)	Alternative running arrangement(s) with substitute open point(s). No network assets out-of-service for construction, maintenance or repair
Planned outages (see NOTE)	Planned outages of specific network assets for construction, maintenance or repair activities
Fault outages (see NOTE)	Running arrangement taking into account credible fault outage scenario(s) for normal/alternative network configuration(s). Compliant with network design limits before fault outage and within a short time after fault outage, where reconfiguration of network is required
Switching operations (including reactive compensation)	Energisation and de-energisation of network assets. Reactive compensation. Reconfiguration of network
Protection operation (including G59 [4] protection operation)	Operation of protection and disconnection of load/generation for which the network is designed to cater for
Demand / generation variations	Variations in demand/generation within rating of network under normal and alternative network configurations
Local embedded/distributed generation	Generally, can be ignored unless there is a long-term guarantee that this generation would be operating at the same time as the disturbing equipment and/or fluctuating installation (see 6.1.5)
NOTE: For various credible planned/fault outage scenarios the scenario that results in the maximum supply system impedance should be generally chosen.	

Where operation of the disturbing equipment/fluctuating installation can be assured so as not to coincide with a particular network operating condition then assessment of that particular network operating condition can be discounted.

6.1.7 Exceeding planning levels

Where emission levels are assessed to exceed the planning levels in this EREC, options for reducing emission levels to acceptable levels should be evaluated. These include but are not limited to:

a) a change in the supply system arrangement including new proposed connection point that would reduce the maximum supply system impedance and/or reduce the disturbance at the PCC;

b) modification to the disturbing equipment or fluctuating installation to reduce voltage fluctuations including use of compensation equipment/techniques[22].

Any cost of taking remedial action to conform to planning levels should be borne by the customer.

Further information on mitigation actions can be found in Part 5 of the BS EN 61000 series of EMC Standards.

Emission levels higher than specified emission limits may be permitted by system/network operators under certain circumstances. Guidance can be found in ENA Engineering Report P28 [8].

6.2 Assessment of step voltage change

Conformance to the 3% step voltage change limit should be assessed as a first step.

In certain cases, where special circumstances apply, the system/network operator may, at its discretion, allow larger step voltage changes to occur, e.g. continuous process plant where larger motors are only started once in several months. The system/network operator may also give special limited approval for the use of some types of equipment that result in step voltage changes in excess of 3% without the need for individual consideration.

6.3 Assessment of flicker

6.3.1 General

Assessment of flicker severity is based on the long established and reliable measures P_{st} and P_{lt}. These measures should be used for assessing disturbance to all other equipment connected not just lighting.

Flicker severity shall be characterised according to a flickermeter conforming to the requirements of BS EN 61000-4-15.

The 95th percentile value of P_{st} and P_{lt} measured over 1 week should be used to assess flicker against flicker planning levels in Table 2. Where measurements are made over several weeks then the value of flicker severity for each weekly measurement period should not exceed the applicable planning limits.

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22 For example: point-on-wave switching for energising transformers.

NOTE: Where flicker severity is measured over a number of weekly measurement periods, the values in each week of measurement need to conform to the applicable planning limit, not the flicker severity over the whole measurement period.

It is generally acceptable for customers to connect disturbing equipment to LV public electricity supply systems without any reference to the network operator or specific assessment of flicker providing:

a) the disturbing equipment is declared as conforming to that part of BS EN 61000 appropriate to the product; and

b) the LV supply system source impedance at the customer supply terminals is equal to or less than:

   i. the reference impedance (Z_{test})[23] stated in that part of BS EN 61000 appropriate to the product; or

   ii. the maximum value of the supply impedance at which equipment would meet required limits (Z_{max}), as declared by the equipment manufacturer.

The LV public electricity supply system impedance can be determined by one or more of the following approaches.

a) Use of generic supply system impedance values for metered connections (see Table 7).

b) Measurements of supply system impedance.

c) Specific supply system impedance values provided by the network operator.

The following supply system impedances, based on generic values of supply impedance for LV public electricity supply systems in the United Kingdom, may be used for approximate calculations in the absence of measurements or specific LV supply system impedance data.

Table 7 — Generic supply impedance for LV metered connections

Supply	Service capacity (per phase)	Supply impedance (single-phase connections)	Supply impedance (three-phase connections)
230 V single-phase PME supply	< 100 A	0.34 Ω	-
230 V single-phase non PME supply	<100 A	0.47 Ω[A]	-
400 V three-phase supply	150 A	0.42 Ω	0.25 Ω
400 V three-phase supply	200 A	0.31 Ω	0.19 Ω
400 V three-phase supply	300 A	0.21 Ω	0.13 Ω
400 V three-phase supply	400 A	0.16 Ω	0.10 Ω
400 V three-phase supply	600 A	0.10 Ω	0.06 Ω

23 Z_{ref} represents a maximum value of source impedance, which is used for testing the appliance or disturbing equipment.

NOTES: 1 The values of supply impedance are derived from values in Table 1, Table 5 and Table 6 of PD IEC/TR 60725, which have been deemed most appropriate to the United Kingdom. 2. For three-phase supplies the supply impedance to be used will depend upon whether disturbing equipment is connected single-phase or three-phase.
[A] Derived from survey data for the UK published in PD IEC/TR 60725, where 98% of 230 V single-phase supplies with <100 A capacity had a supply system impedance, measured at the supply terminals, less than or equal to 0.4 + j0.25 Ω.

NOTE: Actual LV supply system impedances might be higher than the typical values stated. For example, where supplied from pole mounted transformers with low rated power and LV mains cables or service cables with small cross-sectional area.

For LV supplies with a declared supply capacity ≥ 100 A then specific data provided by the network operator should be used for assessment of flicker.

Where individual items of disturbing equipment within a fluctuating installation work together as a system,[24] flicker from the system, as well as those from the individual items of disturbing equipment, should be assessed against the relevant requirements in this EREC.

Assessments should follow a three-stage procedure summarised in Figure 9.

Stage 1 (see 6.3.2) is a simplified assessment for assessing discrete items of LV equipment based on equipment standards; it is not applicable to HV connections or to the assessment of disturbing equipment that work together as a system, which should be assessed under Stage 2. LV disturbing equipment and/or fluctuating installations that meet the Stage 1 assessment criteria can be connected without specific assessment or reference to the network operator. The assessment criteria are such that individual LV equipment conforming to relevant BS EN 61000 product standards or the connection of multiple items of similar LV equipment with limited fluctuating power can be connected under Stage 1 with no prospect of interference.

Stage 2 (see 6.3.3) is an assessment of flicker levels from disturbing equipment and/or fluctuating installations against a specified planning level. The assessment does not require the existing flicker background level to be taken into account. Disturbing equipment and/or fluctuating installations can be connected under Stage 2 without reference to the network operator or further assessment providing emission levels do not exceed the emission limits of $P_{st} \leq 0.5$ (see Figure B.1.2) for the system voltage level concerned. Where expected flicker severity exceeds the limit in Stage 2, then subject to addressing the particular requirements of the system/network operator, the disturbing equipment and/or fluctuating installation may be eligible for Stage 3 assessment.

Stage 3 assessment (see 6.3.4) applies where:

a) emission levels exceed the specified emission limit in Stage 2 despite:

24 For example: Individual micro inverters that form part of a larger PV system or indoor and outdoor parts of a heat pump installation that work together to form a system.

i. good engineering practice having been followed in the design of the disturbing equipment and/or fluctuating installation; and

ii. reasonably practicable alternative connection points and flicker reduction options having been evaluated and discounted.

b) there is a possibility, based on the system/network operator's knowledge of flicker background levels and any other proposed connection(s), that additional flicker with a $P_{st} > 0.5$ would result in planning levels being exceeded.

The assessment is such that existing flicker background level and emission levels from the disturbing equipment and/or fluctuating installation at the PCC need to be taken into account. Disturbing equipment and/or fluctuating installations can be connected under Stage 3 providing the available headroom allocated under Stage 3 assessment is not exceeded.

Disturbing equipment connected to the HV system and/or fluctuating installations connected to the HV system should be assessed under Stage 2 and should not be permitted to be assessed under Stage 3 unless the agreement of the system/network operator is obtained.

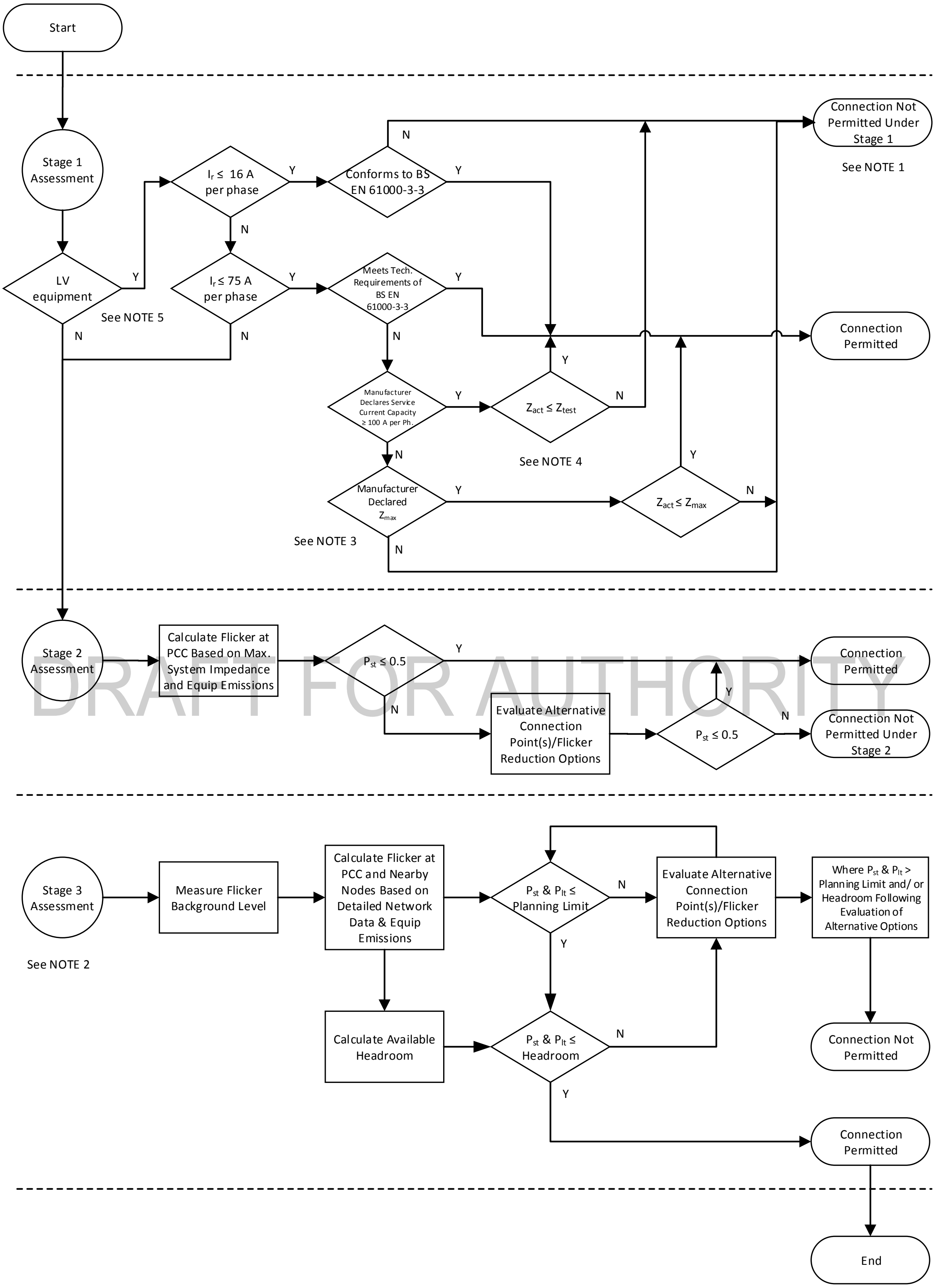

Figure 9 — Three-stage flicker assessment approach

NOTE 1: LV equipment with a rated current (I_r) ≤ 16 A that does not conform to the limits in BS EN 61000-3-3 may be retested and evaluated to show conformance with BS EN 61000-3-11.

NOTE 2: See 6.3.1 concerning the criteria for assessment and connection under Stage 3.

NOTE 3: Zact is the modulus of the actual supply impedance at the customer supply terminals.

NOTE 4: Ztest = 0.15 + j015 Ω for three-phase equipment & Ztest = 0.25 + j0.25 Ω for single-phase equipment.

NOTE 5: Where the PCC is at HV not LV, Stage 1 assessment of LV equipment is not appropriate.

6.3.2 Stage 1 assessment

6.3.2.1 Household appliances and similar electrical equipment

Household appliances and similar electrical equipment with a rated current ≤ 16 A per phase and conforming to BS EN 61000-3-3 are not subject to conditional connection and can be connected to LV public electricity supply systems under this stage without reference to the network operator or further assessment based on LV supply impedance not exceeding the following typical maximum values at the customer supply terminals.

a) Phase-neutral loop impedance of 0.4 + j0.25 Ω ($|Z|$ = 0.472 Ω) for single-phase 230 V connections.

b) Three-phase impedance of 0.24 + j0.15 Ω (|Z| = 0.283 Ω) for three-phase connections.

Interference is very unlikely given network operators design their LV networks to have significantly lower source impedances than those stated in a) and b)[25]. However, it should be recognised that the LV supply impedance of service connections installed pre-1950[26] could be higher than the typical maximum values stated. Where there is doubt whether the impedance at the customer supply terminals is less than the typical maximum values stated then the LV supply impedance should be measured.

Household appliances and similar electrical equipment with a rated current ≤ 16 A per phase but not conforming to emission limits in BS EN 61000-3-3 are subject to conditional connection and can be connected to LV public electricity supply systems under this stage providing they conform to BS EN 61000-3-11 (see 6.3.2.2).

6.3.2.2 Equipment with a rated current ≤ 75 A

Equipment with a rated current ≤ 75 A can be connected to LV public electricity supply systems under this stage without reference to the network operator providing it conforms to the technical requirements in BS EN 61000-3-3 and the service current capacity is confirmed as being adequate for connection of the equipment.

NOTE: Regulation 132-16 of BS 7671 (The Wiring Regulations) requires that the rating and condition of any existing equipment, including that of the network operator, is ascertained as being adequate before any additional or altered equipment is connected.

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[25] LV public electricity systems that are TN-C-S (PME) will typically have a supply impedance ≤ 0.35 Ω.

[26] Services installed pre-World War II and those installed in some council housing estates in the late 1940's and early 1950's could exceed the typical maximum values of LV supply impedance for modern day networks.

Equipment with a rated current > 16 A per phase and ≤ 75 A per phase, not conforming to the technical requirements in BS EN 61000-3-3, is subject to conditional connection and can be connected to LV public electricity supply systems under this stage providing it conforms to the technical requirements in BS EN 61000-3-11.

Equipment that is subject to conditional connection [as required by this clause] can only be connected to the LV public electricity supply system without reference to the network operator providing either:

a) the LV supply impedance at the customer supply terminals is confirmed by measurement (see 7) or from calculated values provided by the network operator as being equal or less than the value (Z_{max}) declared by the equipment manufacturer in the equipment instruction manual; or

b) at the customer supply terminals:

   i. the service current capacity is confirmed as being ≥ 100 A per phase, as required by the equipment manufacturer in the equipment instruction manual, and the equipment has been clearly marked to this effect by the manufacturer; and

   ii. the LV supply impedance is confirmed by measurement as being equal or less than 0.25 + j0.25 Ω (|Z| = 0.35 Ω) for single-phase connections or 0.15 + j0.15 Ω (|Z| = 0.212 Ω) for three-phase connections[27].

The presence of a fuse carrier rated for 100 A per phase does not necessarily mean that the service has a current capacity ≥ 100 A per phase. Where there is doubt regarding the service current capacity at the customer supply terminals or the actual value of LV supply impedance, the installer should contact the relevant network operator for information.

Equipment to be connected to the LV supply system that does not conform to emission limits in both BS EN 61000-3-3 and BS EN 61000-3-11 may be assessed under Stage 2.

NOTE: It is unlikely that disturbing equipment that does not conform to emission limits in both BS EN 61000-3-3 and BS EN 61000-3-11 would meet the limits in Stage 2.

When assessing the suitability of high rated power equipment, i.e. > 16 A per phase, for connection to the public electricity supply system, consideration should be given to: whether the equipment is normally switched infrequently; whether it is designed to avoid unnecessary rapid cycling by control systems; and the magnitude of steady state voltage change to ensure that flicker problems do not arise.

The connection of multiple items of similar LV equipment is addressed in Clause 6.3.2 of BS EN 61000-3-11.

[27] The LV supply impedance for single-phase connections is the phase-neutral loop impedance not the earth fault loop impedance.

6.3.3 Stage 2 assessment

6.3.3.1 General

LV connections that do not come under the Stage 1 assessment process (See Figure 9) and all HV connections should be assessed under the Stage 2 assessment process described in this clause.

Under the Stage 2 assessment process, individual disturbing equipment that is assessed to result in flicker with $P_{st} \leq 0.5$ under the worst case normal operating condition at the PCC can be connected without further detailed assessment[28]. No measurement of existing flicker background level is required for Stage 2 assessment.

An assessment of the P_{st} resulting from connection of the disturbing equipment/fluctuating installation should be conducted. This should be done by simulation, calculation or measurement. Rules to simplify the waveforms generated by particular types of equipment are given in Clause 6.3.3.4.

Simulation of flicker severity from the voltage change characteristics of the disturbing equipment/fluctuating installation being assessed may be carried out using a flicker simulation program providing this accurately simulates the flickermeter in BS EN 61000-4-15[29]. The use of a flickermeter is the preferred method of evaluating flicker severity.

For simple step voltage change patterns or ramp voltage change patterns, or combinations of the two, a simple approximation of P_{st} may be calculated using the 'memory time' technique. The method and examples for calculating P_{st} can be found in Annex G of PD IEC/TR 61000-3-7. Flicker severity should be assessed by simulation if:

a) there is any doubt regarding the values calculated; or

b) the calculated flicker severity is within ±10% of the Stage 2 limit.

Where flicker measurements exist elsewhere for similar disturbing equipment/fluctuating installations to that being assessed, then these measurements may be scaled for the proposed PCC and supply system impedance. The method should follow that in Annex G of PD IEC/TR 61000-3-7, where the ratio of the voltage change is directly proportional to the ratio of the supply system impedance for the worst case normal operating condition at the respective PCCs.

6.3.3.2 Simplified assessment of step voltage changes

The following simplified assessment approach may be applied to most disturbing equipment that causes step voltage changes, ramp voltage changes or simple combinations of these two types of voltage change. Recommendations for assessing other types of voltage change are described in Clause 6.3.3.4.

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[28] Connection of 8 individual disturbing loads each with $P_{st} = 0.5$ and an exponent of $\alpha = 3$ summate to a resultant $P_{st} = 1$. Further information about flicker summation exponents can be found in Table 8.

[29] This Engineering Recommendation does not recommend any particular flickermeter simulation program. However, any party carrying out assessments using flickermeter simulation programs could be required to demonstrate its suitability and accuracy.

The limit of P_{st} = 0.5 for the maximum allowable magnitude of step voltage change with respect to the time between each change is shown by the line in Figure B.1.2.

This limit does not represent the maximum tolerable P_{st} at the PCC but is a value that generally allows individual items of disturbing equipment, which conform to this limit at the PCC, to be connected without any significant probability that the planning level would be exceeded.

Disturbing equipment that results in a flicker severity at any point on or below the line in Figure B.1.2a) can be connected without further detailed assessment.

Figure B.1.2b) is the inverse characteristic of Figure B.1.2a) and shows the maximum number of voltage changes per minute for a given % voltage change.

A step up in voltage followed by a step down in voltage constitutes two separate voltage changes.

Such voltage changes, where the duration between step up and step down are ≤ 1 s are known as 'pulse changes'. Pulse changes can be equated to a single step voltage change for use in Figure B.1.2 using Figure E.1 in PD IEC/TR 61000-3-7.

6.3.3.3 Simplified assessment of ramp voltage changes

Ramp voltage changes are less noticeable in terms of flicker than step voltage changes of the same size.

Figure B.2.5 provides a simplified method for deriving an equivalent step voltage change from ramp voltage changes with different rise/fall times, where the equivalent relative step voltage change is equal to the shape factor (*F*), determined from the characteristic in Figure B.2.5, multiplied by the maximum voltage change (d_{max}).

NOTE: The term d_{max} used in BS EN 61000-3-3 is equivalent to ΔV_{max} used in this EREC.

The acceptability of the voltage change, in terms of flicker, may then be considered as an assessment of simplified step voltage change (see 6.3.3.2).

6.3.3.4 Shape factors

Shape factors may be used for simplified P_{st} assessments for both periodic and non-repetitive voltage fluctuations. Voltage fluctuations of a more random nature, such as those produced by electric arcs, require more advanced techniques for accurate prediction.

In many cases, voltage fluctuations produced by disturbing equipment follow known shapes and predictable patterns. In these cases, the flicker severity that would be produced for a given magnitude of voltage change and shape may be determined using shape factors. These shape factors have been determined from flickermeter simulation programs and can be used in conjunction with the P_{st} = 1 curve to predict P_{st} for known shapes (other than square waveforms).

NOTE: The magnitude of voltage change can be determined from simplified calculations, flickermeter simulation programs or historical data for similar disturbing equipment whereas some knowledge of the operational pattern produced by the disturbing equipment is necessary to evaluate the overall shape of the voltage fluctuation.

The shape factor curves in Annex B may be used for the following fluctuation shapes/patterns.

a) Shape factor curve for pulse and ramp changes.

b) Shape factor curves for double-step and double-ramp changes.

c) Shape factor curves for sinusoidal and triangular changes.

d) Shape factor curve for motor-start voltage characteristics.

6.3.4 Stage 3 assessment

Disturbing equipment that is not permitted to be connected under Stage 2 (see 6.3.3) should be subject to Stage 3 assessment, where agreed by the system/network operator, where a detailed assessment of existing flicker background levels and projected flicker severity should be carried out with the addition of the proposed disturbing equipment/fluctuating installation. In this case the customer should provide all the necessary data to the system/network operator for study purposes (see 6.1.4).

Disturbing equipment and/or fluctuating installations with stochastic voltage fluctuations, such as arc furnaces, should generally be subject to Stage 3 assessment[30].

The flicker background level should, where practicable, be measured at the PCC (see 7.2) during periods the proposed disturbing equipment and/or fluctuating installation is likely to be in operation. Where this is not practicable, the flicker background level may be determined by extrapolation of measurements taken at nearby nodes.

Although the highest flicker level will normally be at the connection point, it could be at another location between the connection point of the proposed disturbing equipment/fluctuating installation and the main source of existing flicker background levels, where existing flicker background levels are high, i.e. $P_{st} > 0.5$. The method in Annex C of PD IEC/TR 61000-3-7 may be used in conjunction with the flicker transfer co-efficient in Table 3 [of EREC P28] to transfer flicker measured at remote nodes to the PCC under consideration.

Where there is doubt about the location of the highest flicker levels then further measurements of flicker background levels should be taken at other locations. In addition, further modelling should be carried out by the customer to determine the location and magnitude of the highest flicker level. Particular consideration should be given to whether the highest flicker levels can be found on the LV network as a result of:

a) existing high flicker background levels on the LV network; and

b) the additional flicker transferred from proposed disturbing equipment/fluctuating installations to be connected to the higher voltage supply system.

30 This recommendation does not preclude assessment under Stage 2, where flicker is expected to conform to the limits in Stage 2.

Where there is reason to believe the flicker background level might be relatively high, $P_{st} > 0.5$ then a direct measurement of the flicker background level at the PCC should be carried out at the pre-connection study stage. A more detailed evaluation of flicker background level may be carried out to identify any scope to reduce flicker levels.

The short-term flicker severity (P_{st}) for the proposed disturbing equipment and/or fluctuating installation should be determined from either:

a) previous measurements of P_{st} for identical disturbing equipment (see NOTE);

b) scaling characteristics of similar disturbing equipment with known P_{st} values;

c) flickermeter simulation[31].

NOTE: A change in network characteristics, e.g. fault level, can affect P_{st} levels even when identical equipment is used elsewhere. The fact that equipment used elsewhere has not resulted in flicker issues does not mean it will continue not to when moved or used at a new network location without assessment.

The effects of any known future connections or system changes, including use of previous measurements of P_{st} for identical equipment used elsewhere, should be assessed[32].

The P_{st} values of the proposed disturbing equipment and/or fluctuating installation, the P_{st} values of any known future connections or system changes and the P_{st} values of flicker background should be summated using the general summation law (see Equation 1).

$$P_{st} = \sqrt[\alpha]{\sum_{i=1}^{i=n} P_{sti}{}^{\alpha}}$$ Equation 1

where:

P_{st} is the magnitude of the resulting short-term flicker level for the considered aggregation of flicker sources (probabilistic value)

P_{sti} is the magnitude of the various flicker sources or emission levels to be combined

α is an exponent that depends on various factors (see Table 8)

Where the summated P_{st} values exceed the P_{st} planning levels in Table 2, connection of the proposed disturbing equipment and/or fluctuating installation should not be permitted.

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[31] Computer programs that simulate flicker severity are commercially available.

[32] Information about known future connections and system changes can be obtained from Long Term Development Statements (LTDS) published by system/network operators, where available, or on request from system/network operators. This includes the Electricity Ten Year Statement (ETYS) for transmission systems in GB.

The long-term flicker level should be calculated from short-term flicker levels using Equation 2.

$$P_{lt} = \sqrt[3]{\frac{1}{n} \sum_{j=1}^{j=n} {P_{stj}}^{3}} \qquad \text{Equation 2}$$

where:

P_{lt} is the magnitude of the resulting long-term flicker level for the aggregation of short-term flicker levels over the time which P_{lt} is required to be measured (see NOTE)

n is the number of P_{st} values in the time over which P_{lt} is required to be measured

P_{st} is the magnitude of the resulting short-term flicker level for the considered aggregation of flicker sources (probabilistic value)

NOTE: P_{lt} is normally evaluated over a 2 h period, where n = 12.

Where relevant, multiple values of P_{lt} should be summated using the general summation law (see Equation 1) as for P_{st} values. Where the P_{lt} value or the summated P_{lt} values exceed the P_{lt} planning levels in Table 2, connection of the proposed disturbing equipment and/or fluctuating installation should not be permitted.

Where consent is given to connect disturbing equipment or a fluctuating installation following Stage 3 assessment, the system/network operator should measure flicker severity at the PCC following commissioning to verify that the actual measured values are consistent with the assessment and, in the worst case, do not exceed the Stage 3 planning levels. If measurements are made at some other point then the results should be transposed to the PCC, with consideration to using the actual compared with the minimum supply system impedance declared by the system/network operator.

Where two or more applications are received to connect new disturbing equipment/fluctuating installations on the same part of the existing electricity supply system, the extent of interaction and their cumulative effect should be considered. If it is not practicable to connect all of the affected parties without exceeding planning limits, it may be permissible to connect all parties by carrying out mitigating measures. However, following connection of the first party and on-site measurement of the resultant flicker severity levels it might be permissible to connect additional disturbing equipment/fluctuating installations. In such circumstances, the system / network operator will inform all affected parties of the situation and will determine the terms of their connection offers.

Flicker levels should be measured at the PCC, with the disturbing equipment/fluctuating installation:

a) connected to the system/network, i.e. to measure the overall flicker level; and

b) disconnected from the system/network, i.e. to measure the flicker background level.

If the disturbing equipment/fluctuating installation is not connected to a “clean” flicker free system/network, the flicker level should be determined by subtracting the flicker background level from the overall flicker level using the summation law equation (see Equation 1).

Table 8 — Flicker summation exponents

Exponent	Application
$\alpha = 4$	Should be used for the summation of flicker when simultaneous voltage fluctuations are very unlikely to occur (e.g. specific equipment controls are installed so as to prevent simultaneous fluctuations and arc furnaces are specifically run to avoid coincident melts).
$\alpha = 3$	Should be used for the summation of flicker for most types of flicker sources where the risk of coincident voltage fluctuations is small. The majority of studies combining unrelated disturbances fall into this category and it is recommended for general use and when where there is any doubt over the magnitude of the risk of coincident voltage fluctuations occurring.
$\alpha = 2$	Should be used for the summation of flicker when coincident voltage fluctuations are likely to occur (e.g. coincident melts on arc furnaces).
$\alpha = 1$	Should be used for the summation of flicker when there is a very high occurrence of coincident voltage fluctuations (e.g. when multiple motors are started at the same time).
NOTE 1: Applies to the addition of either P_{st} or P_{lt} from various sources. NOTE 2: The lower value of α equates to higher coincidence of voltage changes, where α = 1 is the lowest.	

An exponent of $\alpha = 3$ should be used for summation of flicker unless there is information/justification to support the application of another exponent.

There might be applications where using an exponent of $\alpha = 3$ is too conservative, particularly where the risk of coincident voltage fluctuations is very low.

Where the measured flicker background level is $P_{st} > 0.5$ then a more refined method should be used to validate how voltage changes from the fluctuating installation correlate with measured voltage changes.

6.3.5 Simplified voltage change evaluation

For balanced three-phase a.c. electricity supply systems the percentage voltage change caused by disturbing equipment can be derived as follows.

Where the supply system impedance is stated as per unit resistance and per unit reactance values on a base MVA:

$$\frac{\Delta V}{V} = \frac{S}{S_{base}} \left(\cos\varphi \,.\, R_{p.u.} + \sin\varphi \,.\, X_{p.u.}\right) \qquad \text{Equation 3}$$

Where:

ΔV/V Voltage change per unit (p.u.)

S Apparent power change in MVA of the disturbing equipment

S_{base} Base MVA of the supply system impedance

φ Power factor of the disturbing equipment

$R_{p.u.}$ Supply system resistance per unit

$X_{p.u.}$ Supply system reactance per unit

NOTE: Voltage change percent (%) is equivalent to $\Delta V/V$ x 100.

Where the supply system short-circuit power (see 6.1.5) is stated in MVA and the power factor of the load is assumed to be the same as the ratio of supply system resistance to supply system impedance[33]:

$$\frac{\Delta V}{V} = \frac{S}{S_k^{"}} \times 100 \qquad \text{Equation 4}$$

Where:

$\Delta V/V$ Voltage change percent (%)

S Apparent power change in MVA of the disturbing equipment

$S_k^{"}$ Supply system initial symmetrical short-circuit power MVA

Examples of more detailed calculations of voltage changes can be found in Annex G of PD IEC/TR 61000-3-7.

6.3.6 Assessment of equipment against EMC generic standards

Where a dedicated product EMC standard does not exist, then disturbing equipment may be connected to the supply system subject to meeting the requirements and levels for flicker in BS EN 61000 Part 6 Generic standards and with the specific consent of the system/network operator.

Equipment intended to be directly connected to the LV public electricity supply system conforming to BS EN 61000-6-3 shall be subject to Stage 1 assessment (see 6.3.2) as BS EN 61000-3-3 and BS EN 61000-3-11 are normative references in this standard [BS EN 61000-6-3].

Equipment that is supplied from a HV transformer, which is dedicated to the supply of an installation feeding manufacturing or similar plant and is intended to operate in or in proximity to industrial locations, can be connected subject to conformance to BS EN 61000-6-4 and meeting the requirements and levels for flicker stated by the system/network operator.

[33] This is the worst-case condition.

Where conformance to EMC requirements in harmonised product standards or BS EN 61000 Part 6 Generic standards is not applicable or not appropriate then equipment can be connected to public electricity supply systems via the ‘Technical File’ path, where it can be shown to conform to the requirements of The Electromagnetic Compatibility Regulations 2016 [1] [34].

NOTE: The ‘Technical File’ path is a route that manufacturers can opt to follow when declaring conformance to the Electromagnetic Compatibility Regulations 2016. This route is based on relying on evidence assembled within a Technical File by the manufacturer, as opposed to relying on conformance to some or all relevant harmonised standards.

6.4 Assessment of rapid voltage change

6.4.1 General

As a minimum requirement, an assessment to determine the maximum RVC should be carried out:

a) at the minimum fault level for normal operating conditions (see 6.1.6);

b) assuming 0.5 p.u. of remanent flux in transformers[35];

c) assuming the pre-event initial steady state voltage, $V_{0,}$ occurs at the upper and lower statutory voltage limits;

d) at the voltage zero crossing or other point on the voltage waveform, where this results in the maximum magnitude of RVC; and

e) including sympathetic inrush currents between transformers connected in the vicinity unless it can be demonstrated that these currents are insignificant[36].

The assessment procedure should be based on measured changes in r.m.s. voltage refreshed each half cycle starting with the first full cycle of measurements following commencement of the RVC (see 7.3). The first incomplete half cycle measurement following commencement of the RVC should be disregarded.

The maximum RVC should not exceed the relevant limit(s) in Table 4[37].

NOTE: The relevant limits in Table 4 define an envelope for categories of occurrence, which the maximum r.m.s. RVC is required to fit within. The acceptability of voltage change is now assessed over a time period from the start of the RVC event and not just after 30 ms from the start of the event, as was the case in Engineering Recommendation P28 Issue 1.

The magnitude of remanence flux can vary for different types and designs of transformers.

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[34] The Electromagnetic Compatibility Regulations 2016 are the UK implementation of Directive 2014/30/EU of the European Parliament and of the Council relating to electromagnetic compatibility.

[35] In the absence of specific data, a value of 0.5 p.u. remanent flux can be assumed given a value between 0.4 and 0.6 p.u. is typical of measured results.

[36] Sympathetic inrush currents can affect voltage recovery especially in systems/networks with lower fault levels.

[37] Assessment of emission levels is based on the absolute maximum voltage change measured and not the probability the limit could be exceeded for a small period of time.

Where the magnitude of the calculated maximum RVC is marginal, with respect to the limits in this EREC, then the validity of any typical values used, including those for remanence, together with any assumptions should be checked for the particular transformer being studied[38].

6.4.2 Transformer energisation

6.4.2.1 General

Transformer inrush current is asymmetrical with a harmonic content that can last for tens of cycles after transformer energisation. Asymmetry of the inrush current is the result of a d.c. component that can be a significant proportion of the peak current magnitude. For three-phase transformers, at the instant of transformer energisation, the voltage will be different in each phase. Invariably the RVC will be of greater magnitude in one of the phases depending upon the point-on-wave energisation. The maximum voltage change, of the three-phases, should be taken to be ΔV_{max} and used for assessment against the RVC limits in Table 4.

The magnitude of RVC depends on the relative short-circuit capacity of the upstream electricity supply system to the transformer rated power and the inrush characteristic of the transformer. The inrush current characteristic, in terms of the proportion of 50 Hz fundamental frequency current and the initial magnitude and time constant of the d.c. component can vary for different types of transformers.

The study of transformer inrush current is complex and is best done through electromagnetic transient analysis using an appropriate software program. Careful consideration should be given to assigning values to parameters in such software programs.

For example: Magnetising impedance parameters have an important effect on the linear reactance and the decaying time constant related to the magnetic circuit used for estimating the magnetic flux in the core of the transformer.

Studies involving transformer inrush current should consider energisation at a switching angle corresponding to zero volts in one phase[39].

Where the resultant voltage change is marginal, i.e. within 10% of the relevant RVC limit, then energisation at a switching angle corresponding to 5% of the peak rated voltage in that phase should be evaluated[40]. The studies will be acceptable if the resultant voltage change for the latter case is less than 90% of the relevant RVC limit.

Empirical studies show that significant variations can occur in the calculated magnitude of voltage dip depending upon the value of assumed parameters. The sensitivity of the calculated magnitude of voltage dip to changes in parameter values should be understood to ensure the calculated values accurately represent expected measured values.

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[38] In practice, remanence values have been found to be lower than 0.8 p.u.

[39] Theoretically this represents the worst-case condition.

[40] This approach recognises that before the poles of a circuit breaker actually close and touch each other an arc strikes across the poles and current starts flowing in the phase (through the arc). The striking of the arc and flow of current is due to the fact that there is a voltage difference between the circuit breaker poles at that point. Empirically, this voltage is about 5% of the peak rated voltage in the phase when current starts to flow.

6.4.2.2 Simplified assessment

Where detailed information needed to carry out transformer magnetising inrush simulation studies is not available then a simplified assessment may be carried out as a first step to determine whether the magnitude of the voltage dip during energisation is sufficiently close to the RVC limits as to warrant detailed electromagnetic transient analysis.

Simplified assessment can include the following.

- Application of generic curves that relate system fault level to the magnitude of voltage dip for typical distribution type transformers[41].
- Simple modelling of the inrush current from the peak inrush current provided by the manufacturer / supplier and typical constants for different transformer types based on the fundamental frequency component of rated current [42].
- Simple calculation of the magnitude of the initial voltage dip based on the ratio of the peak inrush current to the peak rated current (see Annex C).

It should be noted that using the manufacturer's/supplier's stated peak inrush current as a multiple of rated current might result in an unduly pessimistic magnitude of voltage dip compared with measured results.

The following points should be considered when carrying out simplified assessment.

a) Simplified modelling of the inrush current could underestimate the magnitude of the peak voltage dip by up to 30%, where default values are used and subtransient effects are omitted.

b) The modelling of inrush current decay may differ from that measured in practice given the inrush current decay envelope could be more complex than can be represented by an exponential decay curve and single time constant.

c) The ratio of the peak inrush current and peak rated current can differ appreciably for different types of transformer, therefore it is important to use data that is specific to the transformer being modelled.

d) Dry type distribution transformers will generally result in a greater magnitude of voltage dip on the first energisation than equivalent oil-filled distribution transformers.

e) RVCs are characterised by true r.m.s. voltages not just the power frequency component.

It should be noted that empirically, the magnitude of inrush current and hence voltage dip is generally lower for transformers that comply with BS EN 50588-1, due to lower fixed iron losses.

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41 Such as the Paper 'Assessing P28 Guidelines for Renewable Generation Connections' by R.A. Turner and K.S. Smith [10].

42 Such as the Paper 'A Simplified Method For Estimating Voltage Dips Due To Transformer Inrush', CIRED 20th International Conference on Electricity Distribution, 2009 by Graeme Bathurst [11].

7 Measurements

7.1 General guidelines for measurements

The measurement period should be chosen to include the expected maximum disturbance (flicker severity or RVC) caused by the disturbing equipment/fluctuating installation being assessed.

The measurement period should be generally not less than one week to capture any daily variations in background levels. A shorter measurement period may be used providing this is representative of the measurements that would be expected if measured over one week or would capture the most severe two-hour period of voltage fluctuations (see 7.2.1). In any case, the measurement period should be of sufficient duration to cover at least two full operating cycles of single disturbing equipment and/or at least one full operating cycle for a fluctuating installation with several items of disturbing equipment.

The decision as to whether the limits apply to phase-phase or phase-neutral voltage should be consistent with relevant measurement standards.

Where measurements are taken from systems/networks through a voltage transformer, it is important to give due regard to the phase relationship between measured voltages and LV system/network voltages[43]. This is particularly important for voltage fluctuations which are not symmetrical to all three phases.

Where it is not possible to take measurements under the worst case normal operating condition, the measured values obtained for the particular system/network condition should be analysed to ensure they are consistent with those expected for that condition.

7.2 Flicker measurements

7.2.1 Measurement of flicker severity for an item of disturbing equipment

Direct measurement of all types of voltage fluctuations should be assessed using a flickermeter conforming to the requirements to BS EN 61000-4-15.

Flicker should be measured using the Class A method specified in BS EN 61000-4-30 and BS EN 61000-4-15, except the measurement uncertainty requirement for P_{st} at low modulation rates, i.e. < 40 changes per minute, need only be met for voltage fluctuations ≤ 10% in amplitude over an input voltage in the range of nominal voltage ± 10%. Alternatively, where agreed with the system/network operator, flicker may be assessed using the Class S method for specific applications where the measurement uncertainty requirement is not critical for P_{st} outside the range of 0.4 to 4.

Data should be flagged in accordance with BS EN 61000-4-30 such that abnormal voltage fluctuations[44], e.g. associated with faults or switching events on the network, can be omitted to ensure the measurement is representative of the flicker being assessed.

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43 This is important as lighting equipment, which is most sensitive to voltage fluctuation, is connected between phase and neutral at LV.

44 Abnormal voltage fluctuations include those from unintended sources, such as faults etc.

Measurements of P_{st} and P_{lt} should be 95% probability values over a normal measurement period of one week. For shorter measurement periods, 99% probability values for measurements of P_{st} should be used[45].

NOTE: Comparison of 99% and 95% probability values can be useful as ratios > 1.3 can indicate abnormal results caused by voltage dips and transients.

The calculation of P_{lt} should be based on a sliding window of P_{st} values, where the oldest P_{st} value is replaced by the newest P_{st} value at each 10-minute interval.

A check should be made when starting measurements and when interpreting measurement results that step voltage changes are not exceeding 3% between steady state conditions and/or that P_{st} is not exceeding planning levels (see Table 2).

If the disturbing equipment/fluctuating installation is not connected to a "clean" flicker free supply then the measured flicker background level (see 7.2.2), without the disturbing equipment/fluctuating installation in operation, should be subtracted from the result using the general summation law equation (see 6.3.4).

7.2.2 Flicker background levels

Flicker background levels in each phase should be measured without the disturbing equipment/fluctuating installation in operation. The measurement period should be of sufficient duration to obtain typical flicker background levels that coincide with the operation of the proposed disturbing equipment/fluctuating installation. Measurements in the phase with the highest measured flicker background levels should be used for assessment.

A flicker background level of $P_{st} < 0.35$ is negligible and may be discounted in any simplified flicker assessment approach referenced in this EREC.

In the absence of any measured data, the flicker background level should be assumed to be $P_{st} = 0.5$. If there is reason to believe the flicker background level might be greater than $P_{st} = 0.5$, a direct site measurement should be carried out for the purposes of assessment.

Flicker background levels for new substations may be estimated from measurements at other locations in the electricity supply system by applying relevant transfer coefficients from adjacent nodes (see Table 3 for typical transfer coefficients). Examples of how to apply transfer coefficients between different nodes can be found in Annex B of PD IEC/TR 61000-3-7.

7.3 RVC measurements

RVC measurements should be based on measured changes in the r.m.s. voltage.

The worst case RVC measured over the measurement period should be used to determine the emission level, not probability values.

[45] 99% probability values of P_{st} and P_{lt} are not permitted to exceed planning levels.

Instruments used for power quality measurements should conform to BS EN 61000-4-30 and should be capable of Class A measurements, where r.m.s. voltage measurements are refreshed each half-cycle.

It is likely that the actual RVC measured during the measurement period could differ from the value(s) calculated during studies. The difference between actual measured values and calculated values could be explained by one or more of the following.

a) The actual supply system impedance present during the measurement period might be significantly less than for the worst case normal operating condition used for study.

b) Power quality measurement instruments that measure true r.m.s. voltage will include the additional voltage fluctuation caused by harmonic currents; some studies could consider the 50 Hz fundamental frequency only.

c) Switching during the measurement period will not necessarily take place at the worst case condition(s) as studied, e.g. the worst case point on the voltage waveform and/or the worst case remanence flux.

Given actual measured values are dependent on the point on the voltage waveform that a fluctuating installation is energised then a number of repeat energisations should be carried out, where practicable, to validate emission values.

The effect of actual conditions present during the measurement period should be considered when validating measurement results against calculated results and limits in this EREC.

Where possible, measurements should be conducted when the system is fully intact with no outages of equipment and validated against calculated values of RVC for the same system arrangement.

8 Guidance on application

8.1 General

Where full data is available, a simulation of the pattern of voltage changes should be undertaken. Where this is not possible, then the following approximate methods may be used.

When assessing several sources of flicker the resultant value of P_{st} should be determined by application of the general summation law equation (see 6.3.4).

8.2 Supply system considerations

For connected disturbing equipment or fluctuating installations with $P_{st} > 0.5$, the system/network operator should carefully control the connection of further disturbing equipment/fluctuating installations to affected supply systems. This is to prevent planning levels being exceeded in future.

The system/operator should have an effective system in place to identify, record and monitor these affected supply systems.

As it is not practicable to control the connection of certain LV disturbing equipment, in particular, household appliances and similar electrical equipment, the network operator should only consent to the connection of disturbing equipment or a fluctuating installation under Stage 3 if satisfied that other significant loads cannot be connected without their consent.

Where system alterations are contemplated that could change the realistic maximum impedance at the PCCs used for Stage 3 assessments then the system/network operator should re-assess the flicker severity at these PCCs to ensure planning levels are not exceeded.

8.3 Electric motors

As motors can cause voltage changes on starting, during running and on stopping, all these conditions need to be considered when assessing the acceptability of connecting a motor to the supply system.

8.3.1 Starting

In most cases, starting produces the most severe voltage change in terms of both the magnitude and power factor of the current taken. In the majority of cases for motors with direct-on-line starting, the duration of the magnetising inrush current is several seconds.

Where the voltage change characteristic of the starting event fits within the envelope in Figure 5, the acceptability of the minimum time between occurrences may be assessed from Figure B.1.2 and should conform to the recommendations for planning levels and assessment of flicker stated in this EREC.

Where the voltage change characteristic of the starting event does not fit within the envelope in Figure 5, the acceptability of the magnitude of the voltage change should be assessed against the limits in Table 4.

Where a motor is only started at intervals of several months (very infrequent starting event), the voltage change characteristic should fit within the envelope in Figure 7. The system/network operator may insist on special conditions being put in place. These special conditions may include one or more of the following.

a) Restriction of starting to times when the associated system is fully intact with no outages of equipment.

b) Restriction of starting to certain hours, e.g. 0100 hrs - 0700 hrs, to minimise the likelihood of disturbance to other customers.

c) Liaison with the system/network control engineer prior to starting.

d) Consideration of inhibiting tap-changer operation.

Special consideration may be given to other scenarios, where motors will usually only be started over a limited period of the year, generally when there is no lighting load on the system. In these scenarios, although a very limited number of customers might experience the full voltage depression at the PCC, the probability of resultant voltage complaints will be low. Whilst these and similar cases require judgement to be exercised, voltage depressions within the limits of Figure 7 are acceptable.

For motors where the front time associated with starting is short, e.g. ≤ 30 ms, and the tail time is comparatively longer, then the maximum voltage change, d_{max}, can be substituted as the step voltage change in Figure B.1.2.

Example 1: For a motor with a starting and stopping characteristic lying within the envelope of Figure 5 would need to have a minimum time between starting events of 475 s if the voltage change was 3%.

For direct on line starting the whole cycle may be considered as being equivalent to one step change with the limit taken directly from Figure B.1.2.

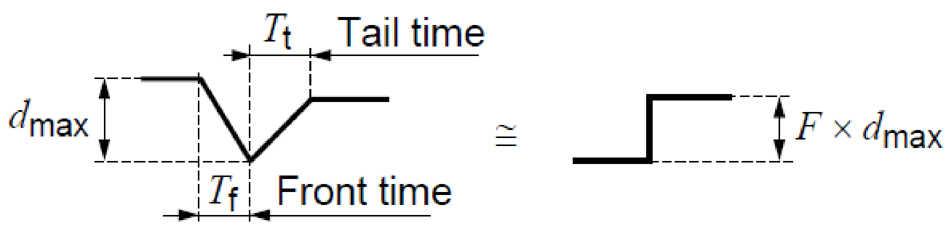
Use of reduced voltage starters, such as star-delta and reactor types, normally causes a second voltage change at the changeover point. This second voltage fluctuation is similar to that in Figure 5 and should be considered equivalent to a further single step voltage change.

For LV motors, where the maximum voltage change (d_{max}), the front time (T_f) and the tail time (T_t) are known then a shape factor (F) can be determined from Figure 5 in BS EN 61000-3-3. The equivalent step voltage change for use in Figure B.1.2 can be obtained by multiplying F and d_{max} (see Figure 10).

For motors with normal magnetising inrush current characteristics the magnitude of the largest r.m.s. voltage change for starting events can be assessed from either:

a) measurement of the motor current with the rotor locked when supplied at the intended operating voltage of the motor; or

b) reference to the manufacturer's published information.



NOTE: The same convention as BS EN Standards has been followed, where a reduction in voltage is represented as a positive value of d_{max}.

Figure 10 — Application of shape factor (*F*) for motor starting

For motors with abnormal magnetising inrush characteristics then the voltage fluctuation should be determined from either measurement of similar motor installations or flickermeter simulation programs.

Previous experience has shown that relatively small direct-on-line LV motors can be connected without detailed consideration. These are listed in Annex A.1.

8.4 Furnaces

At the design stage and for single furnace installations, which are effectively electrically isolated from other furnaces, the following simplified assessment may be adopted, generally for connections to 11 kV and 33 kV networks, which involves the calculation of the short-circuit voltage depression at the PCC.

Assuming the source impedance has a negligible effect on the short-circuit power drawn by the furnace, the short-circuit voltage depression may be calculated with sufficient accuracy from the ratio of the furnace steady state apparent short-circuit power in MVA (S_t) and the system short-circuit power in MVA at the PCC (S_c) (see Equation 4).

The apparent short-circuit power of a furnace (S_t) is that power which would be drawn by the furnace if all three electrodes were immersed in molten steel with the furnace transformer tap set to that corresponding to the highest furnace voltage available. The value of S_t may be taken to be twice the furnace rated power if no other information is available.

In order to meet the Stage 2 limit for flicker severity, the value of short-circuit voltage depression calculated from Equation 4 should be less than 1%[46].

Where the effect of source impedance on the short-circuit power drawn by the furnace is not negligible, a more accurate assessment should be conducted.

For induction furnaces, additional aspects of operation, including consideration of voltage fluctuations, are described in Engineering Recommendation P16 [3].

However, the voltage fluctuation limits in EREC P28 supersede any limits in Engineering Recommendation P16 [3].

The cubic summation law in the case of the summation effects of two arc furnaces (at the 95th & 99th percentile) could be too pessimistic for realistic estimation of summation effects and an exponent of $\alpha = 4$ could be considered.

8.5 Heat pumps

Assessment of domestic heat pumps for connection to LV public electricity supply systems should follow the connection/notification process published by the ENA[47]. The voltage fluctuation requirements of that process for connection of a single heat pump/system are equivalent to the Stage 1 assessment process in this EREC (see 6.3.2).

Multiple heat pumps/systems, each with a rated power ≤75 A per phase including any boost or back-up function, for connection to the LV public electricity supply systems, shall be subject to conditional assessment in accordance with Stage 1 of this EREC.

The short-term flicker severity (P_{st}) of fluctuating installations with multiple heat pumps can be summated according to the summation law and exponents in Equation 1 (see 6.3.4) providing that heat pumps start 30 s apart.

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46 This equates to a step voltage change of 1% not more than every 20 s.

47 The notification process for connecting heat pumps can be found on the ENA website.

The general flicker summation exponent α = 3 may be used to calculate how many heat pumps can be connected to the same PCC without exceeding the flicker planning level. The flicker summation law and exponents are not valid for multiple heat pumps within a fluctuating installation that are centrally controlled to switch at the same time.

The boost function on multiple heat pumps in the same fluctuating installation should be controlled, where unacceptable voltage fluctuations would occur otherwise if the heat pumps were to switch on/off simultaneously[48].

The indoor and outdoor parts of a heat pump system should be tested as a whole integrated system as well as individual items of equipment. The whole integrated system is required to conform to the emission limits in this EREC.

Special consideration should be given to heat pumps with direct-on-line connection as these could result in excessive voltage fluctuations unless steps are taken to reduce the initial starting current, e.g. using soft-start technology.

8.6 Electric vehicles (EVs)

8.6.1 General

Equipment and systems for charging EVs whether installed in an EV or in a fixed installation should conform to BS EN 61851.

General guidance on the notification process for connecting EV charging infrastructure to LV public electricity supply systems is published by the ENA[49].

The following specific recommendations relate to the assessment of flicker from EV charging equipment.

8.6.2 Fixed charging installations

Fixed charging equipment is not subject to conditional connection and can be connected to LV public electricity supply systems under Stage 1 without reference to the network operator where:

a) the equipment has a rated current ≤ 16 A and it conforms to BS EN 61000-3-3;

b) the equipment is connected at a domestic residence has a rated current ≤ 32 A and it conforms to the technical requirements of BS EN 61000-3-3.

Fixed charging equipment ≤75 A per phase not conforming to BS EN 61000-3-3 should be subject to conditional connection in accordance with BS EN 61000-3-11 and can only be connected to the LV public electricity supply system under Stage 1 if the actual impedance of the supply system the equipment is connected to meets the required value (see 6.3.2).

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[48] Some heat pumps are fitted with a boost function that is programmed to operate at specific times. Multiple heat pumps from the same manufacturer, which are fitted with this function, could operate simultaneously if the default time of the programmed boost is not changed.

[49] The notification process for connecting EV charging infrastructure can be found on the ENA website.

Network operators should give special consideration to assessment of installations where multiple EV charging connections are proposed to be connected to a PCC. This may include taking steps to prevent simultaneous switching of multiple active chargers to prevent breaching the 3% step voltage change limit.

Where conformance to flicker limits depends upon minimum control cycle time(s) being applied to fixed charging equipment then these should be declared by the manufacturer/supplier and applied to the charging equipment.

The severity of flicker from fixed charging equipment depends, inter alia, on the characteristics of the charger. Where the charging characteristic resembles a stable load with long control cycle times then meeting the 3% step voltage change limit will most probably be the overriding consideration not flicker. Small variations of load whilst charging an EV, even when frequent, are unlikely to result in flicker as opposed to large infrequent step voltage changes when multiple chargers are simultaneously switched on/off.

Special consideration should be given to fixed charging equipment where the main charge has a pulsed current characteristic, given this equipment could significantly increase P_{st} values. This recommendation also applies to chargers that have a maintenance charge function, where the charge is delivered periodically to keep the vehicle battery ‘topped-up’ after the main charge but whilst it is still connected to the charger.

8.6.3 EV on-board chargers

There is no particular requirement to assess flicker from EVs with on-board charging equipment for plug-in connections ≤ 13 A given connections of individual equipment to LV public electrical supply systems with typical supply impedances (see Table 7) have little effect on flicker background levels.

Where the connection of individual EV on-board charging equipment to the LV system results in flicker limits being exceeded, the network operator may require the customer to take steps to prevent interference to other customers.

8.7 Wind turbine generators

Voltage fluctuations from wind turbines connected to the supply system, where the PCC is at HV, should be measured and assessed using the methods in BS EN 61400-21. The measurement procedures in BS EN 61400-21 are valid and may be used for wind turbines connected via three-phases to the LV supply system.

The assessment should consider voltage fluctuations that would arise in continuous operation and during switching operations. Calculations should be based on the power quality information and type test data provided by the wind turbine manufacturer.

For assessing continuous operation of multiple wind turbines within a fluctuating installation, an exponent of $\alpha = 2$ may be used for summation of flicker severity. An exponent of $\alpha = 3.2$ should be used for summation of flicker severity when assessing the effects of switching operations of multiple wind turbines.

When assessing the connection of additional wind turbines to the PCC, steps should be taken to avoid two wind farms performing switching operations at the same time.

Where simultaneous switching operations can be avoided, no summation effects need to be taken into account. Where the risk of simultaneous switching operations cannot be avoided then the resultant voltage fluctuations should be studied and assessed.

Flicker caused by turbulence, wind gusts, tower shadow and oscillation during continuous operation of wind turbines should be assessed, however, these are not expected to be significant for modern Doubly-Fed Induction Generator (DFIG)/full converter connected wind turbines.

When assessing voltage fluctuations caused by wind turbines, particular consideration should be given to switching operations involving fixed speed wind turbine generators and to the energisation of step-up transformers between the wind farm and the supply system.

The connection of the latest wind turbines, with rated powers > 3 MW are unlikely to result in significant flicker when the resultant reduction in local supply system impedance is taken into account. Where the rated apparent power of the wind turbine(s) (S_n) is large compared with the supply system initial symmetrical short-circuit power ($S_k^{"}$), i.e. S_n / $S_k^{"}$ ≤ 3, flicker from the wind turbine(s) may have a significant impact on flicker background levels.

In these cases, an emission limit of P_{st} ≤ 0.35 applies to calculated emissions, where the actual flicker background level is unknown. Where the calculated emission limit is P_{st} > 0.35 but ≤ 0.5, more detailed assessments that take into account actual flicker background levels should be carried out.

8.8 Photovoltaic (PV) installations

Inverter connected PV ≤16 A per phase should conform to the test requirements and limits in BS EN 61000-3-3 and relevant recommendations in ENA Engineering Recommendation G83 [N1].

When assessing flicker from PV installations, flicker severity should be evaluated for various generation outputs from 0% to 100% at power factor conditions that are representative of those likely to be encountered during operation. It is acceptable to assess flicker severity at a constant power factor for PV installations that do not have reactive power control.

NOTE: Generally, residential small scale commercial PV installations export power at unity power factor.

Calculations of flicker should consider those requirements in BS EN 61400-21, for assessing flicker severity from wind turbine generators, that can be applied to assessment of flicker from PV installations. For example, the applicability of the method for assessing the impact of changes to wind speed to assessing the impact of changes in solar energy.

For installations where multiple inverters are proposed, the acceptability of voltage fluctuations arising from variations in generation output caused by changes in solar energy levels should be assessed using a flickermeter simulation program.

Voltage fluctuations caused by the effect of moving clouds on generation output generally result in ramp voltage changes, as opposed to step voltage changes. The effects of moving clouds may be studied but they are unlikely to result in high flicker levels unless the supply impedance at the PCC is untypically high.

The contribution of the customer’s own PV installation to the fault level at the PCC may be considered, where calculated flicker is marginal with respect to flicker limits.

8.9 Energy storage

The ability of energy storage to change rapidly between importing and exporting electrical power has the potential to cause significant voltage fluctuations on the supply system.

Particular consideration should be given to energy storage providing a frequency response function for the supply system as these schemes are designed to produce rapid power swings, which could result in step voltage changes of significant magnitude. There is also a very high probability of coincident power swings between such installations.

Energy storage which provides voltage control/reactive power support can result in small frequent voltage fluctuations that could result in flicker.

Ramping of power changes will assist with meeting step voltage change limits and flicker limits, where significant changes in power occur frequently such as energy storage with low energy rating to power rating. Ramping of power changes is recommended to minimise voltage fluctuations at the PCC.

Where necessary, charging and discharging rates should be limited so as to conform to the voltage fluctuation limits in this EREC.

Energy storage used to balance load to generation can result in increased flicker levels due to its response to a change in customer load and/or generation output. Systems that could significantly increase flicker severity through large step voltage changes following step changes in load or generation should be assessed as a complete system of generation, load and energy storage. Further guidance can be found in ENA EREC G100 [9].

8.10 Household equipment

8.10.1 High power household cooking appliances

Household cooking appliances with rated power > 2 kW but ≤ 4.5 kW may be connected without individual consideration providing that they meet the technical requirements of BS EN 61000-3-3 and/or BS EN 61000-3-11, as appropriate (see 6.3.2.1).

8.10.2 Electrically heated instantaneous shower units

Although electric shower units have high rated powers, compared with most household appliances, their load factor is so small that large numbers can often be accommodated within the supply capacity of an LV network. However, large numbers of electric shower units with the same PCC can cause unacceptable voltage fluctuations on LV networks and it is necessary to regulate their rated power and/or operating characteristics. Electric shower units which conform to the requirements of BS EN 61000-3-11 may be connected without individual consideration (see 6.3.2.2).

8.11 Welding equipment

8.11.1 General

Welding equipment with a rated current ≤ 16 A per phase can be connected to the LV supply system without further consideration providing it meets the requirements of BS EN 61000-3-3.

Welding equipment with a rated current > 16 A and ≤ 75 A per phase, not conforming to the technical requirements in BS EN 61000-3-3, is subject to conditional connection in accordance with BS EN 61000-3-11 and can only be connected to the LV public electricity supply system under Stage 1 if the actual impedance of the supply system the equipment is connected to meets the required value (see 6.3.2).

The following arc-welding and metal-heating plant applications are unlikely to cause appreciable flicker problems on supply systems.

a) Welding equipment with a small rated power compared with that of the supply system impedance, where any additional flicker caused by the welding equipment would be insignificant with that of other large disturbing loads already connected to the PCC. For example: argon-arc machines, atomic-hydrogen machines, wire welders, and miscellaneous small metal-heating machines, such as rivet heaters, installed in moderately large factories.

b) Welding equipment that presents a steady three-phase balanced load on the system for long periods. For example: three-phase a.c./d.c. automatic wire-fed machines and three-phase a.c./d.c. nonferrous welders.

c) Welding equipment fed from motor generators which do not pose any appreciable flicker problems for inherent physical reasons.

The following characteristics of welding equipment are relevant to flicker severity and should be considered in flicker assessments.

a) The magnitude of the sudden steps in welding current that can be imposed on the supply system.

b) Whether the steps in welding current are two-level or multi-level.

c) The power factor of the load increments constituting these steps.

d) Distribution of the welding current in the phase conductors on the HV supply system.

e) The frequency of the resultant voltage changes.

Where welding equipment is connected directly phase-phase at LV, the resultant phase-neutral voltage change[50] can be calculated from the following equation.

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[50] The phase-neutral voltage is more appropriate since lighting is usually connected phase-neutral.

$$\%\Delta V\ (per\ kVA\ of\ welding\ load) = 0.74\ R_s + 0.68\ X_s \qquad \text{Equation 5}$$

Where:

R_s is the resistance of the LV supply system in ohms

X_s is the reactance of the LV supply system in ohms

kVA refers to the manufacturer's stated rated power

$\%\Delta V$ is in the normal range, i.e. 3%

Load power factor is 0.3 p.u. lagging

Each burst of welding current involves two voltage changes

Where welder equipment has a load power factor greater than 0.3 p.u. lagging, the voltage drop on both the lagging phase and the leading phase should be calculated[51].

Generally electric welding equipment is of the arc or resistance type.

8.11.2 Arc welding equipment

Arc welders are, generally, relatively low powered equipment which produce a step change in the system voltage when the arc is struck and another step change when the arc is broken.

Times between the striking and extinguishing of the arc can vary but are usually in the range of several seconds to a few minutes. Problems with flicker severity are only likely to occur when arc welding equipment is connected to a PCC on a 'weak' LV supply system.

8.11.3 Resistance welding equipment

Resistance welders, both due to their size and operating characteristics, can cause severe voltage fluctuations over a wide area of the supply system. Consequently, every effort should be made to check the full range of a resistance welder's likely operating patterns. The voltage changes that each of the pulse size/frequency patterns can cause should be checked using a suitable assessment procedure (see 6.3). Where complex multi-level voltage changes are involved, they should be assessed using a flickermeter or flickermeter simulation program.

Where resistance welding equipment does not incorporate point-on-wave switching control, the voltage change (%ΔV) should be increased by V_m (see Equation 6) to allow for magnetising in-rush.

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[51] Further information on the flicker effects of welding plant, including frequency-changing transformer, d.c. and stored energy types, which are not dealt with by simplified assessment in Equation 5, can be found in ACE Report No 7.

$$\%V_m(per\ kVA\ of\ welding\ load) = 0.50\ R_s + 0.87\ X_s \qquad \text{Equation 6}$$

Where:

R_s is the resistance of the LV supply system in ohms

X_s is the reactance of the LV supply system in ohms

kVA refers to the manufacturer’s stated rated power

Annex A

Connection of LV electric motors

A.1 Motors that can be connected without reference to the network operator

Previous experience has shown that certain relatively small motors detailed in Table A.1 starting direct-on-line can be connected without consideration of flicker or RVC.

Table A.1.1 — Motors started very frequently[1]

Type	**Rated Power Output (kW)**	**Rated Power Input (kVA)**
Single-phase 230 V	≤ 0.37	≤ 1.0
Single-phase 460 V	≤ 1.50	≤ 3.0
Three-phase 400 V	≤ 2.25	≤ 4.0
NOTES: 1. Rated power output and rated power input relates to normal running. 2. Motor rated power can be expressed as rated power output (kW) and/or rated power input (kVA)		
[1] Very frequent means started at intervals less than one minute.		

Table A.1.2 — Three-phase motors with the PCC not covered by (a) or (c)

Type	**Rated Power Output (kW)**	**Rated Power Input (kVA)**
Single-phase 230 V	≤ 0.75	≤ 1.7
Single-phase 460 V	≤ 3.00	≤ 4.5
Three-phase 400 V	≤ 4.50	≤ 6.00
NOTES: 1. Rated power output and rated power input relates to normal running. 2. Motor rated power can be expressed as rated power output (kW) and/or rated power input (kVA)		
[1] Very frequent means started at intervals less than one minute.		

Table A.1.3 — Three-phase motors with the PCC at the LV busbar of a distribution substation

Distribution Transformer Rated Power (kVA)	Rated Power Output (kW)
200	22.5
300/315	30.0
500	45.0
750/800	50.0
1 000	75.0
NOTES: 1. Rated power output relates to normal running. 2. Applies to motors started at intervals of 10 minutes or longer.	

A.2 Three-phase motors with star-delta starting

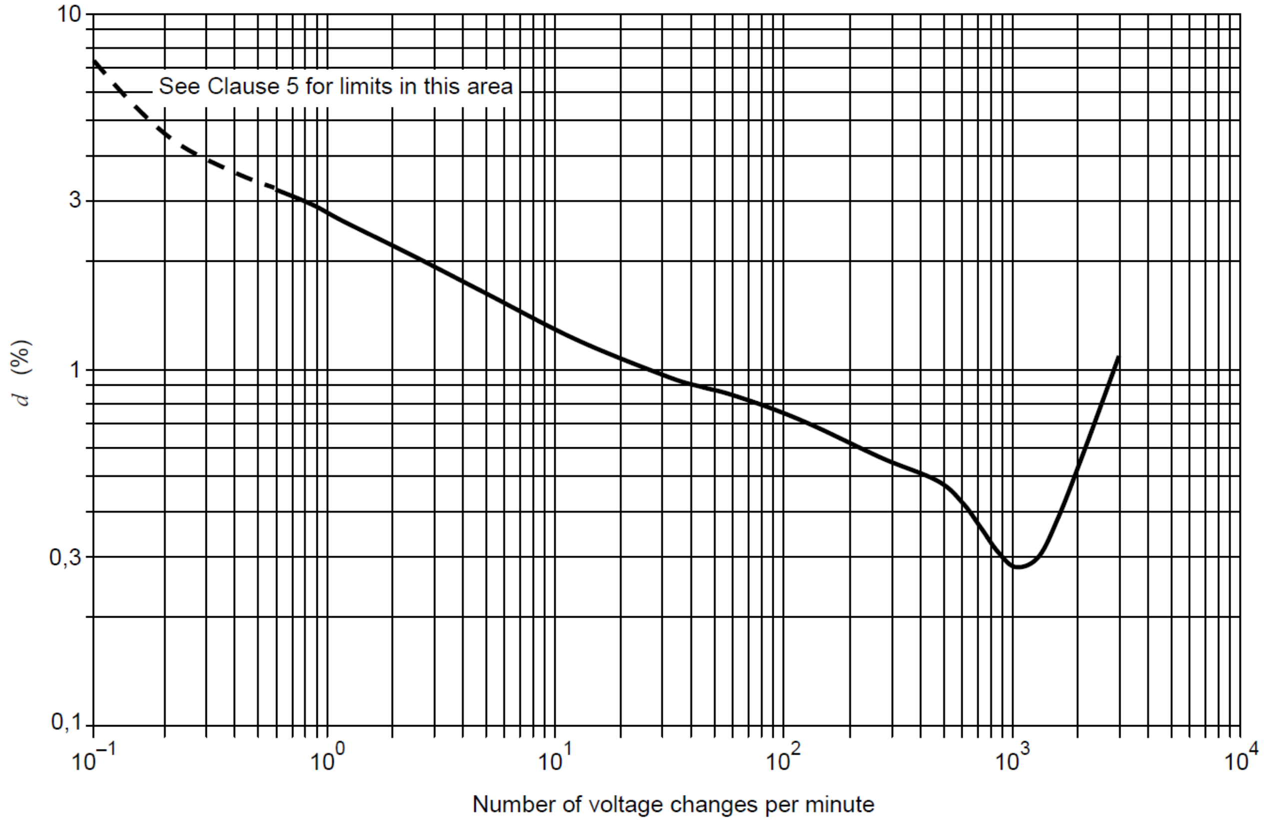
Where star-delta starting is employed, LV motors of up to 1.5 times the rated powers given in Table A.1.1, Table A.1.2 and Table A.1.3 may be accepted without consideration of flicker or RVC.

Annex B

P_{st} curves and shape factor curves

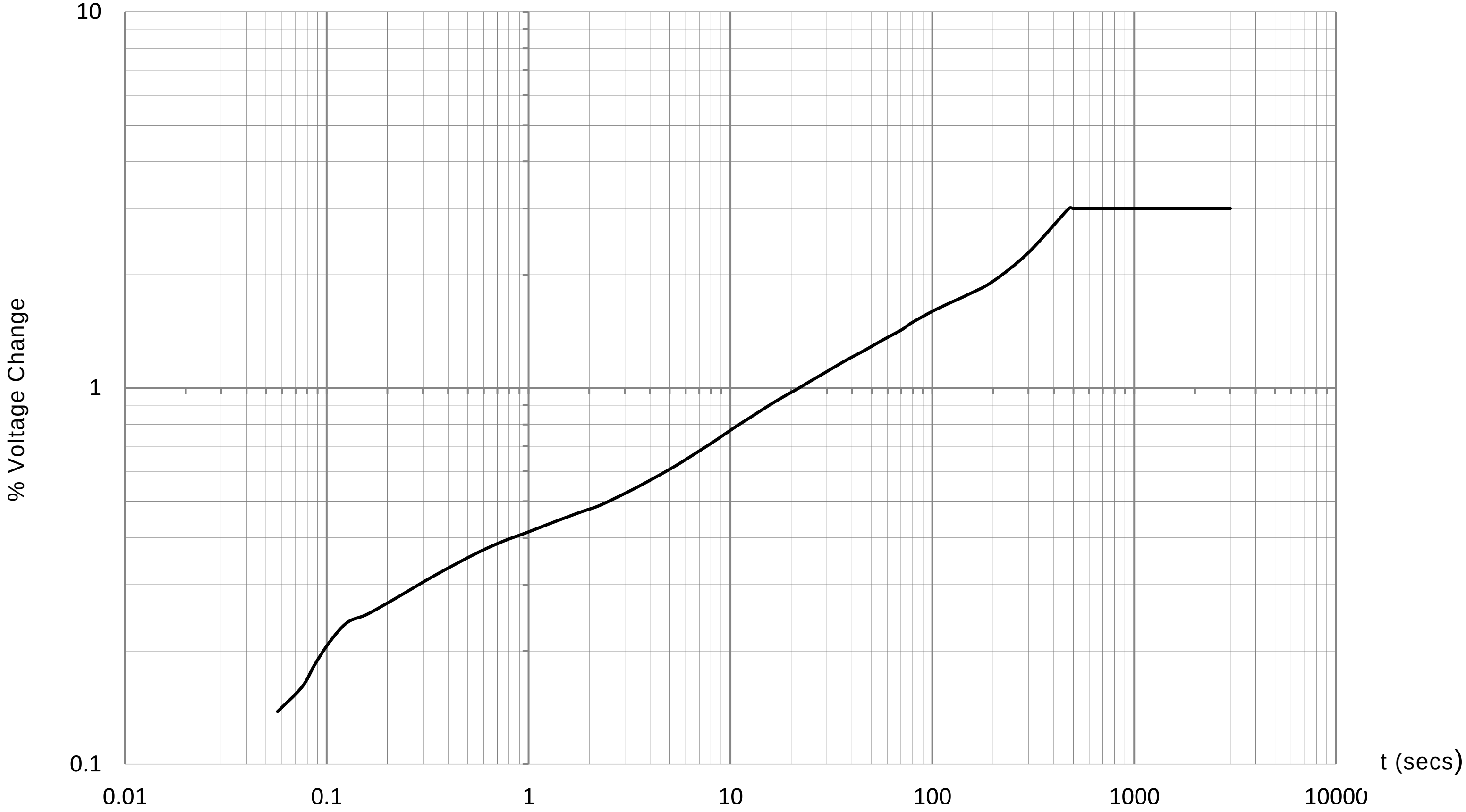
B.1 P_{st} curves

The following P_{st} = 1 curve has been replicated from Figure 2 of BS EN 61000-3-3.



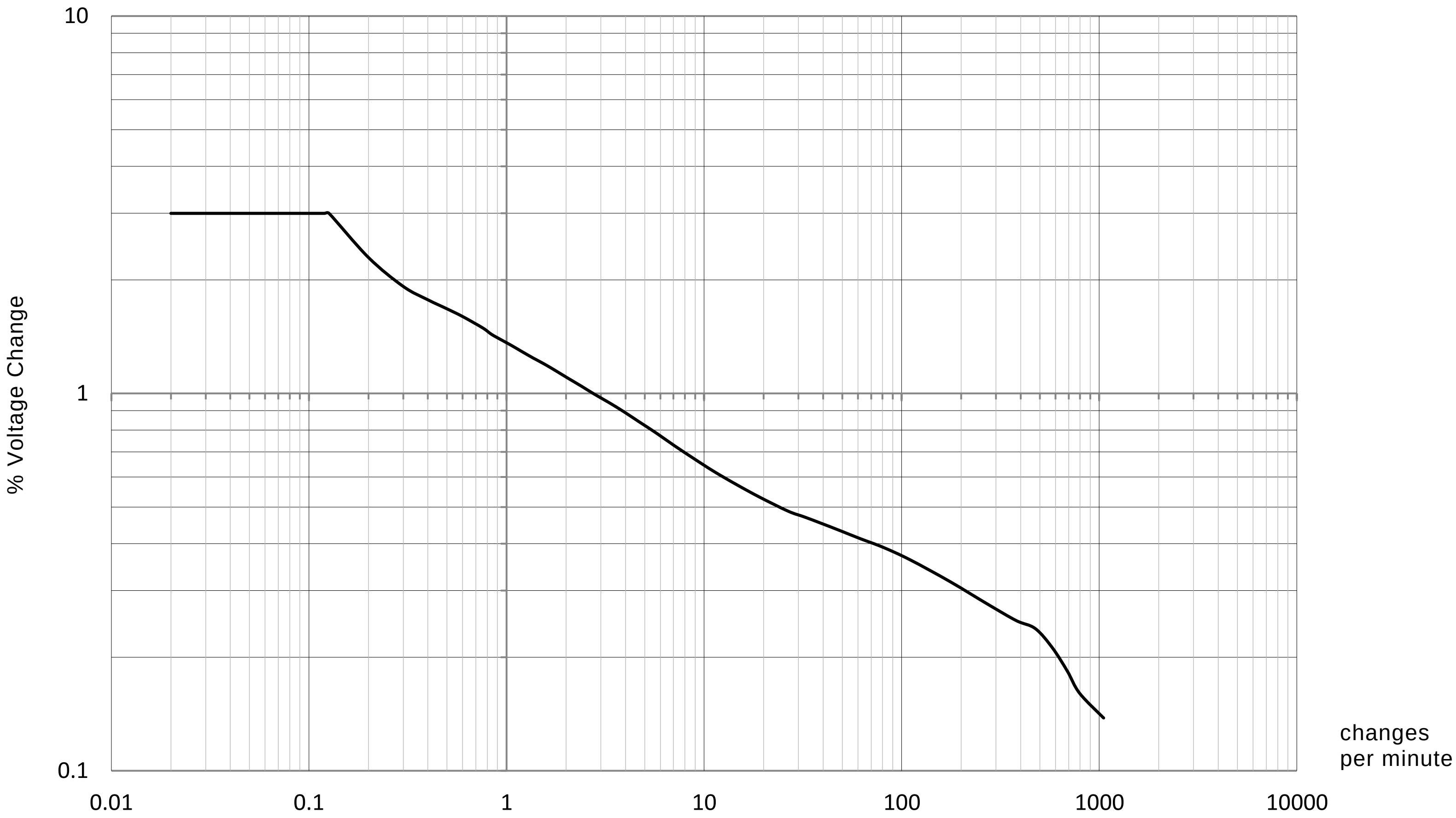
NOTE: 'Clause 5' in this figure refers to Clause 5 of BS EN 61000-3-3.

Figure B.1.1 — Curve for P_{st} = 1 for rectangular equidistant voltage changes



a) Minimum time interval between voltage changes

Figure B.1.2 — P_{st} = 0.5 curve for rectangular voltage changes



b) Maximum number of voltage changes per minute

Figure B.1.2 — Pst = 0.5 curve for rectangular voltage changes

Notes for Figure B.1.2

NOTE 1: The P_{st} = 0.5 curve is derived from the P_{st} = 1 curve in Figure A.1 of PD IEC/TR 61000-3-7, given the linear relationship between the value of P_{st} and the magnitude of voltage change. For example: a 2% step voltage change that would give P_{st} = 1 equates to a 1% step voltage change at P_{st} = 0.5 at the same frequency of occurrence.

NOTE 2: The P_{st} = 0.5 curve has been deliberately capped at a maximum symmetrical step voltage change of 3% once every 475 secs given the simplified nature of assessment.

NOTE 3: % voltage change represents the magnitude of a relative voltage change with a rectangular (step) voltage characteristic expressed as a percentage of the nominal system voltage (V_n).

NOTE 4: Figure B.1.2 replaces Figure 4 in P28 Issue 1.

B.2 Shape factor curves

The following shape factor curves have been replicated from Annex E of PD IEC/TR 61000-3-7 and Clause 6 of BS EN 61000-3-3.

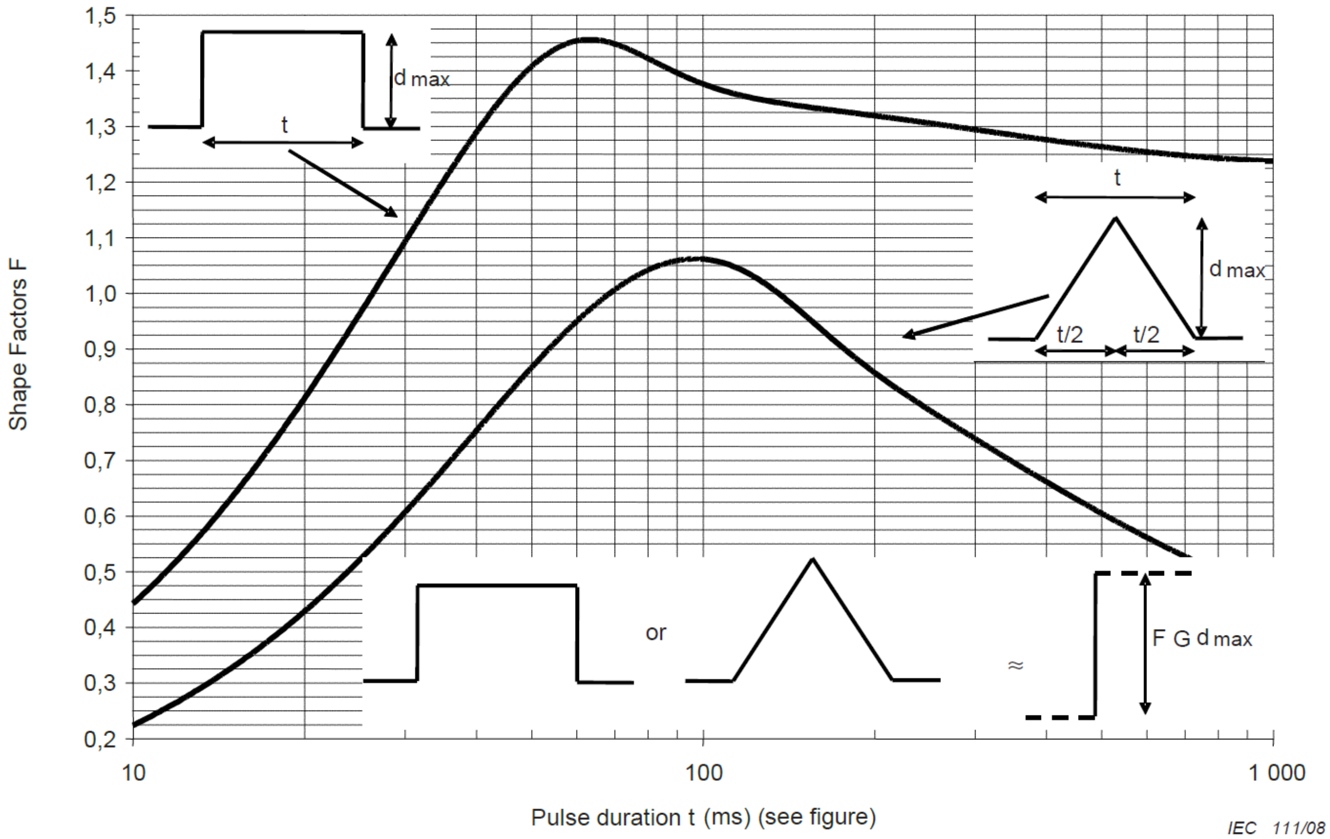


Figure B.2.1 — Shape factor curve for pulse and ramp changes

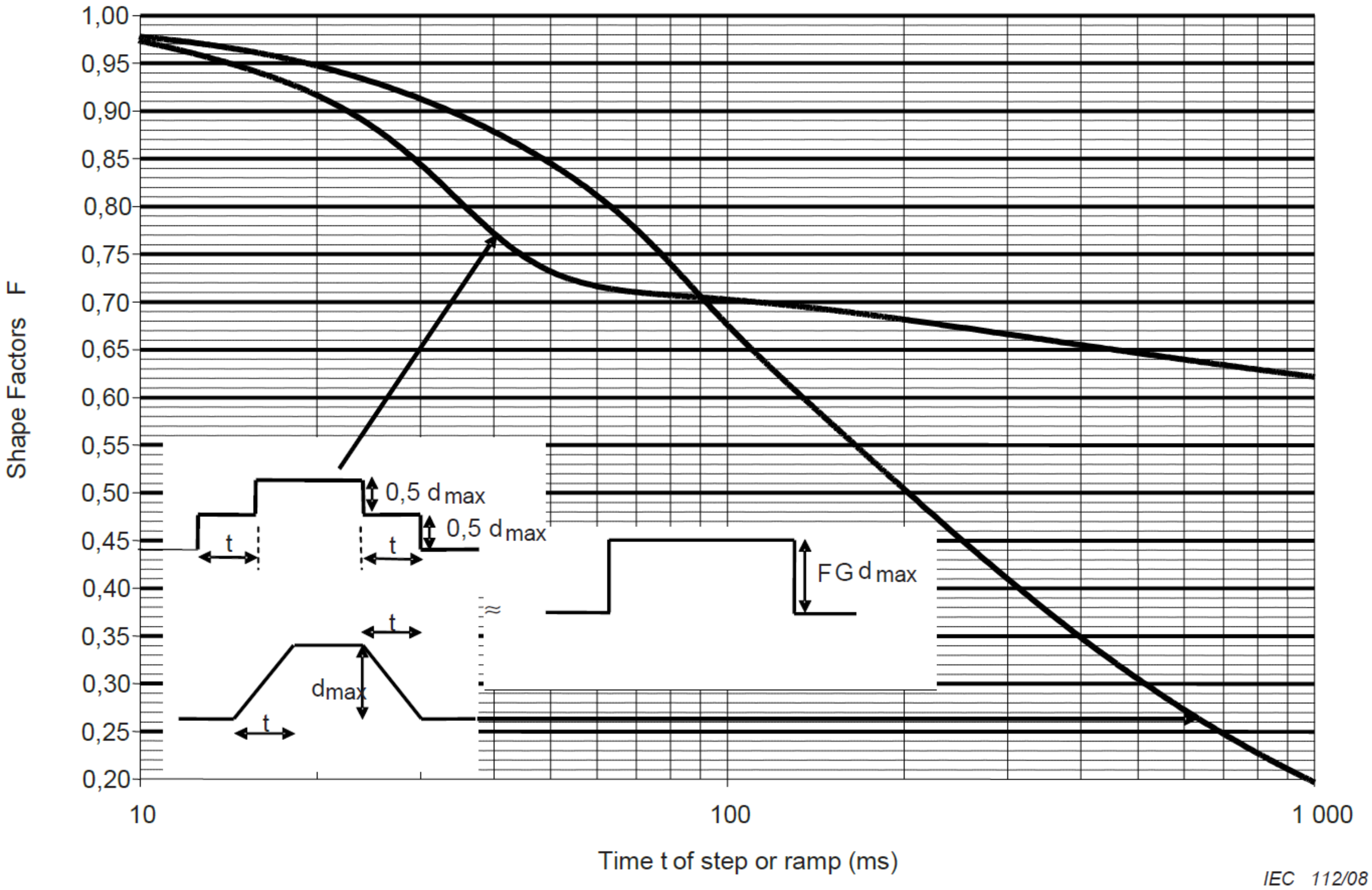


Figure B.2.2 — Shape factor curve for double-step and double-ramp changes

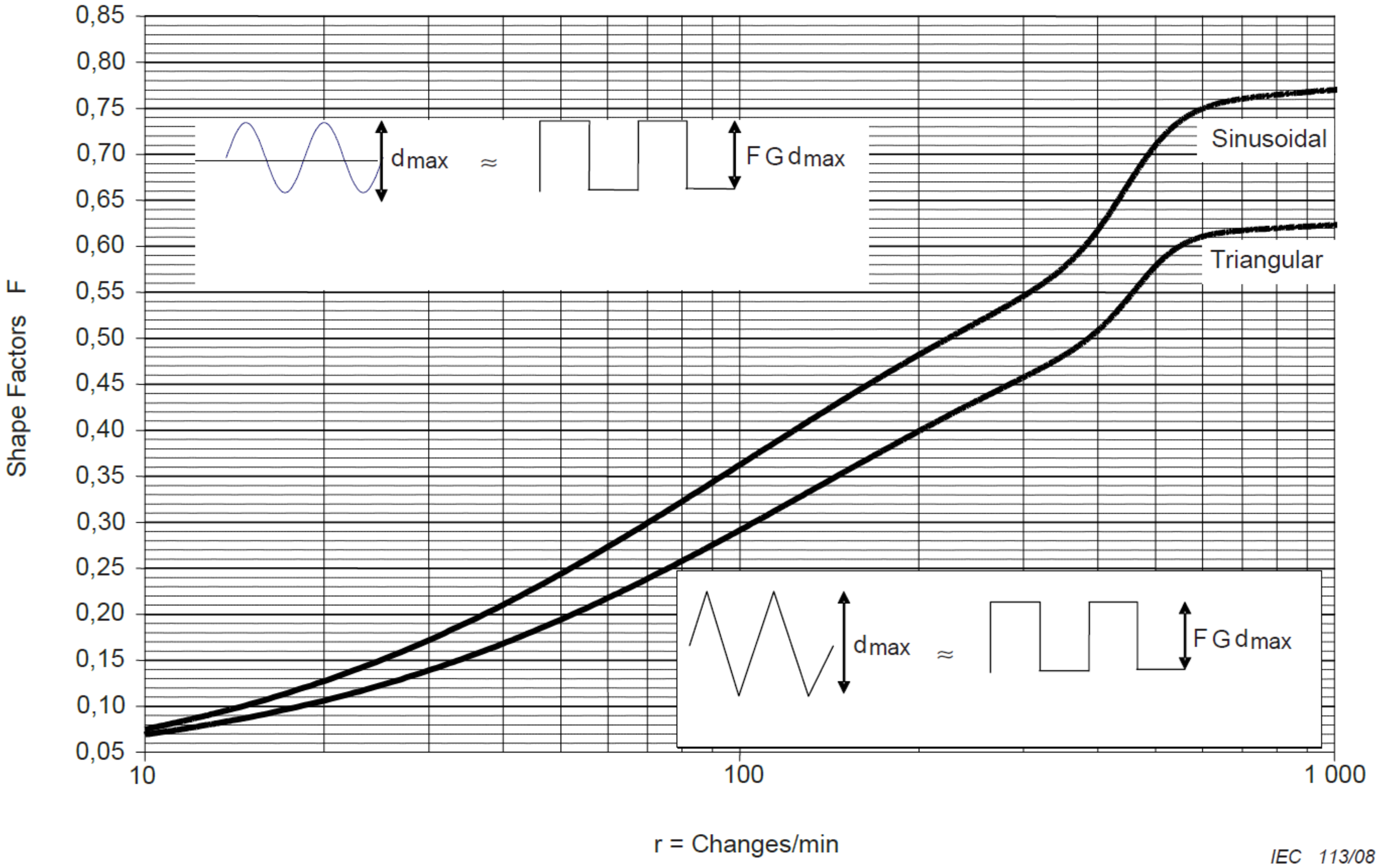


Figure B.2.3 — Shape factor curve for sinusoidal and triangular changes

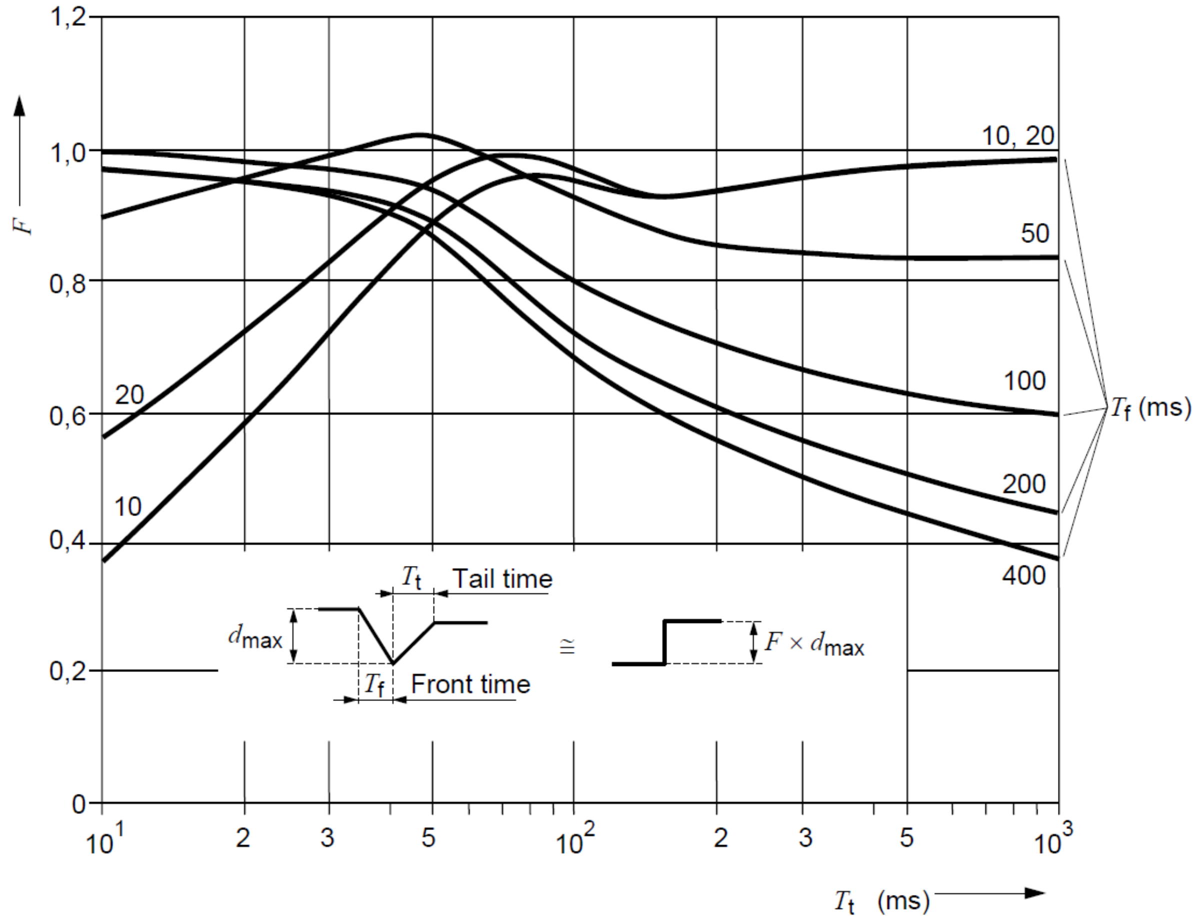
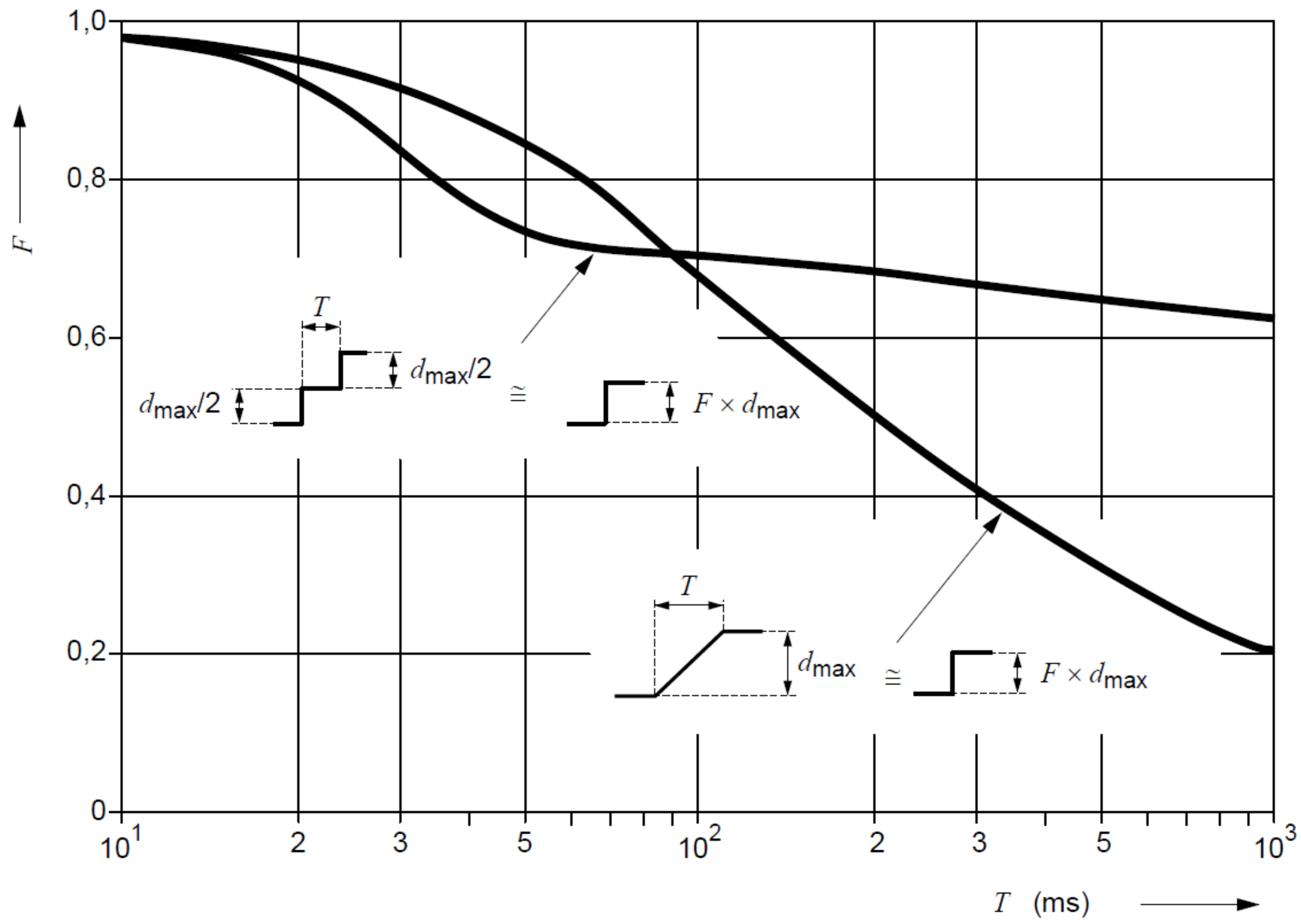


Figure B.2.4 — Shape Factor curves for motor-start characteristics having various front times



NOTE: Equivalent to Figure 3 in BS EN 61000-3-3.

Figure B.2.5 — Shape factor (*F*) for ramp type voltage characteristic

Annex C

Simplified calculation to estimate voltage change due to inrush current

C.1 Introduction

Where it is necessary to estimate the approximate voltage change due to magnetising inrush current, a simplified calculation (Equation C.1 in this Annex) can be carried out as a first step.

This calculation is not a substitute for detailed electromagnetic transient analysis but can help to determine whether the magnitude of the initial voltage dip during energisation is sufficiently close to the RVC limits as to warrant detailed electromagnetic transient analysis.

This calculation estimates the initial voltage change (decrease) only and does not give any indication of the voltage characteristic of the voltage recovery.

If the estimated voltage change is well within the RVC envelopes (see 5.3.2), it is likely that the energisation would be compliant with limits for RVC in this EREC.

This calculation is applicable to transformer energisation, motor start, and other inrush currents with similar behaviour.

C.2 Simplified calculation

$$\%\Delta V = m \times k \times \frac{S}{S_{sc}} \times 100 \qquad \text{Equation C.1}$$

Where:

$\%\Delta V$ is the percentage voltage change

m is the ratio of peak inrush current to peak rated current

k is a factor to convert the peak value of the inrush current to a r.m.s. value

S is the rated power of the transformer or motor

S_{sc} is the short-circuit power of the supply system

Bibliography

Standards publications

For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

BS EN 50160, *Voltage characteristics of electricity supplied by public electricity networks*

BS EN 50588-1:2015 + A1:2016, *Medium power transformers 50 Hz, with highest voltage for equipment not exceeding 36 kV. General requirement*

BS EN 60909-0, *Short-circuit currents in three-phase a.c. systems. Calculation of currents*

IEC 60050-601, *International Electrotechnical Vocabulary (IEV) – Part 601: Generation, transmission and distribution of electricity – General*

PD 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*

PD IEC/TR 61000-3-14, *Electromagnetic compatibility (EMC). Limits. Assessment of emission limits for harmonics, interharmonics, voltage fluctuations and unbalance for the connection of disturbing installations to LV power systems*

Other publications

[1] *The Electromagnetic Compatibility Regulations 2016*

[2] *The Distribution Code and the Guide to the Distribution Code of Licensed Distribution Network Operators of Great Britain*: DCode: www.dcode.org.uk]

[3] ENA Engineering Recommendation P16, *EHV or HV Supplies to Induction Furnaces*

[4] ENA Engineering Recommendation G59, *Recommendations for the connection of generating plant to the distribution systems of licensed distribution network operators*

[5] ENA Engineering Recommendation G12, *Requirements for the Application of Protective Multiple Earthing to Low Voltage Networks*

[6] Statutory Instrument 2002 No. 2665, *The Electricity Safety, Quality and Continuity Regulations 2002*: http://www.legislation.gov.uk/uksi/2002/2665/made

[7] Statutory Rules of Northern Ireland 2012 No.381, *The Electricity Safety, Quality and Continuity Regulations (Northern Ireland) 2012*: http://www.legislation.gov.uk/nisr/2012/381/made

[8] ENA Engineering Report P28, *Guidance and supporting information relating to EREC P28*

[9] ENA Engineering Recommendation G100, *Technical guidance for customer export limiting schemes*

[10] ‘Assessing P28 Guidelines for Renewable Generation Connections’ by R.A. Turner and K.S. Smith. Paper submitted to the International Conference on Power Systems Transients (IPST’11) in Delft, The Netherlands, 14-17 June, 2011

[11] ‘A Simplified Method for Estimating Voltage Dips Due to Transformer Inrush’ by Graeme Bathurst. Paper 0988, CIRED 20th International Conference on Electricity Distribution in Prague, 8-11 June 2009

[12] Commission Regulation (EU) No 548/2014 of 21 May 2014 on implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to small, medium and large power transformers

Appendix D – DCRP/PC/18/01/RtA

Modification	At what stage is this document in the process?
# DCRP/MP/18/01/Report to Authority **Revision to Engineering Recommendation P28 "*Voltage fluctuations and the connection of disturbing equipment to transmission systems and distribution networks in the United Kingdom*"**	01 Modification 02 DCRP report 03 Public Consultation 04 Final Modification Report

The purpose of this report is to assist the Authority in its decision to implement the proposed modifications to the Distribution Code and Engineering Recommendation P28 (subsequently referred to as EREC P28). The proposed modifications were subject to industry consultation in January 2018. Responses from this consultation show that the industry is in favour of these modifications.

Date of publication: 17th May 2018

Recommendation

The Distribution Code Review Panel (DCRP) and the distribution network licencees recommend that modifications are made to the Distribution Code and Engineering Recommendation P28, in relation to voltage fluctuations resulting from the connection of disturbing equipment to transmission systems and distribution networks in the United Kingdom that address the following:

a) Introduce requirements and planning levels for Rapid Voltage Changes (RVCs).

b) Improve definition and clarity of 'worst case operating conditions' to be used in the assessment of voltage fluctuations.

c) Include an intermediate planning level and associated flicker severity limits for supply systems with nominal voltages of 3.3 kV, 6.6 kV, 11 kV, 20 kV and 33 kV to improve co-ordination of flicker severity from higher to lower voltage supply systems.

d) Improve the definition of voltage step change.

e) Clarify information requirements for assessment and responsibilities for provision of information.

f) Include the application of transfer coefficients for determining voltage fluctuation contributions from different nodes.

g) Assess voltage fluctuations caused by renewable energy and low carbon technologies.

	The Proposer recommends that this modification should be: Submitted to the Authority for approval
	High Impact: None
	Medium Impact: New developers of embedded generation installations, new demand users and existing users that make changes to existing installations with significant number of transformers that cause rapid voltage changes (RVCs) when energised, who are required to design their installations in accordance with the requirements and planning levels for RVCs in EREC P28.
	Low Impact: All Users of the Distribution System. The modifications are intended not to unduly impact on or cause interference to existing Users of public electricity systems/networks. Users that propose to connect disturbing equipment/fluctuating installations to the system, which could result in flicker, who need to carry out assessments and measurements in accordance with EREC P28.

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Document Control

Version	Date	Author	Change Reference
0.1	02/03/2018	ENA	Draft Report
0.2	12/03/2018	ENA	Minor Changes
0.3	19/03/2018	ENA	Timetable and implementation section modified
0.4	09/04/2018	ENA	Modified to address comments from 5/4/18 DCRP Panel meeting

Timetable

Work Group Report presented to Panel	24/11/2017
Draft Modification Report issued for consultation	08/01/2018
Consultation Closed	31/01/2018
Final Modification Report available for Panel	20/03/2018
Final Modification Report submitted to Authority	16/05/2018

1. Executive Summary

1.1 EREC P28 was first published in 1989 to provide recommended planning limits for voltage fluctuations for connection of equipment to public electricity supply systems in the UK. Issue 1 was primarily concerned with assessment of voltage fluctuations and associated flicker produced by traditional domestic, commercial and industrial loads.

1.2 Since EREC P28 was first published, the factors affecting development of transmission systems and distribution networks, and equipment connected to them have changed significantly. There has been a shift towards connection of distributed/embedded generation equipment powered by renewable energies and other low carbon technology equipment. These types of modern equipment are capable of causing voltage fluctuations.

1.3 Significant developments in Electromagnetic Compatibility (EMC) requirements have also taken place, which are captured in the International Electrotechnical Commission (IEC) 61000 series of Standards and technical reports. United Kingdom implementation of these Standards is captured in the various parts of BS EN 61000.

1.4 In addition to being a Distribution Code Annex 1 qualifying standard, EREC P28 is referenced in the Grid Code hence a joint Distribution Code and Grid Code Working Group was established to oversee the revision of EREC P28 and associated modification to requirements for voltage fluctuation in the Distribution Code. The Terms of Reference for the Working Group can be found in Annex 9.1 to this report. This Report to Authority (RTA) relates to the proposed changes to the Distribution Code and associated Qualifying Standards. Any necessary changes to the Grid Code will be governed separately by the Grid Code Review Panel.

1.5 Consequently, proposed modifications to EREC P28 (subsequently referred to as EREC P28 Issue 2) and associated modifications to the Distribution Code were developed by the Working Group. Section 4 [of this report] details the Working Group's discussions and details concerning material modifications to EREC P28.

1.6 The scope of EREC P28 has been modified to cover voltage fluctuations that are characterised as RVCs as well as those that result in flicker. The requirements in EREC P28 Issue 2 apply to new connections of customer disturbing equipment to the public electricity supply system as well as changes to existing connections, in so far as they affect voltage fluctuation. EREC P28 Issue 2 is not intended to be applied retrospectively to existing connections that have been previously assessed under Issue 1 of EREC P28 and which remain unchanged.

1.7 The proposed EREC P28 Issue 2 (see Annex 9.7) constitutes a full technical revision of Issue 1. The main technical modifications in EREC P28 Issue 2 include the following.

- Introduction of requirements and planning levels for RVCs.
- Improved definition and clarity of worst case operating conditions to be used in the assessment of voltage fluctuations.
- An intermediate planning level and associated flicker severity limits for supply systems with nominal voltages of 3.3 kV, 6.6 kV, 11 kV, 20 kV and 33 kV.

- Improved definition of voltage step change.
- Improved clarity concerning information requirements for assessment and responsibilities for provision of information.
- Concept of transfer coefficients for determining voltage fluctuation contributions from different nodes.
- Additional recommendations for assessing voltage fluctuations caused by renewable energy and low carbon technologies.

1.8 Distribution Code public consultation (DCRP/PC/18/01) was published on the 8th January 2018 and sought views from industry stakeholders on the proposed modification to Engineering Recommendation P28. The Consultation Pack can be found in Annex 9.2 to this report. The deadline for responses was the 31st January 2018.

1.9 A number of responses to the Distribution Code public consultation were received. All of the respondents agreed that the modification proposal:

- better facilitates the Distribution Code objectives;
- provides improved clarity of what constitutes 'worst case normal operating conditions';
- assists with co-ordination of the transfer of flicker severity from higher voltage to lower voltage supply systems through the intermediate planning level proposed.

Two respondents provided extensive comments in relation to the proposed requirements and planning levels for RVCs as provided in Figure 5, Figure 6, Figure 7 and Table 4 of EREC P28 Issue 2. The Working Group's full response can be found in Annex 9.3 to this report. A summary of the consultation responses can be found in Section 5 of this Report to Authority.

1.10 No major impacts have been identified by the Working Group.

1.11 The most significant medium impact of the modification affects those Users, who are required to assess and measure RVCs for conformance against EREC P28 Issue 2 requirements. In particular, developers of embedded generation installations with significant numbers of transformers that cause RVCs when energised, who are required to design their installations in accordance with the requirements and planning levels for RVCs in EREC P28 Issue 2. This modification allows for a greater number of RVCs at any point in the system in a given calendar year to facilitate disconnection and reconnection of complete customer sites with significant numbers of transformers for infrequent or very infrequent switching operations, including unplanned outages, with the ability to re-establish distributed generation more quickly after an unplanned outage, e.g. fault outage.

1.12 The assessment of the Working Group is that the proposed amendments will better facilitate the Distribution Code objectives. A more detailed commentary on the impacts and assessment of the proposed modification can be found in Section 6 of this report.

1.13 The Working Group has made a number of recommendations in Section 7 of this report, the principal one being that EREC P28 Issue 2 as it was consulted upon

(Annex 9.2 - ENA_EREC_P28_Issue 2_2017_Final Draft_v3.5_Issued') is approved and implemented subject to the proposed amendments.

1.14 At the meeting of the Distribution Code Review Panel (the Panel) held on 05/04/2018, a number of clarifications on the Report to Authority were requested. Subsequently, the Panel were consulted via email on a small number of amendments. The Panel were content with the amendments and therefore agreed to the submission of this amended Report to Authority and the Final amended version of P28 Issue 2 (Annex 9.7 - ENA_EREC_P28_Issue 2_2017_Final Draft_v3.7_Issued') as the Panel agreed that the Modification proposal better facilitated the objectives of the Distribution Code.

2. Purpose & Scope of the Working Group

2.1 Purpose

2.1.1 The joint Working Group of various key stakeholders was constituted by the Grid Code Review Panel (GCRP) and the Distribution Code Review Panel (DCRP) of Great Britain (GB) to review Engineering Recommendation P28 Issue 1 1989. Facilitation of the Working Group was provided by the Energy Networks Association (ENA). The first meeting of the working group took place on the 9 December 2014.

2.1.2 The purpose of the Working Group was as follows.

- To review the standards and processes employed by Distribution Network Operators (DNOs) and Transmission System Operators (TSOs) in GB for assessing voltage fluctuations and associated light flicker produced by potentially disturbing User equipment.
- To revise Engineering Recommendation P28 in light of the recommendations from the Working Group.

2.2 Scope

The scope of the Working Group included the following aspects.

2.2.1 General

a) Update references and associated recommendations in EREC P28, including standards.

b) Consider whether it is appropriate to employ different standards and/or processes for transmission compared with distribution connections.

c) Consider issues where EREC P28 is unclear and provide guidance on interpretation (e.g. which fault level to consider).

d) Consider voltage fluctuations from a wider network context and the adequacy of voltage fluctuation requirements in DPC4 of the Distribution Code.

2.2.2 Standards

a) Consider whether there are standards that could be adopted/referenced (e.g. PD IEC/TR 61000-3-7) in anticipation of the implementation of EU Network Codes.

Consideration will be given to reviewing IEEE Standards, where there is no appropriate National, European or International Standard.

b) Consider whether BS EN 61000-3-3 and BS EN 61000-3-11 are effective at controlling flicker for multiple LV installations.

c) Consider whether other technical standards or recommendations would need to change as a result of any change to EREC P28.

2.2.3 Limits

a) Consider whether the planning limits for voltage fluctuations and flicker are adequate or acceptable, in particular for infrequent switching events and rapid voltage changes.

b) Consider whether changes are necessary because of the new range of lighting technologies.

c) Consider whether transformer magnetising inrush should be within the scope of EREC P28.

d) Consider requirements for guidance on the application of EREC P28 and data requirements for use in models/calculations of flicker severity, in particular, data accuracy and any initial conditions to be used.

2.2.4 Evaluation of background levels

a) Clarify the interpretation of measured background values and what duration of measurement is appropriate.

b) Consider how to progress with flicker measurements where a new substation is not yet built (i.e. how is the background level at a new substation best estimated?)

2.2.5 ‘First-come, first-served’ versus allocation of rights

a) Consider the process used to allocate the limits described in EREC P28 between different Users in similar areas including whether ‘first-come, first-served’ is the appropriate way of allocating limits or whether there are alternative methods (e.g. equal rights as per PD IEC/TR 61000-3-7) that can be justified.

b) Consider how ‘competing’ applications are dealt with and how changes to customers’ requirements may impact on their right to produce voltage fluctuations and flicker.

c) Research whether other countries have moved from ‘first-come, first served’ to ‘equal rights’ and consider whether any lessons can be learned.

2.2.6 Other technical issues

a) Develop proposals to update EREC P28 to fully cover the variety of equipment now commonly encountered.

b) Consider the best approach to co-ordinate 'outages' between transmission and distribution systems under fault level consideration (e.g. one transmission Supergrid transformer out at the same time as one distribution 132 kV feeder).

3. Why change?

3.1 General

3.1.1 Engineering Recommendation (ER) P28, P*lanning Limits for Voltage Fluctuations Caused by Industrial, Commercial and Domestic Equipment in the United Kingdom* was first published in 1989. Although EREC P28 has proven to be a valuable technical document that has served industry stakeholders well, many important changes affecting its scope and recommendations have taken place in the intervening period. In particular, the following aspects were identified as needing to be addressed in the revision of EREC P28.

3.1.2 Changes to standards, limits and allocation of rights

a) Standards used in Stage 1 assessments (i.e. BS 5406) are now withdrawn.

b) The EMC Directive and subsequent EMC Regulations have introduced new standards that now apply to LV equipment (i.e. BS EN 61000-3-3 and BS EN 61000-3-11).

c) BS EN 61400-21 used in disturbance assessment of large wind turbines is not referenced.

d) Stage 3 of EREC P28 involves taking background measurements of flicker but no guidance is provided on whether to use maximum values or those based on a level not exceeded for a specified percentage of time. Engineering Recommendation G5/4-1 concerning harmonics accounts for this using the 95% of time concept and a similar approach may be justified for flicker.

e) PD IEC/TR 61000-3-7 has been published and introduces new concepts worthy of consideration; namely:

i) Margins between 'Planning Levels' and 'Compatibility Levels' to allow co-ordination of flicker between voltage levels.

ii) Planning limits for rapid voltage changes occurring less frequently than once every 10 minutes with the limits varying with how often the changes occur. This includes indicative limits with the highest reaching 6% for rapid voltage changes occurring up to two times a day at medium voltage.

iii) Apportionment according to agreed supply capacity. NOTE: EREC P28 Issue 1 allows a first-comer to utilise the whole margin; consideration was given, in cases of multiple connection applications, to some form of apportionment according to agreed supply capacity. A similar issue is being considered for harmonics in the G5/4-1 joint Panel working group.

3.1.3 Changes in networks and codes

a) Discussions are in progress with European Transmission Network Operators (ENTSO-E) concerning harmonised EU Network Codes. Documents such as PD IEC/TR 61000-3-7 may be referenced and so the impact on EREC P28 needed to be considered.

b) The Distribution Code now includes limitation on voltage fluctuations due to transformer magnetising inrush current. A review considered whether inrush should be included within the scope of EREC P28 and what the appropriate limit would be.

NOTE 1: This was also linked to consideration of the PD IEC/TR 61000-3-7 rapid voltage change indicative planning limits and associated CIGRE work. NOTE 2: A separate paper - PP11/51 - related to this was presented to the GCRP by National Grid on 22/09/2011.

c) EREC P28 Issue 1provides somewhat contradictory statements with regards to which fault level – normal or abnormal – should be used in Stage 2 and 3 assessments.

3.1.4 Changes in connections and lighting technology

a) Lighting technology is changing and modern lights have a different flicker performance than the 60 W tungsten filament lamp upon which the flicker limits in EREC P28 Issue 1 are based. Work in this area is underway at IEC level.

b) LV equipment subject to restricted connection falling within the scope of BS EN 61000-3-11 is supposed to be connected only after the customer checks that the network has sufficiently low impedance. The manufacturer is supposed to make a statement to this effect where it applies. However, in reality the manufacturer statement is often not provided or only on request and customers/installers fail to make the relevant checks. Furthermore, the impacts need to be understood of the widespread adoption of heat pumps and electric boilers, which can operate at similar times in large numbers, and the fact that BS EN 61000-3-11 allows higher levels of flicker than the EREC P28 Stage 2 limit.

c) LV equipment subject to BS EN 61000-3-3 is intended for unconditional connection. However, this standard allows higher flicker levels than the EREC P28 Issue 1 Stage 2 limit at the supply terminals and it may be possible to exceed compatibility levels with multiple installations (i.e. when a whole housing estate has such equipment operating at similar times).

4. Work Group Discussions

4.1 General

4.1.1 The Work Group agreed that EREC P28 Issue 1 should be a full technical revision and that the document should be completely restructured and formatted in line with recent ENA engineering documents.

4.1.2 It was agreed that EREC P28 would be revised so that EREC P28 Issue 2 can continue to be read as a 'standalone' document.

4.1.3 Appendix D of EREC P28 Issue 1, containing network impedance characteristics, was agreed to be obsolete and has been removed from the revision.

4.2 Changes to standards, limits and allocation of rights

Standards

4.2.1 The Work Group agreed that opportunity should be taken to align, wherever possible, terms and requirements in EREC P28 Issue 2 with those in the IEC 61000 series of Standards (or equivalent BS EN Standards, where they are published), where appropriate. Consequently, the Stage 1 flicker assessment in EREC P28 Issue 2 now aligns with the test requirements in BS EN 61000-3-3 and BS EN 61000-3-11, as applicable to the nature of the equipment and connection. In addition, methods for measuring and assessing voltage fluctuations from wind turbines now align with BS EN 61400-21. EREC P28 Issue 2 adopts requirements in BS EN 61000-4-15 in relation to flickermeters and BS EN 60868 for evaluation of flicker severity. Although consideration was given to IEEE Standards, the trend has been for these Standards to adopt requirements of IEC Standards in the area of voltage fluctuation, and hence reference to IEEE Standards was considered to be of limited value.

4.2.2 The Work Group reviewed how effective BS EN 61000-3-3 and BS EN 61000-3-11 are at controlling flicker for multiple LV installations. The review did not identify issues relating to planning limits being exceeded, where multiple equipment installations are installed on the same LV network, providing that individual equipment being connected complies with limits in BS EN 61000-3-3 or BS EN 61000-3-11, as appropriate, and that similar equipment is under independent control. EREC P28 Issue 2 now includes the requirement to consider the control of multiple equipment to prevent excessive voltage fluctuations.

4.2.3 The Working Group did not identify any global technical standards or engineering recommendations that would need to change as a result of any change to EREC P28 except for changes to relevant text in the Distribution Code, Grid Code and Engineering Recommendation G59 (see Section 6).

4.2.4 In light of the method in PD IEC TR 61000-3-7, planning levels and measurements of P_{st} and P_{lt} stated in EREC P28 Issue 2 are based on 95% probability values.

Limits

4.2.5 The planning levels for flicker severity at any point of the supply system are currently stated in Table 1 of Engineering Recommendation P28 Issue 1.

Table 1 of Engineering Recommendation P28 Issue 1

Supply system Nominal voltage	**Planning level**	
	P_{st}	**P_{lt}**
132 kV and below	1.0	0.8
Above 132 kV	0.8	0.6

4.2.6 The short-term flicker severity planning level (P_{st}) is currently 1.0 for supply systems with a nominal voltage of 132 kV and below. Given that the current planning level for these supply systems is the same as the low voltage (LV) compatibility level, the Working Group concluded there was opportunity to adjust the existing planning levels to improve the co-ordination of flicker transfer from higher voltage to lower voltage supply systems.

4.2.7 Table 2 of EREC P28 Issue 2 captures the Working Group's proposal for an intermediate planning level and associated flicker severity limits for supply systems with nominal voltages of 3.3 kV, 6.6 kV, 11 kV, 20 kV and 33 kV.

Table 2 of Engineering Recommendation P28 Issue 2

Supply system Nominal voltage	**Planning level**	
	P_{st}	**P_{lt}**
LV	1.0	0.8
3.3 kV, 6.6 kV, 11 kV, 20 kV, 33 kV	0.9	0.7
66 kV, 110 kV, 132 kV, 150 kV, 200 kV, 220 kV, 275 kV, 400 kV	0.8	0.6

4.2.8 This proposal is intended to improve the co-ordination of flicker transfer from higher voltage to lower voltage supply systems, which will reduce the possibility of background flicker severity levels exceeding compatibility limits at LV from the transfer of voltage fluctuations down through the supply system.

Rapid Voltage Changes (RVCs)

4.2.9 A key consideration for the Working Group was the introduction of new recommendations for assessment and limits for RVCs as distinct from separate flicker assessment and limits. Early meetings of the Working Group identified the need to address the omission of recommendations and limits for RVCs in Engineering Recommendation P28 Issue 1, particularly given the increased embedded generation connected to systems and the associated need to energise significant numbers of transformers, e.g. wind turbine transformers, with RVC characteristics from time to time.

4.2.10 The voltage envelopes for RVC events proposed by the Working Group in the figures below are replicated from EREC P28 Issue 2 (see Figure 5, Figure 6 and Figure 7). These limits take into account those in the recent GC0076 modification to the Grid Code.

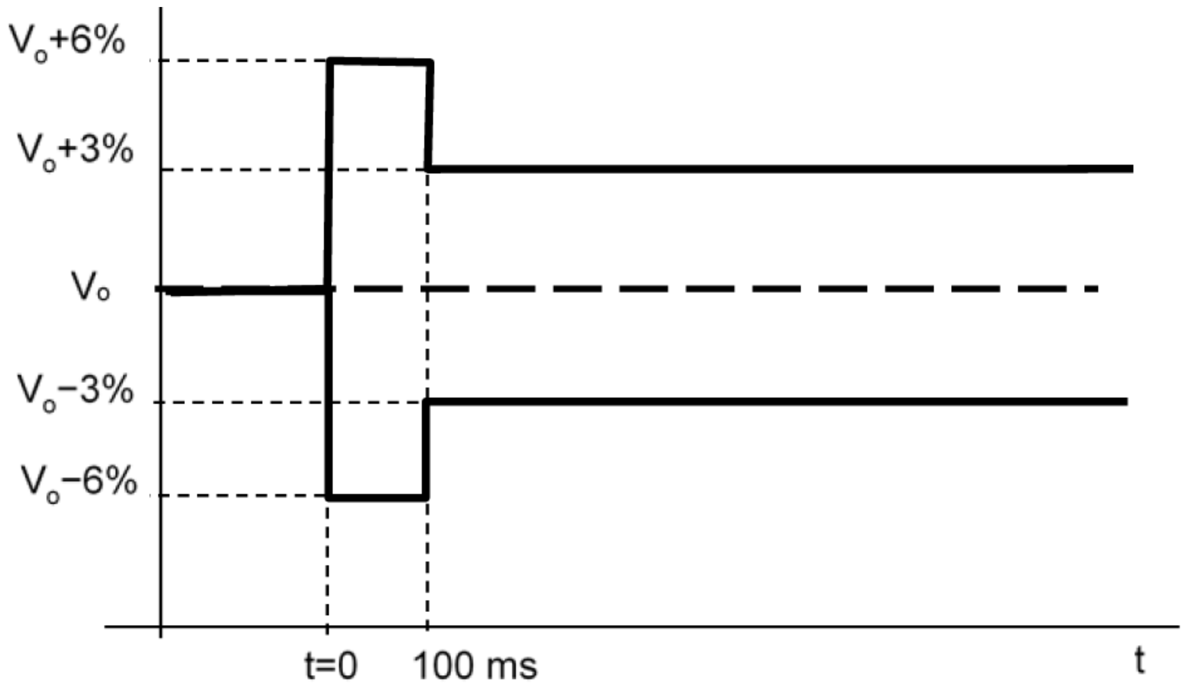

Figure 5 — Voltage characteristic for frequent events (Category 1)

4.2.11 The minimum interval between frequent events fitting within the envelope in Figure 5 is determined by conformance to flicker severity (P_{st}) limits in EREC P28 Issue 2.

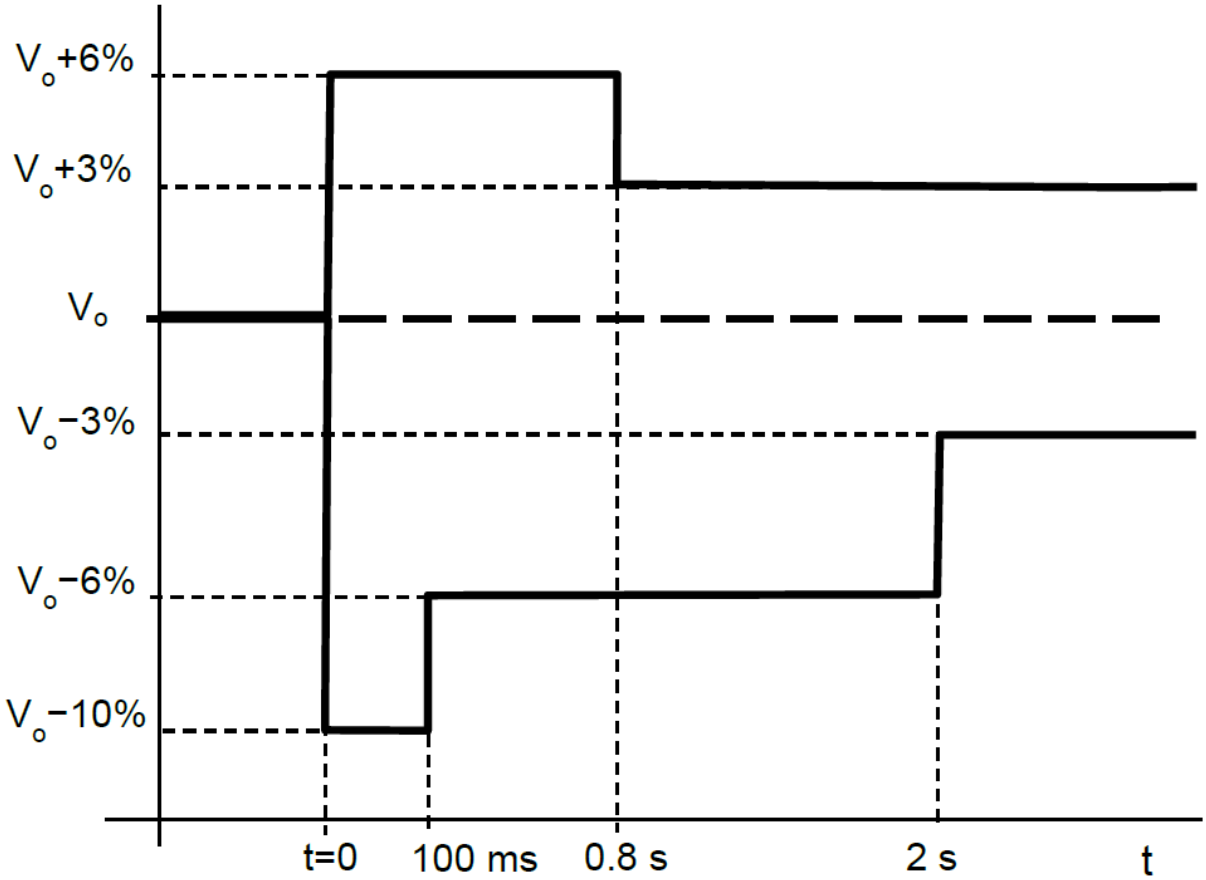

Figure 6 — Voltage characteristic for infrequent events (Category 2)

4.2.12 Up to 4 RVC events per calendar month are permitted for voltage fluctuations fitting within the envelope in Figure 6.

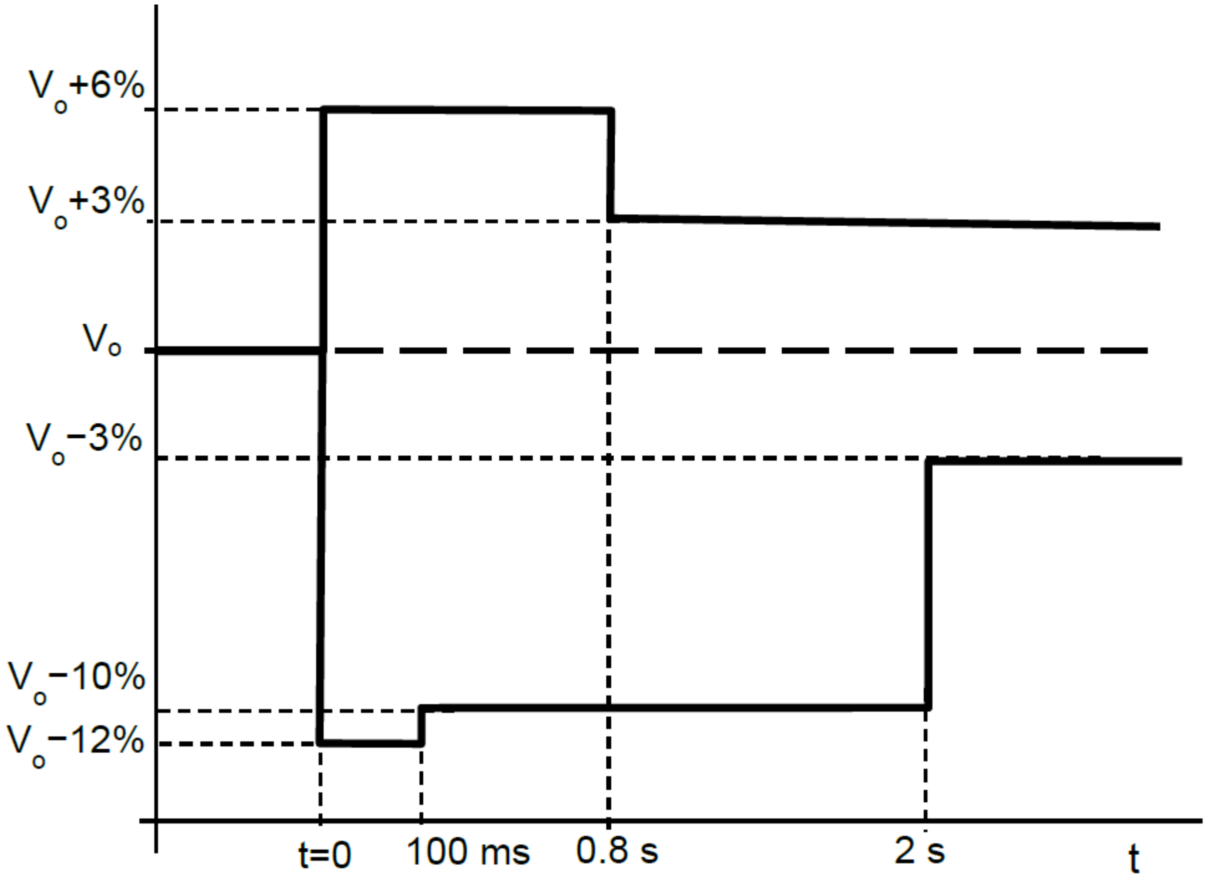

Figure 7 — Voltage characteristic for very infrequent events (Category 3)

4.2.13 The limits for RVCs proposed in EREC P28 Issue 2 take into account those in the recent GC0076 modification to the Grid Code.. It should be noted that the intention is to align the requirements in the Grid Code with those in EREC P28 Issue 2, which will provide greater flexibility for customer connections and will be less onerous to comply with for customers. The key differences between the requirements in EREC P28 Issue 2 and those in the Grid Code are as follows:

- Allowable voltage changes are expressed as a percentage of nominal voltage (V_n) in P28 Issue 2 as opposed to a percentage of the initial voltage (V_o) in the Grid Code. The intention being to align with the approach taken in National and International Standards.
- For increases in voltage:
    - EREC P28 Issue 2 proposes a limit on the maximum voltage change between two steady state conditions of $\Delta V_{max} \leq 6\%$ for a maximum duration of 0.8 s from the initiation of a voltage change.
    - The Grid Code has a limit of $\Delta V_{max} \leq 5\%$ for a maximum duration of 0.5 s.
- For decreases in voltage:
    - EREC P28 Issue 2 proposes a time limit of 100 ms from initiation of a

voltage change during which the maximum voltage change permitted (-12% for ‘very infrequent events’ and -10% for ‘infrequent events’) can persist.

  - The Grid Code has a time limit of 80 ms from initiation of a voltage change during which the maximum permitted voltage change is -12%.

- For increases and decreases in voltage, EREC P28 Issue 2 permits a greater maximum number of occurrences for Category 3 ‘very infrequent’ events:

  - EREC P28 Issue 2 proposes to permit up to a maximum of 4 RVCs in one day (irrespective of type of operational event causing the RVC) not more frequent than once every 3 months.

  - The Grid Code permits up to a maximum of 4 RVCs in one day (for commissioning, maintenance and fault restoration) typically not planned more than once per year on average over the lifetime of the connection.

- EREC P28 Issue 2 introduces an intermediate category of RVC (Category 2) for ‘infrequent events’, where up to a maximum of 4 RVCs in one day are permitted not more frequent than 4 times per month providing the $\Delta V_{max} \leq -10\%$ for ≤ 100 ms then reducing to ≤ 6% for up to 2 s after initiation of the event (see Figure 6).

4.2.14 Table 4, is replicated from EREC P28 Issue 2, which summarises the proposed categories, maximum number of occurrences within a defined time period, limits and examples of applicability for RVCs.

4.2.15 The proposed RVC limits in EREC P28 Issue 2 (and associated differences with the requirements in the Grid Code) reflect the:

- further work carried out by the Working Group and the experience of National Grid in applying RVC limits since the GC0076 modification was implemented in the Grid Code;

- limits for RVCs in Category 2 and Category 3 of Table 4 taking into account differences in the perceptibility of RVC compared with flicker associated with continuously fluctuating loads.

4.2.16 These proposals allow for a greater number of RVCs at any point in the system in a given calendar year on the basis they would be required to either be completed within a 2-hour time window or would be sufficiently spaced apart so as not to result in unacceptable disturbance. Such a modification is intended to facilitate disconnection and reconnection of complete customer sites with significant numbers of transformers for infrequent or very infrequent switching operations, including unplanned outages, with the ability to re-establish distributed generation more quickly after an unplanned outage, e.g. fault outage.

NOTE: DPC4.2.3.3 of the existing Distribution Code places a restriction of not more than one switching event per year for a single voltage change event up to 10% in magnitude. The proposal is to replace this code requirement with the planning levels for RVC in EREC P28 Issue 2.

4.2.17 The Working Group agreed that transformer magnetising inrush should be addressed in the scope of EREC P28 Issue 2. Provision for a simplified assessment of the magnitude of voltage dip caused by transformer energisation is now included in EREC P28 Issue 2. Similarly, the Working Group has provided guidance on the application of EREC P28 and data requirements for use in models/calculations of flicker severity and RVC. The intention is to highlight the sensitivity of voltage fluctuations to certain parameters and initial conditions used.Table 4 — Planning levels for RVC

Category	Title	Maximum number of occurrence	Limits $\%\Delta V_{max}$ & $\%\Delta V_{steadystate}$	Example Applicability
1	Frequent events	(see NOTE 1)	As per Figure 5	Any single or repetitive RVC that falls inside Figure 5
2	Infrequent events	4 events in 1 calendar month (see NOTE 2)	As per Figure 6 $\lvert \%\Delta V_{steadystate} \rvert \le 3\%$ For decrease in voltage: $\lvert \%\Delta V_{max} \rvert \le 10\%$ (see NOTE 3) For increase in voltage: $\lvert \%\Delta V_{max} \rvert \le 6\%$ (see NOTE 4)	Infrequent motor starting, transformer energisation, G59 [4] re-energisation (see NOTE 7)
3	Very infrequent events	1 event in 3 calendar months (see NOTE 2)	As per Figure 7 $\lvert \%\Delta V_{steadystate} \rvert \le 3\%$ For decrease in voltage: $\lvert \%\Delta V_{max} \rvert \le 12\%$ (see NOTE 5) For increase in voltage: $\lvert \%\Delta V_{max} \rvert \le 6\%$ (see NOTE 6)	Commissioning, maintenance & post fault switching (see NOTE 7)

NOTE 1: ±6% is permissible for 100 ms reduced to ±3% thereafter as per Figure 5.
If the profile of repetitive voltage change(s) falls within the envelope given in Figure 5, the assessment of such voltage change(s) shall be undertaken according to the recommendations for assessment of flicker and shall conform to the planning levels provided for flicker.
If any part of the voltage change(s) falls outside the envelope given in Figure 5, the assessment of such voltage changes, repetitive or not, shall be done according to the guidance and limits for RVCs.

NOTE 2: No more than 1 event is permitted per day, consisting of up to 4 RVCs, each separated by at least 10 minutes with all switching completed within a two-hour window.

NOTE 3: −10% is permissible for 100 ms reduced to -6% until 2 s then reduced to -3% thereafter as per Figure 6.

NOTE 4: +6% is permissible for 0.8 s from the instant the event begins then reduced to +3% thereafter as per Figure 6.

NOTE 5: −12% is permissible for 100 ms reduced to −10% until 2 s then reduced to -3% thereafter as per Figure 7.

NOTE 6: +6% is permissible for 0.8 s from the instant the event begins then reduced to +3% thereafter as per Figure 7.

NOTE 7: These are examples only. Customers may opt to conform to the limits of another category providing the frequency of occurrence does not exceed the 'Maximum frequency of occurrence' for the chosen category.

Allocation of rights (Apportionment)

4.2.18 There was no evidence that the current 'first-come, first-served' approach in EREC P28 Issue 1 has resulted in any particular problems for stakeholders, e.g. voltage complaints, flicker headroom being used up.

4.2.19 Notwithstanding, the Working Group considered whether allocating flicker headroom for Stage 3 assessment, as described in PD/IEC/TR 61000-3-7, would be potentially simpler and fairer than the current approach. The pros and cons for maintaining the status quo versus a change in approach were considered. The Working Group concluded that there was no clear merit or justification for changing the 'first come first served approach', in particular given the low number of Stage 3 assessments carried out. The decision to retain the current policy of 'first come first served' was based on the following.

a) There is no compelling evidence to date that shows there are significant issues with the current 'first come first served policy' in practice; the application of the allocation method would appear to be a solution looking for a problem that doesn't exist.

b) Experience in other countries that have adopted the allocation method in PD IEC/TR 61000-3-7, including Australia, suggests there are complexities and problems with applying it in practice, particularly to existing networks, and that a modified approach based on measurement of flicker background levels and allocation based on available headroom is required to address the short comings.

c) The allocation approach appears to have been taken up more in relation to transmission system operators than for distribution network operators, where there are a greater number of connections.

d) There are fairness arguments for both methods and it would be incorrect to say that the current 'first come first served' method could be considered to be overwhelmingly unfair. There is not a compelling case to move to the allocation method on the grounds of fairness.

e) A move to an allocation method will be more complex technically and marginally more expensive commercially given that it will require more information and consideration for network operators and connectees than at present.

Background Measurements

4.2.20 The Working Group has now included guidance on background levels for flicker assessment, particularly where there is no measured data. In the absence of any data the flicker background level can be assumed to be P_{st} = 0.5 unless there is reason to believe the flicker background level might be greater than this value, in which case a direct site measurement should be carried out for the purposes of assessment.

4.2.21 The application of transfer coefficients in EREC P28 Issue 2 by the Working Group allows flicker background levels for new substations to be estimated from measurements at other locations in the electricity supply system by applying relevant transfer coefficients from adjacent nodes (see Table 3 of EREC P28 Issue 2 for typical transfer coefficients).

4.3 Changes to network codes

4.3.1 The impact of European Network Codes on EREC P28 was evaluated by the Working Group and no particular issues or conflicts were identified.

4.3.2 The Working Group recognised that EREC P28 Issue 1 provides somewhat contradictory statements with regards to which fault level should be used in Stage 2 and 3 assessments. In particular, whether planned outages of the system should be considered. The Working Group agreed that clear definitions of what should constitute normal operating conditions for assessment, should be provided including how credible outage conditions should be assessed.

4.3.3 Consequently, EREC P28 Issue 2 has been amended to provide improved clarity for the assessment of voltage fluctuations under the 'worst case normal operating condition' (see Clause 6.1.6 of EREC P28 Issue 2), which broadly aligns with the approach in PD IEC/TR 61000-3-7. Normal operating conditions for the supply system are now defined as those operating conditions, where the system/network is designed to operate and remain within acceptable/statutory limits. Table 6 of EREC P28 Issue 2 lists what should be considered normal operating conditions. These conditions include credible outage conditions (both planned and/or fault outages) consistent with securing demand as required by relevant security of supply standards, i.e. ENA Engineering Recommendation P2 for HV distribution networks and National Electricity Transmission System Security Quality of Supply Standards (NETS SQSS) for transmission systems. Notwithstanding, the limits in EREC P28 Issue 2 are not intended to apply to transient voltage fluctuations between fault initiation and fault clearance or during any reconfiguration of the public electricity supply system immediately following a fault to secure supplies.

4.3.4 The Working Group believe the improved definition of normal operating conditions in EREC P28 Issue 2 will provide a more consistent understanding and application of the network conditions by customers and system/network operators for EREC P28 type assessments and will address the lack of definition in the current EREC P28 Issue 1, which is not particularly clear in this respect and is open to interpretation. The Working Group believe the definition of normal operating conditions in EREC P28 Issue 2 are not unduly conservative and formalise good practices with respect to assessing voltage fluctuation.

4.4 Changes in connections and lighting technology

4.4.1 Although for a given voltage disturbance, illuminance variation may be less and therefore flicker may be less perceptible for certain types of modern lighting compared with traditional tungsten filament light bulbs, this response is not universal across all types of lighting technology. On this basis, the Working Group agreed that evaluation of flicker severity in EREC P28 Issue 2 should still be based on the standard flickermeter defined in IEC 61000-4-15 given there is insufficient evidence or industry consensus at present to adopt any changes to the design or function of the standard flickermeter.

4.4.2 The Working Group considered the assessment of LV equipment falling within the scope of BS EN 61000-3-11, where the customer is required to confirm that the network has sufficiently low impedance. After considerable discussions by the

Working Group the output was a revised Stage 1 assessment process in EREC P28 Issue 2, which provides the equipment manufacturer and customer with guidance and approaches to determining the value of supply system impedance and assessing whether this is sufficiently low for connection of equipment with a value of Z_{max} declared by the manufacturer.

4.4.3 The Working Group reviewed the process for assessing LV equipment subject to BS EN 61000-3-3, which is intended for unconditional connection. Although, this standard allows higher flicker levels than the EREC P28 Stage 2 limit at the supply terminals, the Working Group did not find any evidence that unconditional connection of multiple installations of similar equipment under Stage 1 in EREC P28 Issue 2 would pose an unacceptable risk of LV compatibility levels being exceeded at the point of common coupling, providing such equipment conforms to BS EN 61000-3-3 and is independently controlled. Guidance on this aspect is provided in Clause 6.3.2 of EREC P28 Issue 2.

4.5 Improved definition of voltage step change

4.5.1 The Working Group discussed the appropriateness of the general limit on the magnitude of voltage step changes of ±3%. The Working Group believes that this should not be changed to minimise the risk that voltage fluctuations will exceed statutory voltage limits.

4.5.2 However, EREC P28 Issue 2 now clarifies that the ±3% general limit relates to the voltage change between steady state conditions, referred to as $V_{steadystate}$, (see Clause 4.7 of EREC P28 Issue 2). Although EREC P28 Issue 2 does not place a limit on the time for transient decay, it requires that voltage changes must be within ±3% after 2 s from event initiation.

NOTE: Limits for voltage fluctuations in between steady state conditions (referred to as V_{max}) can be greater than ±3% for infrequent events and very infrequent events and fall under requirements for Rapid Voltage Changes in EREC P28 Issue 2.

4.5.3 The intention of this proposal is to allow a clear distinction between distinct different voltage change events.

4.5.4 EREC P28 Issue 1 was not clear whether voltage fluctuation was expressed as a percentage of the initial voltage (V_o) or the nominal voltage (V_n) of the system concerned. The Working Group discussed the need to provide clarity and agreed to align with the approach in the BS EN 61000 series of Standards, where the philosophy is to express voltage changes as a percentage of V_n. Analysis carried out by the Work Group confirms this is not expected to have a material impact on the voltage change limits in EREC P28.

5. Consultation Responses

Responses received from the Public Consultation

5.1 A Distribution Code public consultation took place from the 8th January 2018 to 31st January 2018 on the proposed modification to Engineering Recommendation P28. Industry stakeholders were invited to respond expressing their views or providing any further evidence on any of the matters contained within the consultation document together with the rationale for their responses to the following questions.

Q1 Do you agree with the proposed requirements and planning levels for RVCs in EREC P28 Issue 2 (as provided in Figure 5, Figure 6, Figure 7 and Table 4 of EREC P28 Issue 2)?

Q2 Do you agree with the proposal for providing improved clarity of what constitutes 'worst case normal operating conditions' for the assessment of voltage fluctuations under EREC P28?

Q3 Do you agree with the proposals for an intermediate planning level to assist with co-ordination of the transfer of flicker severity from higher voltage to lower voltage supply systems?

Q4 Do you have any objections to the proposed amendments in EREC P28 Issue 2 as they currently stand? If so, please describe your concerns and if possible propose any alternatives.

Q5 Do you agree that the proposed modification proposal better facilitates the Distribution Code objectives?

Q6 Recognising that any consequential changes to the Grid Code will need to be progressed via the Grid Code governance process, the Working Group would welcome any concerns you have at this stage if the EREC P28 Issue 2 proposal was to be considered for adoption in the Grid Code?

Q7 Do you have any other comments to make on the proposed changes?

5.2 Four responses were received: 1 from a generator stakeholder, 2 from renewable energy stakeholders and 1 from a network operator stakeholder. A summary of the responses received and the subsequent response by the Working Group can be found in Annex 9.3 to this report.

5.3 Two of the four respondents were fully supportive of the proposals and had no objections to the proposed amendments in EREC P28 Issue 2 as they currently stand.

5.4 All four respondents agreed that the modification proposal better facilitates the Distribution Code objectives (see Question 5).

5.5 All four respondents also agreed with the proposals for providing improved clarity of what constitutes 'worst case normal operating conditions' (see Question 2) and the proposals for an intermediate planning level to assist with co-ordination of the transfer of flicker severity from higher voltage to lower voltage supply systems (see Question 3).

5.6 However, two of the respondents provided extensive comments in relation to the proposed requirements and planning levels for RVCs as provided in Figure 5, Figure

6, Figure 7 and Table 4 of EREC P28 Issue 2 (see Question 1). The responses to Question 1 related to the following.

a) The apparent setting of planning levels the same as operating levels for the higher categories of RVCs concerned one respondent because when the network is not operating correctly, equipment could be constrained off for long periods due to external events causing them to trip off.

   i) In response the Working Group believe there would be no realistic prospect of operation of the G59 undervoltage stage 1 protection for external RVC events that conform with the limits and requirements of EREC P28 Issue 2. Furthermore, the reference to "Commissioning, maintenance and post fault switching" in Table 4 of EREC P28 Issue 2 is an example of applicability. NOTE 7 in Table 4 states that these are examples only and that customers may opt to conform to the limits of another category providing the expected frequency of the events do not exceed the maximum frequency permitted for the chosen category. Commissioning, maintenance or post fault switching activities could be classed as Category 1, Category 2 or Category 3 events depending upon the maximum number of occurrences foreseen for those events.

   Subsequent to their initial response the Working Group would point out that Table 4 of EREC P28 Issue 2 refers to planning levels for RVCs, which should be used for design and planning of connections. Whilst design pre-connection should be based on an <u>expected</u> number of both planned and unplanned RVCs over specified time periods to comply with Table 4, it is recognised that Users do not have control of the number of <u>actual</u> unplanned RVC events, including G59 trips, that could occur post connection.

b) One respondent believes that the requirements in Table 4 of EREC P28 Issue 2 are more onerous than CC.6.1.7 of the Grid Code under certain circumstances and that designing for the maximum number of occurrences permitted for Category 2 and Category 3 events in EREC P28 Issue 2 could have cost implications for developers. In addition, that the maximum number of 4 RVCs per day permitted in Category 2 and Category 3 of EREC P28 Issue 2 is impractical for re-energising wind farms based on one wind turbine transformer being energised at a time.

   i) In response, the Working Group do not believe the requirements in EREC P28 Issue 2 are more onerous than Category 2 of Grid Code CC.6.1.7. The time and voltage magnitude limits for Category 3 RVCs shown in Figure CC.6.1.7 of the Grid Code when compared with Figure 7 of EREC P28 Issue 2 confirm that both the time and voltage limits in EREC P28 Issue 2 for Category 3 very infrequent events (not more than 4 RVCs in 1 day providing less frequent than once every 3 calendar months) are less onerous than those for Category 3 RVCs in the Grid Code.

   ii) Regarding the maximum number of 4 RVCs permitted per day under Category 2 and Category 3 of P28 Issue 2. The respondent has assumed only one wind turbine transformer can be energised at a time. EREC P28

Issue 2 does not preclude more than one wind turbine transformer being energised at the same time. The intention of the limits in Category 2 and Category 3 is to allow several transformers to be energised at any one time whilst complying with the applicable limits.

iii) In their response, the Working Group pointed out that the limits in Table 4 of EREC P28 Issue 2 and the associated amendments to the Distribution Code have been carefully chosen to allow a greater number and magnitude of RVC type voltage fluctuations than is currently permitted whilst not posing an unacceptable risk of voltage complaints from other customers connected to the system. It would not be acceptable to increase the RVC limits proposed for Category 2 and Category 3 events in EREC P28 Issue 2 simply to avoid the need for disturbing equipment connectees to mitigate unacceptable voltage fluctuations caused by the energisation of their equipment, where these fluctuations could cause an unacceptable risk of interference to other customers.

iv) The Working Group would also point out that the changes in EREC P28 Issue 2 are a significant relaxation compared with the current requirements in DPC4.2.3.3 of the Distribution Code, which only permits a voltage depression of -10% not more frequently than once per year for energisation of transformers, as a result of post fault switching, post maintenance switching, or carrying out commissioning tests. On this basis, the P28 Working Group is of the opinion that the requirements in Table 4 of EREC P28 Issue 2 should not be relaxed for Category 2 and Category 3 as proposed by the respondent.

5.7 In response to Question 4 concerning any objections to the proposed amendments in EREC P28 Issue 2 as they currently stand.

a) Both respondents referred to their response in Question 1 concerning the proposed requirements and planning levels for RVCs.

5.8 In response to Question 6 concerning the adoption of EREC P28 Issue 2 requirements into the Grid Code.

a) One respondent was concerned that assets could be sitting for long periods of time without generating power as indicated in answer to Q1 representing a major loss of revenue for a windfarm owner/developer.

i) The Working Group believes that the limits and maximum number of occurrences for rapid voltages changes permitted in EREC P28 Issue 2 are less onerous than those in the Grid Code. The intention of the planning levels for rapid voltage changes in EREC P28 Issue 2 are to provide more flexibility for generators, who need to energise large numbers of wind turbine transformers, than currently exists in the Grid Code. The Working Group trusts that their response to Q1 allays these concerns and that there would be no objection to ultimately adopting the relevant limits and requirements from EREC P28 Issue 2 in the Grid Code.

b) Another respondent was concerned that the categories in Table 4 of EREC P28 Issue 2 are different to those in CC.6.1.7 of the Grid Code, which could cause confusion. In particular that the permitted frequency of events for Category 3 in Table 4 of EREC P28 Issue 2 appears to be more onerous than CC.6.1.7 of the Grid Code.

i) The response from the Working Group highlights that although the categories of RVC events in EREC P28 Issue 2 and the Grid Code have similar numbers, e.g. 'Category 3', the titles, maximum number of occurrences and limits are different. This reflects the further work carried out by the Working Group and the experience of National Grid in applying RVC limits since the GC0076 modification was implemented in the Grid Code. Notwithstanding, the intention is to align the categories in the Grid Code with those in EREC P28 Issue 2, which would avoid confusion.

ii) With respect to Category 2 and Category 3 events in EREC P28 Issue 2: Under both Category 2 & Category 3, one event is permitted in a given day, where one event can consist of up to 4 separate RVCs (see NOTE 2 of Table 4). Therefore, up to 4 RVCs in a given day are allowed under both Category 2 & Category 3 of Table 4 [EREC P28 Issue 2], which is similar to the maximum of 4 RVCs per day permitted in Category 3 of the Grid Code. The difference being that the permitted occurrence of RVC events in EREC P28 Issue 2 is more frequent (less onerous) than Category 3 of the Grid Code. Category 3 of the Grid Code permits a maximum of 4 RVCs per day typically not planned more than once per year on average over the lifetime of a connection compared with 4 events (each event consisting of up to 4 RVCs) per calendar month for Category 2 events in EREC P28 Issue 2 and 1 event (consisting of up to 4 RVCs) every 3 calendar months for Category 3 events in EREC P28 Issue 2. On this basis the Working Group believes that EREC P28 Issue 2 provides for a greater number of RVCs in any given time period than is currently permitted in the Grid Code. The intention is to provide Users, including generators, with more flexibility for energising transformers than currently exists in the Grid Code.

c) A respondent was concerned that limits for the maximum number of occurrences over a particular time period as stated in Table 4 of EREC P28 Issue 2 appear to be more stringent than those in CC.6.1.7 of the Grid Code and do not allow for operational problems. The wording in CC.6.1.7 states: "…typically not planned more than once per year on average…", whereas EREC P28 Issue 2 does not have such wording.

i) With respect to the application of the wording "…typically not planned more than once per year on average over the lifetime of a connection…" in CC.6.1.7 (a) (viii) of the Grid Code. The Working Group believes the limits and maximum number of occurrences for RVCs in the Grid Code apply to both design and operation of the system. Although the requirements in EREC P28 Issue 2 primarily relate to the design and assessment of connections, the P28 Working Group does not intend for any particular difference in the application of associated aspects of EREC P28 Issue 2 and the Grid Code. The P28 Working Group would point out that EREC P28 Issue 2 acknowledges that the final decision as to whether or not disturbing equipment exceeding the limits in EREC P28 Issue 2 may be connected to the system is at the discretion of the relevant system/network operator (see Lines 276-280) in EREC P28 Issue 2.

a. Subsequent to their initial response the Working Group would like to clarify that EREC P28 Issue 2 is a planning document. Whilst design at the pre-connection stage should be based on an expected number of both planned and unplanned RVCs over specified time periods to comply with planning levels in Table 4, it is recognised that Users do not have control of the actual number of unplanned RVC events, including G59 trips, that could occur post connection; these could be greater in number than the expected number allowed for in the design. Table 4 of EREC P28 Issue 2 does not restrict the number of unplanned events that happen post-connection in the network, given network Users cannot control these events, e.g. where G59 protection trips due to voltage or frequency events in the network. However, if the number of actual events proves to be unacceptable to other network Users to the extent that 'interference' is caused then the system/network operator would be required to act under Regulation 26 of the Electricity Safety Quality & Continuity Regulation (ESQCR) and may judge that mitigation is needed in a reasonable time period.

5.9 In response to Question 7 concerning any other comments:

a) One respondent commented that is surprising after the description in the introduction [EREC P28 Issue 2] of the importance for restricting flicker to stop customer annoyance and complaints that the same requirements do not apply to all equipment by exempting licenced Distribution and Transmission Operators, given their equipment will be very similar.

i) In response the Working Group pointed out that the scope of EREC P28 Issue 1 applies to voltage fluctuations caused by industrial, commercial and domestic equipment connected to the system. The terms of reference for the revision of EREC P28 Issue 1, as set by the Joint Distribution Code and Grid Code Review Panels, was for EREC P28 Issue 2 to remain a 'customer facing' document and for any overarching application of requirements and limits in EREC P28 to be contained within the Distribution Code. Notwithstanding, the Working Group, as part of their Terms of Reference, has sought to be fair and even-handed in the application of requirements taking into account the different operating context and objectives of Users and network operators.

b) The same respondent also noted there is a reference to current version P28 figure 4 in the SQSS and EREC P28 Issue 2 replaces the original figure 4 with figure B.1.2 and asked for confirmation whether these are the same and whether the SQSS will be corrected?

i) The Working Group note the acknowledgment in the SQSS that EREC P28 Issue 1 Figure 4 was used in the derivation of Figure 6.1 ‘Maximum Voltage Step Changes Permitted for Operational Switching’. Figure B.1.2 in EREC P28 Issue 2 is intended to replace Figure 4 in EREC P28 Issue 1 but has been aligned with the current flicker severity curve in Figure A.1 of PD IEC/TR 61000-3-7 – except that the curve has been deliberately capped at a maximum symmetrical step voltage change of 3% once every 475 s. Consequently, the curve in Figure B.1.2 in EREC P28 Issue 2 differs from that in Figure 4 of EREC P28 Issue 1 and Figure 6.1 of the SQSS. The P28 Working Group recommend that Figure 6.1 in the SQSS is reviewed in light of the current flicker severity curve in Figure A.1 of PD IEC/TR 61000-3-7 and the aligned Figure B.1.2 in EREC P28 Issue 2.

Responses received outside the Public Consultation

5.10 A response was received outside the official public consultation process concerning interpretation of Clause 5.4 Step voltage change limit (lines 835-842). The respondent believes the clause might need re-phrasing as, unless it was intended to do so, it currently states that voltage fluctuations greater than 3% in magnitude should not cause interference where the shape of the voltage characteristic is equivalent to a step change less than or equal to 3%. In other words, a voltage fluctuation of 5% should not cause interference if the disturbing equipment is ramped up/down over a period that will correspond to a step change equivalent figure (using the shape factors) of less than 3%.

a) In response, the Working Group would like to clarify that the general limit on the magnitude of voltage step changes is ±3%. This general limit equates to the maximum change in steady state voltage ($V_{steadystate}$) from the initial voltage to the resulting voltage level. For frequent events that need to be assessed for flicker the voltage characteristic should not exceed the envelope in Figure 5 of EREC P28 Issue 2. On this basis a 5% voltage fluctuation that is ramped up/down over a period but it expected to occur frequently would not be acceptable even though the equivalent step voltage change derived using the appropriate shape factor corresponds to an equivalent step voltage change of less than 3%.

In order to avoid misinterpretation with the requirements in EREC P28 Issue 1 it is proposed to delete lines 840 to 842 inclusive of EREC P28 Issue 2

~~Voltage fluctuations greater than 3% in magnitude should not cause interference where the shape of the voltage characteristic is equivalent to a step voltage change less than or equal to 3% (see 6.3.3.4) or is of sufficiently low frequency of occurrence (see 5.2.2).~~

6. Impact & Assessment

6.1 Impact on the Distribution Code and Grid Code

6.1.1 The revision of EREC P28 Issue 2 materially affects DPC4.2.3.2 (Voltage Disturbances) and DPC4.2.3.3 (Voltage Step Changes) of the Distribution Code. The Working Group recommends the changes to the legal text of the Distribution Code, Issue 33 – 01 August 2018 contained in Annex 9.4 of this report.

6.1.2 The Working Group also recommend that the requirements of CC.6.1.7 of the Grid Code are aligned with those in EREC P28 Issue 2. NGET are looking to propose legal text changes to the Grid Code as a separate code modification.

6.2 Impact on Distribution Code Users

6.2.1 The proposed modification provides Users with improved clarity of requirements concerning assessment and measurement of voltage fluctuations, in particular, the definition of what constitutes 'worst case normal operating conditions' for assessments. The respective responsibilities of Users and system/network operators in the assessment process are better defined, which is expected to allow for a more consistent application of EREC P28 requirements by system/network operators.

6.2.2 The proposed planning levels for RVC, whilst allowing for a greater number and magnitude of RVC type voltage fluctuations than is currently permitted is not considered to pose an unacceptable risk of voltage complaints from other Users connected to the system.

6.2.3 The proposal for an intermediate planning level and adjustment of associated flicker severity limits for supply systems with nominal voltages of 3.3 kV, 6.6 kV, 11 kV, 20 kV and 33 kV will improve the co-ordination of flicker transfer from higher voltage to lower voltage supply systems. This is expected to reduce the possibility of background flicker severity levels exceeding compatibility limits at LV from the transfer of voltage fluctuations down through the supply system.

6.2.4 The modifications are intended not to unduly impact on or cause interference to existing Users of public electricity systems/networks.

6.3 Impact on embedded generators

6.3.1 The proposed modification to the Distribution Code will allow embedded generators to plan for a greater number of RVCs at any point in the system in a given calendar year than currently exists in EREC P28 Issue 1 and the Distribution Code. The intention of the modification is to facilitate disconnection and reconnection of complete customer sites with significant numbers of transformers for infrequent or very infrequent switching operations, including unplanned outages, with the ability to re-establish distributed generation more quickly after an unplanned outage, e.g. fault outage.

6.4 Impact on National Electricity Transmission System (NETS)

6.4.1 The proposed changes to the RVC voltage envelopes arising from Figure 5, Figure 6 and Figure 7 of EREC P28 Issue 2 are expected to have a minimal impact on the NETS compared with those in CC.6.1.7 of the Grid Code. Under EREC P28 Issue 2 the maximum no. of occurrences of RVCs would change from typically 4 RVCs in one day (for commissioning, maintenance and fault restoration) typically not planned more than once per year on average over the lifetime of the connection to 4 RVCs in one day not more than once per three months. Whilst this increases the number of planned RVCs permitted per year these will be sufficiently spaced apart so as to minimise any potential disturbance to customers connected at point of common couplings No impact is foreseen regarding notification of Category 3 events, which still require notification to NGET.

6.4.2 The NETS SQSS uses EREC P28 Issue 1 Figure 4 in the derivation of Figure 6.1 'Maximum Voltage Step Changes Permitted for Operational Switching'. Figure B.1.2 in EREC P28 Issue 2 replaces Figure 4 in EREC P28 Issue 1 so that the curve has been deliberately capped at a maximum symmetrical step voltage change of 3% once every 475 s compared with once every 600 s previously. The Working Group would recommend that Figure 6.1 in the NETS SQSS is reviewed in light of the current flicker severity curve in Figure A.1 of PD IEC/TR 61000-3-7 and the aligned Figure B.1.2 in EREC P28 Issue 2. If the SQSS were to be subsequently modified on this basis it would permit more voltage step changes of a given magnitude of 3% over a given time period than is currently allowed now.

6.5 Assessment against Distribution Code Objectives

6.5.1 The proposed amendments would better facilitate the following applicable Distribution Code objectives:

(a) permit the development, maintenance, and operation of an efficient, co-ordinated, and economical system for the distribution of electricity.

i) The proposals provide improved clarity of voltage fluctuation requirements for Users wishing to connect to public electricity supply systems. The proposals facilitate improved co-ordination of planning levels for flicker related voltage fluctuations and RVCs down through voltage levels to minimise the risk of compatibility levels being exceeded at LV.

ii) The proposals allow Users to have a greater number and magnitude of RVC type voltage fluctuations over a year than is currently permitted in P28 Issue 1 and the Distribution Code. This provides Users with greater flexibility on how they design their equipment/connection to meet voltage fluctuation limits and how they can avoid costs with providing additional equipment to reduce the magnitude of voltage fluctuations.

(b) facilitate competition in the generation and supply of electricity

i) The proposals are expected to facilitate connection of embedded generation, which may otherwise not be connected to the system because of the limits on the magnitude and number of voltage fluctuation events permitted in DPC.4.2.3.3 of the current issue of the Distribution Code, in relation to the energisation of complete sites with a significant presence of transformers.

(c) efficiently discharge the obligations imposed upon distribution licensees by the distribution licences and comply with the Regulation and any relevant legally binding decision of the European Commission and/or the Agency for the Co-operation of Energy Regulators.

i) The proposals align requirements in EREC P28 Issue 2 with provisions for voltage fluctuations in the relevant series of BS EN 61000 standards. so far as considered relevant and suitable by the Working Group. The proposals are intended to comply with the requirements for voltage fluctuations in the proposed European Network Codes.

(d) promote efficiency in the implementation and administration of the Distribution Code.

i) The proposals allow detailed requirements in DPC.4.2.3.3 of the Distribution Code concerning fluctuations to be addressed in EREC P28 Issue 2. The intention is to avoid any conflict between the Distribution Code and EREC P28.

6.6 Impact on core industry documents

6.6.1 The proposed modifications to EREC P28 and the Distribution Code impacts on requirements in clauses 9.5.7 to 9.5.11 inclusive of Engineering Recommendation G59. These clauses refer to limits and requirements in EREC P28 that have been modified under these proposals. In essence, minor text changes are required to align with EREC P28 Issue 2 as documented in Annex 9.5 - EREC G59 Issue 3 Amendment 4 July 2018 .

6.6.2 In addition, Clause 3.2 of Engineering Recommendation G59 will need to be amended to reflect the modified title of EREC P28 (see Annex 9.5).

6.6.3 As stated in 6.4.2 of this report Figure 6.1 'Maximum Voltage Step Changes Permitted for Operational Switching' in the NETS SQSS is possibly impacted should the decision be taken to align this with the new Figure B.1.2 in EREC P28 Issue 2.

6.6.4 The proposed modification does not affect any other core industry documents other than the Grid Code.

6.7 Implementation

6.7.1 The Working Group confirms there are no reasons why implementation should be unduly delayed and recommends that the proposed changes be implemented from 1st August 2018, or other such date as the Authority might agree to. The proposed date for implementation has been chosen to follow other modifications that pre date EREC P28 Issue 2 and to coincide with proposed Issue 33 of the Distribution Code.

6.7.2 In accordance with DGC11.2 of the Distribution Code:

(a) the proposed changes in EREC P28 Issue 2 are not intended to apply retrospectively to equipment already existing at the date of implementation of the Distribution Code change.

(b) any material changes to Equipment after the date of implementation will need to comply with the requirements of EREC P28 Issue 2.

7. Working Group Recommendations

7.1 The recommendations of the Working Group are as follows.

a) EREC P28 Issue 2 as it was consulted upon (see Annex 9.2 'ENA_EREC_P28_Issue 2_2017_Final Draft_v3.5_Issued') is accepted subject to the following specific amendments.

The following proposed amendments i), ii) and iii) arising from the public consultation (as documented in 'ENA_EREC_P28_Issue 2_2017_Final Draft_v3.6_Issued').

i) Clause 5.3.2 Planning Levels (Line 765-767):

"The planning levels in Table 4 define absolute limits of maximum voltage change (ΔV_{max}) and steady state voltage change ($\Delta V_{steadystate}$) for RVCs according to the maximum number of occurrences ~~permitted~~ expected within a specified time period."

ii) Table 4 Note 7:

"These are examples only. Customers may opt to conform to the limits of another category providing the frequency of occurrence ~~does~~ is not expected to exceed the 'Maximum frequency of occurrence' for the chosen category."

iii) Clause 5.4 Step voltage change limit (Lines 840-842)
~~"Voltage fluctuations greater than 3% in magnitude should not cause interference where the shape of the voltage characteristic is equivalent to a step voltage change less than or equal to 3% (see 6.3.3.4) or is of sufficiently low frequency of occurrence (see 5.2.2)."~~

The following additional amendment iv) proposed below arising from the meeting of the Distribution Code Review Panel (DCRP) held on 05/04/2018 (as documented in 'ENA_EREC_P28_Issue 2_2017_Final Draft_v3.7_Issued' – See Annex 9.7).

iv) Table 4 Note 7:

Addition of the following sentence at the end of the proposed note: "Where the measured emission level exceeds the expected emission level, paragraph 4 of Clause 6.1.4 applies."

b) The proposed requirements and planning levels for RVCs in EREC P28 Issue 2 (as provided in Figure 5, Figure 6, Figure 7 and Table 4 of EREC P28 Issue 2) are implemented.

c) The definition of 'worst case normal operating conditions' and associated requirements for assessing these conditions in EREC P28 Issue 2 are accepted.

d) The intermediate planning level and associated flicker severity limits for supply systems with nominal voltages of 3.3 kV, 6.6 kV, 11 kV, 20 kV and 33 kV is accepted to improve the transfer of flicker severity from higher voltage to lower voltage supply systems.

e) The proposed changes to the legal text of the Distribution Code, Issue 33 – 01 August 2018 as documented in Annex 9.4 and 9.4.1 to this report are implemented.

f) The relevant clauses in Engineering Recommendation G59 that refer to limits and requirements in EREC P28 are aligned with the proposed amendments in EREC P28 Issue 2 as documented in Annex 9.5 - EREC G59 Issue 3 Amendment 4 July 2018.

g) It is recommended that the Grid Code Review Panel draft and progress proposed changes to the legal text of the Grid Code via the Grid Code governance process to align with the proposals in EREC P28 Issue 2.

h) It is recommended that the SQSS Review Panel review Figure 6.1 in the NETS SQSS in light of the current flicker severity curve in Figure A.1 of PD IEC/TR 61000-3-7 and the aligned Figure B.1.2 in EREC P28 Issue 2.

8. Distribution Code Review Panel Recommendation

8.1 At the meeting of the Distribution Code Review Panel (the Panel) held on 05/04/2018, a number of clarifications on the Report to Authority were requested. Subsequently, the Panel were consulted via email (09/05/18) on a small number of amendments. The Panel members subsequently responded indicating they were content with the amendments and therefore agreed to the submission of this amended Report to Authority and the Final amended version of P28 Issue 2 (Annex 9.7 - ENA_EREC_P28_Issue 2_2017_Final Draft_v3.7_Issued') as the Panel agreed that the Modification proposal better facilitated the objectives of the Distribution Code.

9. Annexes

9.1 Working Group Terms of Reference

Please see the separate attachment to this report titled 'Annex 9.1_DCRP/MP/18/01/RtA'

9.2 Public Consultation Pack for Revision of EREC P28

Please see the separate attachment to this report titled 'Annex 9.2_DCRP/MP/18/01/RtA'

9.3 Responses to the Public Consultation for Revision of EREC P28

Please see the separate attachment to this report titled 'Annex 9.3_DCRP/MP/18/01/RtA'

9.4 Proposed changes to the legal text of the Distribution Code

Please see the separate attachment to this report titled 'Annex 9.4_DCRP/MP/18/01/RtA'

9.4.1 Revised draft Distribution Code V33 (with the changes referenced in 9.4)

Please see the separate attachment to this report titled 'Annex 9.4.1_DCRP/MPPC/18/01/RtA'

9.5 Proposed changes to the legal text of EREC G59 Issue 3 Amendment 4 July 2018

Please see the separate attachment to this report titled ‘Annex 9.6_DCRP/MP/18/01/RtA’

9.6 Final amended version of EREC P28 Issue 2 for approval by the Authority

Please see the separate attachment to this report titled ‘Annex 9.7_DCRP/MP/18/01/RtA’

Appendix E – Attendance Register

Name	Company	5th September 2018	31 October 2018
David Spillett (Proposer)	Energy Networks Association	✘	✓
Mark Dunk	Energy Networks Association	✘	✘
Gregory Heavens	NGET	✓	✓
Isaac Gutierrez	Scottish Power Renewables	✓	✓
Forooz Ghassemi	NGET	✓	✘
Alan Creighton	Northern PowerGrid	✓	✘
Mark Horrocks	Mclellan and Partners Ltd	✓	✓
Steve Mould	UK Power Networks	✓	✓
Alastair Frew	Scottish Power Generation	✓	✓
Andrew Hood	Western Power Distribution	✓	✘
Muhammad Ali	TNEI Services Ltd	✓	✘