GC0076 Grid Code Limits On Rapid Voltage Changes

What stage is this document at?

01	Working Group Report
02	Industry Consultation
03	Report to the Authority

This proposal seeks to modify the Grid Code limits on rapid voltage changes triggered by planned transmission system owner and transmission system User operations

This document is open for Industry Consultation. Any interested party is able to make a response in line with the guidance set out in Section 5 of this document.

Published on: **02 April 2014**
Length of Consultation: **20 Working Days**
Responses by: **02 May 2014**

National Grid recommends:
Implementation of changes to the Connection Conditions to better facilitate applicable objectives (i) and (ii)

High Impact:
None

Medium Impact:
Transmission Licensees
Network Operators
Generators

Low Impact:
None

Contents

Any Questions?

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About this document

This Industry Consultation outlines the information required for interested parties to form an understanding of a defect within the Grid Code seeks the views of interested parties in relation to the issues raised by this document.

Parties are requested to respond by **02 May 2014** to grid.code@nationalgrid.com

Document Control

Version	Date	Author	Change Reference
0.1	08 January 2014	National Grid	Draft Industry Consultation
1.0	02 April 2014	National Grid	Final Industry Consultation
1.1	02 April 2014	National Grid	Correction to formula $\%\Delta V_{max} = 100 * \Delta V_{steadystate} / V_0$ to $\%\Delta V_{max} = 100 * \Delta V_{max} / V_0$

1 Executive Summary

1.1 The Grid Code sets out criteria relating to "Voltage Fluctuations" at a Point of Common Coupling within CC.6.1.7. This clause includes references to step changes, voltage excursions and a cross reference to Engineering Recommendation P28 for the Transmission System in Scotland.

1.2 CC.6.1.7 (a) states that voltage excursions other than steps changes may be allowed, up to a level of 3%. This requirement applies regardless of the impact of an excursion, either in duration, frequency or the repetitiveness of the occurrence.

1.3 Excursions of greater than 3% have been observed coincident with the energisation of transmission Users' transformers. These excursions, which are associated with transformer magnetisation or inrush current, are short-lived and occur infrequently. A number of developers have indicated that they have not yet found a way to meet the existing limits in future projects.

1.4 This paper recommends revisions to the voltage change criteria in the Grid Code to give due account to short lived, infrequent and non-repetitive voltage changes. This would remove the need for disproportionate additional investment in equipment and changes to connection designs whilst maintaining current standards of safety, security and quality of supply to customers.

1.5 The Grid Code requirements are specified in respect of each User connecting at a Point of Common Coupling. As several users can be connected at one site there is potential for voltage changes to become frequent or repetitive. Consequently the revisions specify that, for new connections, the user switching may be restricted at a site where this would contribute to unacceptable voltage performance in respect of changes at the site.

1.6 The issue paper GC0076 Grid Code Limits On Rapid Voltage Changes (pp11/24) was submitted to the Grid Code Review Panel on 19 May 2011. National Grid then submitted a revised proposal to the Panel on 15 January 2014. The Panel asked that the proposal should progress to Industry Consultation for a period of 20 business days subject to incorporation of final comments from Panel members.

1.7 Views are invited upon the proposals outlined in this report, which should be received by 02 May 2014. Further information on how to submit a response can be found in section 5.

2 Why Change?

Grid Code, SQSS and Engineering Recommendation Context

2.1 The voltage change criteria applicable to the National Electricity Transmission System (NETS) are set out in a number of documents.

2.2 The SQSS sets out step change limits applicable to operational switching and to secured events (ie faults) which the NETS needs to be designed and operated within. A 3% limit applies to operational switching, with 6% and 12% limits applied to secured events. The SQSS also includes a cross reference to Engineering Recommendation P28.

2.3 The SQSS definitions also state that the voltage step limits apply at the "end of the transient time phase", where the transient time phase is "typically 0 to 5 seconds after an initiating event". The transient time phase is also described as the time within which "transient decay and recovery occurs".

2.4 The Grid Code specifies criteria on "Voltage Fluctuations" to be applied "at a Point of Common Coupling with a fluctuating Load" in CC.6.1.7. These criteria apply to changes in voltage following a number of possible patterns including dips, ramps and steps. The current text is:

"CC.6.1.7 Voltage fluctuations at a **Point of Common Coupling** with a fluctuating **Load** directly connected to the **Onshore Transmission System** shall not exceed:

(a) In England and Wales, 1% of the voltage level for step changes which may occur repetitively. Any large voltage excursions other than step changes may be allowed up to a level of 3% provided that this does not constitute a risk to the **National Electricity Transmission System** or, in **NGET's** view, to the **System** of any **User**. In Scotland, the limits for voltage level step changes are as set out in **Engineering Recommendation** P28."

2.5 Note that the Voltage Fluctuation criteria within CC.6.1.7 (b) includes Flicker, but it is not considered necessary to review this as the treatment of flicker is well defined in IEC documentation and the Grid Code is consistent with this.

2.6 The Grid Code also sets out requirements on transmission users to ride through faults, including events (voltage dips) where voltage goes to zero for up to 140ms, or for longer in some circumstances.

<u>Impact of Voltage Changes</u>

2.7 Voltage changes of limited magnitude, duration and frequency affect power quality but do not have a direct impact on the safety and security of a network. Their impact can be observed on perceived levels of electric lighting for example.

2.8 Beyond a certain point, voltage changes can impact adversely on the operation of network customers' equipment (eg motors, computing equipment), including generating station auxiliaries. Some industrial processes are known to use low voltage relays to protect the equipment concerned. There is therefore a continuing need to manage voltage changes, including the impact of any limits on users creating voltage changes and the impact on users affected by voltage changes.

Impact of the Current Grid Code Criteria

2.9 CC.6.1.7 imposes an absolute ceiling of 3% on the magnitude of voltage fluctuations at a Point of Common Coupling in England and Wales. For sites in Scotland there is a cross reference to P28 for voltage steps, to which P28 imposes a limit of 3%. The requirement as currently expressed is equally applicable to events which occur frequently (eg a number of times per day) or occur once or twice a year, and events which are short lived or events which have a semi-permanent effect.

2.10 Additional equipment can be needed in order to make sure that the 3% limit can be met under all circumstances. Mitigation measures can include Point on Wave controlled switching equipment, additional switchgear and reconfiguration and/or re-design of the Transmission network up to and including the construction of additional circuits. For some design choices, in certain locations, it is not possible to stay within the 3% limit.

2.11 Where the voltage change of concern is short lived (in the case of transformer energisation this is likely to be less than 1 second), and is caused by re-energisation after maintenance, this can mean that additional equipment is needed to deal with an effect which occurs for a few seconds over the lifetime of the plant concerned. In cases where no transmission users are adversely affected, the case for such investment is weak.

3 Solution

Proposed Solution

3.1 The following proposals are based on a review of international experience, equipment specifications and academic research. The numbered references quoted in the text below within square brackets are listed in Annex 3

Definitions

3.2 EN 50160 [1] defines a supply voltage 'dip' as a sudden reduction of the supply voltage to a value between 90% and 10% of the declared voltage (ie greater than 10%), followed by a voltage recovery after a short period of time. Conventionally the duration of a voltage dip is between 10 ms and 1 minute.

3.3 The depth of a voltage dip is defined as the difference between the minimum root mean square (rms) voltage during the voltage dip and the declared voltage. Voltage changes which do not reduce the supply voltage to less than 90 % of the declared voltage are not considered to be dips.

3.4 EN 50160 defines a Rapid Voltage Change (RVC) as voltage variation less than 10%. IEC 61000-2-1 [2] states that; 'Voltage fluctuations can be described as a cyclical variation of the voltage envelope or a series of random voltage changes the magnitude of which does not normally exceed the range of operational voltage changes mentioned in IEC 38 (up to ± 10 %).'

Characterisation and Quantification of a Rapid Voltage Change

3.5 A Rapid Voltage Change is defined [3] as the change in the rms value of a voltage signal that moves from a steady state value to a maximum change and then gradually varies and settles at a new level determined by $V_{steadystate}$. It is characterised by maximum depth, ΔV_{max}, duration (T) and new steady state value (see Figure 1).

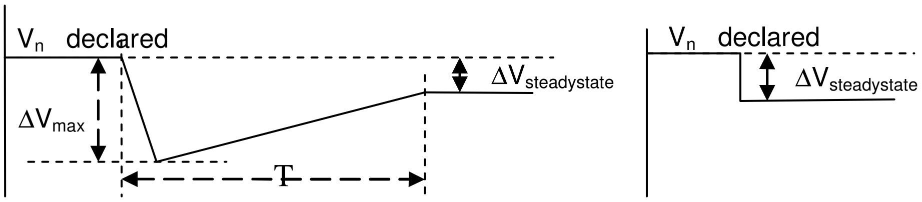

Figure 1- RVC Characterisation

3.6 In order for the event to be classified as a RVC, ΔV_{max} should be less than ±10%. Voltage changes with larger depth are generally classified as voltage dips.

3.7 References [4] and [5] have provided significant contribution in the analysis of RVCs. SINTEF and Norwegian Water Resources and Energy Directorate have published the result of their investigation in Reference [4].

3.8 Their work included a survey for visibility of light when voltage changes. Ninety six people of different age groups (students to pensioner) took part.

3.9 The results of the survey suggested:

- Even a 2% instantaneous voltage change is visible for the majority of the population (67%). For 5% instantaneous voltage change 100% of the population noticed the change in light levels;

- There was a marked difference between the light perceptions of population when RVCs caused by motor start were considered. For the maximum voltage change of 5% and time to stationary voltage of 0.5seconds, 68% of population noticed the light change; and

- Most people will notice a change in light when the rate of change of rms voltage averaged over one second is greater than 0.5% ($dV/dt \geq 0.5\%$).

3.10 We understand that these findings were used in the development of limits for RVCs in the Norwegian Grid Code which were set at ±10%. Exactly the same limits have been used in the Swedish Grid Code. It should be noted however that RVCs due to inrush current from transformers appear to be excluded from this criteria, along with faults, fault restoration and actions taken to improve quality of supply as a whole.

Review and Assessment

3.11 The main objective of this review is to ensure that proposals are developed in the full knowledge of whether the effect of Rapid Voltage Changes is an immunity and compatibility issue (which causes damage or disruption) or an issue of nuisance to customers. An extensive literature survey was carried out and a large number of references were collected to determine:

- Impact of voltage variations other than voltage dips on domestic and industrial equipment;
- Relationship between equipment immunity levels and voltage variations; and
- Human eye perception sensitivity level to less frequent voltage variations.

Immunity of Electrical Equipment

3.12 Reference [6] sets out the test procedure for equipment connected to a low voltage (up to 1kV) network, which includes domestic appliances. Class 1 products are tested on a case by case basis. Class 2 products are tested for defined voltage changes up to 70% of the nominal voltage for 25 cycles (0.5 second) and Class 3 products are tested up to 70% for 250 cycles.

3.13 Reference [7] requires that all products with currents less than 16A per phase are tested for voltage changes. For Class 1, no test is required. Class 2 the change in voltage ΔV is ±8% of V_n for equipment intended for connection to public networks or other lightly disturbed networks. For Class 3, $\Delta V = \pm 12\%$ of V_n for equipment connected to heavily disturbed networks (i.e. industrial networks). The test duration is relatively long at 5 seconds.

3.14 CIGRE working group C4.110 published their report [8] in 2010 after investigating a wide range of equipment and industrial processes. All equipment and processes examined withstood voltage changes of up to 10%. A large number of processes were examined in a separate exercise looking at Process Immunity Time (PIT) [9] and shown to withstand voltage changes of 20% for at least 3 seconds.

3.15 ERA Technology surveyed voltage dip immunity in industrial and commercial power distribution systems in 1999 [10]. The report concludes that the immunity levels of all equipment surveyed were higher than 10% voltage change. It appeared that the most sensitive equipment type was variable speed drives which could though ride through a voltage change of 100% for about 60 to 70 ms.

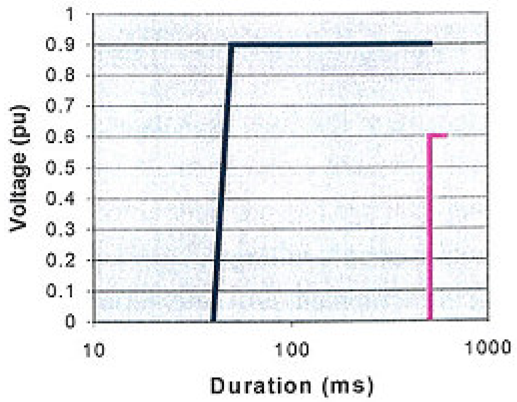

Figure 2: Sample measured maximum and minimum sensitivities of a variable speed drive

(Figure sourced from ERA Technology Ltd's "How to Improve Voltage Dip Immunity in Industrial and Commercial Power Distribution Systems" publication at www.era.co.uk)

3.16 Reference [11] shows that all commercially available variable speed drives tested did not trip for three phase voltage changes of motor start type of up to 72%.

3.17 Reference [12] studied the susceptibility of Personal Computers (PCs), high pressure sodium (HPS) lamps, fluorescent lamps and industrial ac contactors for different voltage dip depth, angle and duration. The paper illustrates a generic curve that shows that all equipment maintains correct operation for 20% voltage dip lasting for 1 second. Reference [13] examined PCs, gas discharge lamps and industrial contactors. It states that all contactors tested tolerated 70% of voltage with dip duration effect. HPS lamps were found to be most sensitive when they can tolerate no voltage (100% dip) for only 0.5 to 1 cycle but they could ride through of voltage dip of 20% (voltage of 80%). More rigid lamp standards allow 90% of the nominal voltage for continuous operation.

3.18 Electric synchronous and asynchronous motors are more tolerant to voltage changes than other equipment because of their inertia. They can ride through voltages of 70% of nominal for longer than 1 second [14].

3.19 In conclusion, no evidence was found in amongst the literature surveyed that a voltage change of 10% over a limited period affects equipment and industrial processes supplied by the public network. Thus setting a limit for RVCs is not an equipment immunity problem rather an issue of visibility and annoyance to customers.

<u>Relationship of Rapid Voltage Changes to Flicker</u>

3.20 Repetitive changes in voltage, such as those generated by arc furnaces for example, are captured by the standards relating to Flicker. The Rapid Voltage Changes described above are different in nature in that they are not repetitive and need to be treated as discrete events.

3.21 However, if a number of Rapid Voltage Changes occur in relatively quick succession, they could potentially have a similar effect on visual disturbance.

3.22 By applying the Flicker level calculation method to the Rapid Voltage Change characteristic described above it is possible to derive a limit on the number of occurrences per day which would ensure there was no impact on flicker levels. Such a limit provides assurance that visual disturbance levels would not exceed those to which network users are currently exposed.

3.23 For RVCs up to 12%, the equivalent limit is approximately 7 per day based on the 95th percentile of P_{st} and P_{lt} over one week [3]. In order to provide an additional assurance, the proposal set out in this consultation sets a maximum limit of 4 per day on the largest category of Rapid Voltage Change. This limit is based on the number of changes experienced by customers at a site, and may therefore require lower limits to be applied to connectees at sites where more than one may cause significant changes. As there are no current system operational issues with RVCs, the proposal allows for application of these lower limits to new connections only.

Relationship between EHV and LV networks during Rapid Voltage Changes

3.24 The majority of the network customers are connected to Low Voltage networks. Therefore, in developing the Rapid Voltage Change criteria to be applied to the Transmission System within the Grid Code, it is essential to consider how a rapid voltage change will propagate to the point of connection for most customers.

3.25 The relationship between voltage levels can be expressed in terms of transfer coefficients. The actual transfer coefficient at any particular point of common coupling will depend on the network topology, loads, embedded generators and transformer winding arrangements (which can have the effect of redistributing unbalanced voltage changes across the phases giving them a smaller magnitude). IEC 61000-3-7 gives guidance on the transfer coefficient which should be assumed between EHV and LV networks and advises that a coefficient of 1.0 should be applied for repetitive voltage changes.

3.26 Reference [15] explores the relationship between voltages at EHV and LV and provides evidence by analysis and measurement that a coefficient of less than 1.0 can be assumed, driven in part by the voltage dependency of electricity demand (demand reduces as voltage falls), as does Reference [8], the CIGRE Working Group C4.110 report, "Voltage dip immunity of equipment and installations"

Proposal

3.27 The total number of Rapid Voltage Changes (ΔV) from all connectees should not exceed the following limits specified in Table 1 at the point of common coupling with the stated frequency of occurrence.

Category	Maximum number of occurrences (n)	$\%\Delta V_{max}$ & $\%\Delta V_{steadystate}$
1	No Limit	$\%\Delta V_{max} \leq 1\%$ & $\%\Delta V_{steadystate} \leq 1\%$
2	For n ≤ 2 per hour & n > 4 per day	$\%\Delta V_{max} \leq 3\%$ [1] & $\%\Delta V_{steadystate} \leq 3\%$
3	Commissioning, Maintenance and Fault Restoration up to n ≤ 4 per day	$\%\Delta V_{max} \leq 12\%$ & $\%\Delta V_{steadystate} \leq 3\%$ (see Figure 2)

Table 1- Limits for Rapid Voltage Changes

Where: $\%\Delta V_{steadystate} = 100 \times \Delta V_{steadystate} / V_0$

and $\%\Delta V_{max} = 100 \times \Delta V_{max} / V_0$

3.28 For new connections, it is proposed that Bilateral Agreements may include clauses that will allow the System Operator to restrict switching activity where this will lead to operation at the site outside of the limits in Table 1.

Categories 1 and 2 Rapid Voltage Change

3.29 The proposed limits fall within the criteria currently specified within the Grid Code in magnitude.

Category 3 Rapid Voltage Change

3.30 For this category of Rapid Voltage Changes, operations are restricted to those required for commissioning, planned maintenance and fault restoration which are infrequent in nature. The cost benefit case for applying tighter limits is weak in these situations as the cost of mitigation would be spread across a limited number of short occurrences.

3.31 The proposed time dependent characteristic is shown in Figure 2.

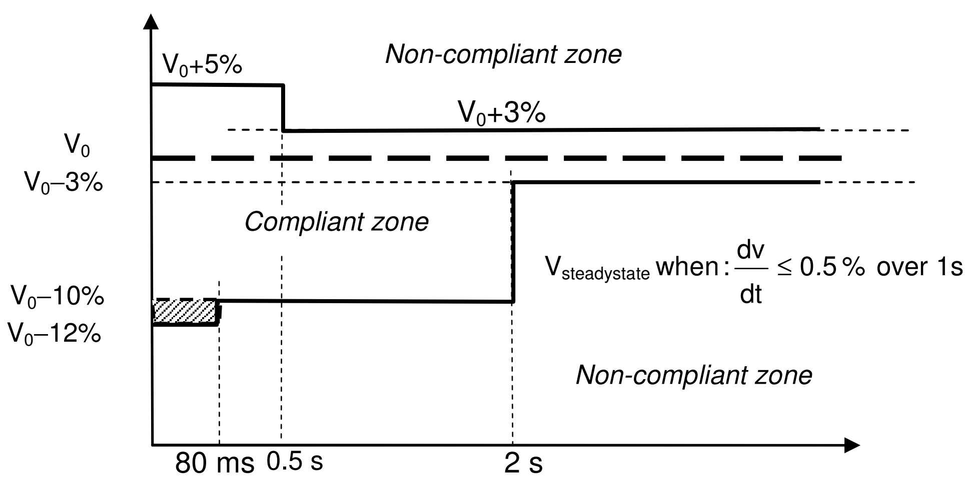

Figure 2- Limits for Category 3 Rapid Voltage Changes

3.32 Note also that:

1) V_0 is the initial steady state system voltage;

2) All voltages are the root mean squared (rms) of the voltage measured over one cycle and refreshed every half a cycle as per IEC 61000-4-30 [16];

3) A steady state voltage is said to have been reached when dv/dt ≤ 0.5%, with reference to the rms of voltage averaged over 1 second;

4) The shaded area is proposed as it is in accordance with the 12% voltage change stipulated in NETS SQSS. The duration of the maximum allowable depth (V_0 - 12%) has been specified in coordination with fast acting voltage controllers;

5) The voltage changes specified are the absolute maximum allowed, applied to phase to ground or phase to phase voltages whichever is the highest. Thus in order to determine maximum voltage changes, assessments should consider propagation of voltage changes to other voltage levels through three phase transformers with different winding arrangements.

Applicability of New Grid Code Provisions

3.33 As explained in section 2 of this document, CC.6.1.7 expresses similar criteria in different ways to be applied to networks in England and Wales and to networks in Scotland. In order to ensure Transmission Users are treated equitably it would be desirable to remove these regional differences in any new proposals.

3.34 However, there may still be a case for preserving regional differences due to the differences in network characteristics, voltage levels and the proximity of the voltage changes captured here to the majority of electricity consumers. No changes are proposed to the arrangements for offshore transmission which are site-specific reflecting the nature of current offshore network designs.

3.35 Note that the proposed solution is consistent with the NETS SQSS provisions on voltage changes treated as steps. The NETS SQSS limits apply at the "end of the transient time phase" and the transient time phase is "typically 0 to 5 seconds after an initiating event". Therefore no consequential changes to the SQSS have been identified in this consultation.

4 Impact & Assessment

Impact on the Grid Code

4.1 This proposal modifies the Connection Conditions, CC.6.1.7 paragraph (a).

Impact on National Electricity Transmission System (NETS)

4.2 The proposal will allow larger rapid voltage changes to occur up to defined limits and will lift a potential restriction on the use of transformers of a standard size.

Impact on Grid Code Users

4.3 The proposals will allow Users to use standard transformers and connection arrangements. The impact on electricity end consumers will be limited such that there will be no material change to observed power quality.

Impact on Greenhouse Gas emissions

4.4 None

Assessment against Grid Code Objectives

4.5 National Grid considers that GC0076 Grid Code Limits On Rapid Voltage Changes

4.6 would better facilitate the Grid Code objectives;

(i) to permit the development, maintenance and operation of an efficient, coordinated and economical system for the transmission of electricity

by facilitating standard connection arrangements and equipment choices

(ii) 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)

by facilitating standard connection arrangements and equipment choices

(iii) 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

by setting clear limits on the magnitude and duration of Rapid Voltage Changes

(iv) 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

by setting requirements which are consistent with international standards and practice

Impact on core industry documents

4.7 The proposed modification does not impact on any core industry documents

Impact on other industry documents

4.8 The proposed modification does not impact on any other industry documents

5 Consultation Responses

5.1 Views are invited upon the proposals outlined in this consultation, which should be received by 02 May 2014.

5.2 Your formal responses may be emailed to grid.code@nationalgrid.com.

5.3 The proposals set out in this consultation are intended to better meet the Grid Code Objectives. To achieve this, they are intended to facilitate efficient and economic connection arrangements whilst ensuring there is no impact on the safety and security of the transmission system, and no discernible impact on the visual disturbance to electricity consumers.

5.4 Responses are invited to the following questions:

(i) Do the proposed changes facilitate efficient connection arrangements for large electrical components (eg transformers)? If not, why do they fail to do so?

(ii) Do the proposed changes protect the interests of users affected by Rapid Voltage Changes? If not why do they fail to do so?

(iii) Should the proposed changes cover the whole of the onshore Transmission System, or should different criteria be applied to the networks in Scotland (P28 for example) or to different voltage levels.

(iv) Are there further technical considerations to be taken into account, for example in the relationship between voltage changes on the Transmission System and voltage changes seen at lower voltages?

(v) Is there any evidence that Users will be inappropriately adversely affected by the proposed changes? If so please provide it.

(vi) Do the criteria applicable to Voltage Changes in Category 3 strike an appropriate balance between the needs of Users causing Rapid Voltage Changes and those subject to the consequences of them?

(vii) Do you believe that GC0076 better facilitates the appropriate Grid Code objectives?

(viii) Please provide any other comments you feel are relevant to the proposed change.

5.5 If you wish to submit a confidential response please note the following:

(i) Information provided in response to this consultation will be published on National Grid's website unless the response is clearly marked "Private and Confidential", we will contact you to establish the extent of the confidentiality. A response marked "Private and Confidential" will be disclosed to the Authority in full but, unless agreed otherwise, will not be shared with the Grid Code Review Panel or the industry and may therefore not influence the debate to the same extent as a non confidential response.

(ii) Please note an automatic confidentiality disclaimer generated by your IT System will not in itself mean that your response is treated as if it had been marked "Private and Confidential".

Annex 1 - Proposed Legal Text

This section contains the proposed legal text to give effect to GC0076. The proposed new text is in red and is based on Issue 5 Revision 6 – 13 December 2013.

Connection Code

"CC.6.1.7 Voltage ~~fluctuations~~ changes at a **Point of Common Coupling** ~~with a fluctuating **Load** directly connected to~~ on the **Onshore Transmission System** shall not exceed:

(a) ~~In England and Wales, 1% of the voltage level for step changes which may occur repetitively. Any large voltage excursions other than step changes may be allowed up to a level of 3% provided that this does not constitute a risk to the **National Electricity Transmission System** or, in **NGET's** view, to the **System** of any **User**. In Scotland, the limits for voltage level step changes are as set out in **Engineering Recommendation** P28~~. The limits specified in Table CC.6.1.7 with the stated frequency of occurrence, where:

(i) $\%\Delta V_{steadystate} = 100 \times \frac{\Delta V_{steadystate}}{V_0}$

and

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

(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;

(iv) All voltages are the rms of the voltage measured over one cycle refreshed every half a cycle as per IEC 61000-4-30;

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

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

(vii) Voltage changes in category 3 only occur in circumstances notified to **NGET** 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**.

For connections with a **Completion Date** after 1st September 2014, **Bilateral Agreements** may include provision for **NGET** to reasonably limit the number of voltage changes in category 2 or 3 to a lower level than specified in Table CC.6.1.7 to ensure that the total number of 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 (n)	$\%\Delta V_{max}$ & $\%\Delta V_{steadystate}$
1	No Limit	$\%\Delta V_{max} \leq 1\%$ & $\%\Delta V_{steadystate} \leq 1\%$
2	For $n \leq 2$ per hour & $n > 4$ per day	$\%\Delta V_{max} \leq 3\%$ & $\%\Delta V_{steadystate} \leq 3\%$
3	Commissioning, Maintenance and Fault Restoration up to $n \leq 4$ per day	$\%\Delta V_{max} \leq 12\%$ & $\%\Delta V_{steadystate} \leq 3\%$ (see Figure CC6.1.7)

Table CC.6.1.7 - Limits for Rapid Voltage Changes

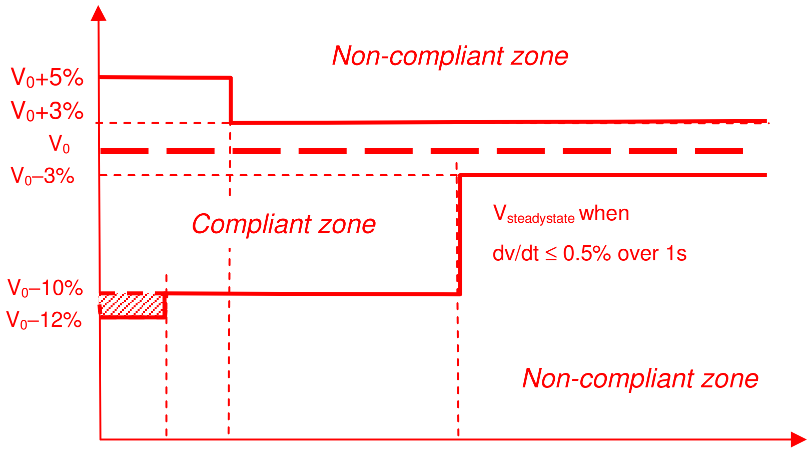

Figure CC6.1.7- Limits for Category 3 Rapid Voltage Changes

Annex 2 - References

List of literature surveyed in the development of this proposal:

[1] BS EN 60160:2000, Voltage characteristics of electricity supplied by public distribution systems.

[2] IEC 61000-2-1:1990, Guide to Electromagnetic environment for low-frequency conducted disturbances and signalling in public power supply systems.

[3] IEC 61000-3-7:2008, Electromagnetic compatibility (EMC) — Part 3-7: Limits — Assessment of emission limits for the connection of fluctuating installations to MV, HV and EHV power systems.

[4] Brekke K, etal, Rapid voltage changes - definition and minimum requirements, CIRED 20th International Conference on Electricity Distribution Prague, 8-11 June 2009, Paper 0789.

[5] Halpin M, etal, Suggestions for overall EMC co-ordination with regard to rapid voltage changes, CIRED 20th International Conference on Electricity Distribution Prague, 8-11 June 2009, Paper 0758.

[6] IEC 61000-4-11:2004, Electromagnetic compatibility (EMC) —Part 4-11: Testing and measurement techniques — voltage dips, short interruptions and voltage variations immunity tests.

[7] BS EN 61000-4-14:1999+A2:2009, Electromagnetic compatibility (EMC) — Part 4-14: Testing and measurement techniques — Voltage fluctuation immunity test for equipment with input current not exceeding 16 A per phase.

[8] CIGRE Working Group C4.110 report, Voltage dip immunity of equipment and installations, April 2010.

[9] Van Reusel K, etal, "Process Immunity Time" assessment of its practicality in industry, 14th International conference on harmonics and quality of power, 2010.

[10] Greig E, ERA Technology, Report 99-0632R, How to improve voltage dip immunity in industrial and commercial power distribution systems, 1999.

[11] Djokic S Z, etal, Sensitivity of AC Adjustable Speed Drives to Voltage Sags and Short Interruptions, IEEE Transactions on Power Delivery, Vol. 20, No. 1, January 2005, pp 494-505.

[12] Shareef H, etal, Voltage sags and equipment sensitivity: A practical investigation.

[13] Pohjanheimo P, etal, Equipment sensitivity to voltage sags – test results for contactors, PCs and gas discharge lamps, 10th International conference on harmonics and quality of power, 2002, pp 559-564.

[14] Mahmoud A, etal, voltage sag effects on the process continuity of a refinery with induction motors loads, On line journal on power and energy engineering, Vol (1), No. (1), pp 11-16.

[15] Bollen M, On voltage dip propagation, IEEE Power Engineering Society Summer Meeting, 2001.

[16] BS EN 61000-3-3:2008, Electromagnetic compatibility (EMC) – Part 3-3: 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.

[17] BS EN 61000-4-30:2003, Electromagnetic compatibility (EMC) — Part 4-30: Testing and measurement techniques — Power quality measurement methods.
[18] Deswal S S, etal, Enhance Ride-Through Capability of Adjustable Speed Drives by Maintaining DC-Link voltage, International Journal of Computer and Electrical Engineering, Vol. 1, No. 2, June 2009, pp 1793-8163
[19] Manana M, etal, The role of the dc-bus in voltage sags experienced by three-phase adjustable-speed drives, International Conference on Renewable Energies and Power Quality (ICREPQ'10), Granada (Spain), 23rd to 25th March, 2010
[20] Union of Electricity Industry (Euroelectric), Application guide to the European Standard EN 50160 on "voltage characteristics of electricity supplied by public distribution systems" Electricity Product Characteristics and Electromagnetic Compatibility, July 1995, Ref : 23002Ren9530.
[21] Das J C, Effects of Momentary Voltage Dips on the Operation of Induction and Synchronous Motors, IEEE Transactions on Industry Applications, Vol. 26, No. 4, July/August 1990, pp 711-718.
[22] Ferry A, etal, The Impact of Synchronous Distributed Generation on Voltage Dip and Overcurrent Protection Coordination, International Conference on Future Power Systems, 2005.
[23] McGranaghan M F, etal, Voltage Sags in Industrial Systems, IEEE Transactions on Industry Applications, Vol. 29, No. 2, March/April 1993, pp 391-403
[24] Van Coller J, etal, The Effect of a Synchronous Condenser on the Voltage Dip Environment - As Expressed in terms of the Eskom ABCD Dip Chart, IEEE 4th AFRICON, 1996.
[25] Bollen M, Voltage Recovery After Unbalanced and Balanced Voltage Dips in Three-Phase Systems, IEEE Transactions on Power Delivery, Vol. 18, No. 4, October 2003, pp 1376-1381.
[26] Bollen M, etal, Effect of Induction Motors and Other Loads on Voltage Dips: Theory and Measurements, IEEE Conference, Bologna PowerTech, June 23-26, 2003.
[27] Stephens M, etal, Evaluating Voltage Dip Immunity of Industrial Equipment, CIRED 18th International Conference on Electricity Distribution, Turin, 6-9 June 2005.
[28] Bollen M, etal, Quantifying voltage variations on a time scale between 3 seconds and 10 minutes CIRED 18th International Conference on Electricity Distribution Turin, 6-9 June 2005.
[29] Brekke K, The Regulatory View on Voltage Dip Immunity, CIRED Prague, 8-11 June 2009.
[30] Neumann R, Voltage dip immunity classes and applications, Prague. 8-11 June 2009.
[31] Vittal K, Impact of Wind Turbine Control Strategies on Voltage Performance, IEEE PES General Meeting Calgary, Alberta, Canada July 2009, pp 1-7.
[32] Bollen M, etal, Voltage dip immunity of equipment in installations - main contributions and conclusions, CIRED 20th International Conference on Electricity Distribution Prague, 8-11 June 2009, Paper 0149, CIGRE/ CIRED/ UIE Joint Working Group C4.110,

[33] Gómez-Lázaro E, etal, Characterization and Visualization of Voltage Dips in Wind Power Installations, IEEE Transactions on Power Delivery, Vol. 24, No. 4, October 2009 pp 2071-2078
[34] Bok J, etal, Personal Computers Immunity to Short Voltage Dips and Interruptions, 13th International Conference on Harmonics and Quality of Power, 2008. ICHQP 2008.
[35] Bollen M, etal, Voltage Dip Immunity of Equipment in Installations – Status, ICHQP 2008, CIGRE/CIRED/UIE JWG C4.110.
[36] Bollen M, etal, A Framework for Regulation of RMS Voltage and Short-Duration Under and Overvoltages, IEEE Transactions on Power Delivery, Vol. 23, No. 4, October 2008 pp 2105-2012
[37] Abderrazzaq M, Assessment of voltage dip staging for low voltage systems, Proceedings of the 41st UPEC '06, 2006.
[38] Sakis Meliopoulos A, etal, Voltage Stability and Voltage Recovery: Effects of Electric Load Dynamics, IEEE International Symposium on Circuits and Systems, 2006. ISCAS 2006. Proceedings. 2006.
[39] Bollen M, etal, Voltage dip immunity aspects of power-electronics equipment– Recommendations from CIGRE/CIRED/UIE JWG C4.110, 14th International Power Electronics and Motion Control Conference, EPE-PEMC 2010.
[40] Halpin M, Voltage Fluctuations and Lamp Flicker in Power Systems, 2006 by Taylor & Francis Group, LLC.
[41] Ebner A, Reduction of voltage stress and inrush current of power transformers using controlled switching, CIR E D, 20th International Conference on Electricity Distribution Prague, 8-11 June 2009, Paper 0194.
[42] Mrs. Fay Geitona, Comments to the ERGEG Consultation Paper ”Towards Voltage Quality Regulation In Europe, CEER, E06-EQS-09-03 DM-74125-v1 Oslo, 21th February 2007.
[43] E.ON Hungária Zrt., Voltage Quality Regulation in Europe Opinion on ERGEG Public Consultation, Document Ref.: E06-EQS-09-03, February 2007.
[44] Energy Network Association (ENA), distributed generation connection guide (G59/2), Version 3.1, April 2011.
[45] Cheng-Ting Hsu, Under-voltage relay settings for the tie-lines tripping in an upgrading cogeneration plant, 0-7803-8560-8/04, 2004, IEEE.
[46] Andersson T, Test and evaluation of voltage dip immunity, STRI, Project No 3261, November 2002.
[47] Bollen M, etal, Voltage Dip Immunity of Equipment and Installations – Status and Need for Further Work, CIGRE/CIRED/UIE Working Group C4.110 and UIE Working Group 2, International Conference on Electricity Distribution, 2010 China.
[48] Bollen M, etal, Impact of Static Load on Voltage Stability of an Unbalanced Distribution System, 2010 IEEE International Conference on Power and Energy (PECon2010), Nov 29 - Dec 1, 2010, Kuala Lumpur, Malaysia.
[49] Bhattacharyya S, etal, Assessment of the Impacts of Voltage Dips for a MV Customer, 14th International Conference on Harmonics and Quality of Power (ICHQP), 2010.
[50] OLGUIN G, Voltage Dip (Sag) Estimation in Power Systems based on Stochastic Assessment and Optimal Monitoring PhD thesis, Chalmers University of Technology, Göteborg, Sweden 2005.

[51] Rendroyoko I, etal, Load Influence on Voltage Dip Characteristics, Department of Electrical & Computer Science, Monash University, PO Box 35, Clayton, Victoria 3800.