Grid Code Review Panel
Voltage Unbalance

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Summary

This proposal is submitted to revise the existing Grid Code criteria applied to Voltage Unbalance within CC.6.1.5 (b).

The Grid Code sets limits for phase unbalance on the transmission networks of 2% in Scotland and 1% in England and Wales. In England and Wales, a 2% limit can be applied for periods of "short duration" under Planned Outage conditions. The 1% limit in England and Wales looks conspicuously different to the limit in Scotland and the 2% limit in Engineering Recommendation P29 and EN50160.

The phase unbalance limits lead to a requirement to:

- Build new substations;
- Add transpositions;
- Install phase-balancers;
- Limit flows; and
- Install inter-trips.

Unnecessarily restrictive limits therefore trigger additional investment costs and operational constraints. Generator connections and traction connections are impacted.

However, if the limits are set too high on the transmission networks, this can lead to restrictions on the distribution networks. In the extreme, User equipment (both transmission and distribution) could be adversely affected.

It is proposed that a uniform approach based on recommendations by international standards and publications is adopted across the electricity network in Scotland and England and Wales to set the limit at EHV level to 1.5% and lower voltages to 2%. EHV is defined as voltages above 150kV. Changes in the Grid Code text for CC 6.1.5 (b) and CC 6.1.6 covering the voltage unbalance limit are proposed.

Transfer coefficients from EHV to 132kV, obtained from network simulations, were used to apportion the compatibility limit of 2% at 132kV between the voltage unbalance transferred from the EHV network and contribution from DNO networks. This is in line with the recommendations from relevant IEC and CIGRE Working Group.

A technical report has been prepared to present the basis for this proposal and outline its implications. The report is an integral part of this proposal.

Users Impacted

High

Non-Embedded Customers, Distribution Network Licensees

Medium

Generators

[1] The Code Administrator will provide the paper reference following submission to National Grid.

Low

None Identified

Description & Background

Grid Code CC.6.1.5 (b) [1] sets the limit for voltage unbalance at any point in the transmission network.

CC.6.1.5

…

(b) Phase Unbalance

Under Planned Outage conditions, the maximum Phase (Voltage) Unbalance on the National Electricity Transmission System should remain, in England and Wales, below 1%, and in Scotland, below 2%, unless abnormal conditions prevail and Offshore (or in the case of OTSDUW, OTSDUW Plant and Apparatus) will be defined in relevant Bilateral Agreements.

CC.6.1.6 *In England and Wales, under the Planned Outage conditions stated in CC.6.1.5 (b) infrequent short duration peaks with a maximum value of 2% are permitted for Phase (Voltage) Unbalance, subject to the prior agreement of NGET under the Bilateral Agreement and in relation to OTSDUW, the Construction Agreement. NGET will only agree following a specific assessment of the impact of these levels on Transmission Apparatus and other Users Apparatus with which it is satisfied.*

Grid Code CC.6.1.5 (b) states that the maximum voltage unbalance on the National Electricity Transmission System must be below 1% in England and Wales and 2% in Scotland. Connection Condition CC.6.1.6 allows maximum of 2% voltage unbalance in the Transmission network for short duration provided prior agreement from NGET is sought.

The Grid Code limit of 1% in England and Wales also applies to 132kV busbars as they are part of the Transmission System and hence NGET is obliged to comply with the limit at this voltage level. On the other hand, Distribution Code DPC4.2.3.2 [2] sets the rule in distribution networks to comply with Engineering Recommendation (ER) P29 [3].

ENA ER P29 sets the limit of 2% for voltages of 132kV and below and allows up to 1.33% to be allocated to one customer, e.g. traction. Distribution Network Owners (DNO) also use BS EN 50160 [4] as a guide for compliance. This standard allows 2% voltage unbalance for voltages of 150kV and below and in exceptional cases, e.g. radial networks with single phase loads, up to 3% is allowed.

As shown above the limits for 132kV busbars seems to be different in the Grid Code and Distribution Code.

This proposal's objective is to implement a uniform approach and rationale for all voltage levels based on recommendations by international standards, industry practices and technical publications.

Unbalance in the power system has the following impacts:

i) Increase in losses through extra loss in negative phase sequence (nps) and zero phase sequence (zps) networks, which otherwise in a balance system do not exist.

ii) Negative phase sequence current in rotating equipment produces excessive heat in the rotor which may lead to equipment failure. It also increases stator losses.

iii) Negative phase sequence current creates pulsating torque in rotating equipment and thus leads loss of life and possible premature breakdown.

Voltage unbalance in percentage is measured by the ratio of the root mean square (rms) of the nps voltage to the rms of the positive phase sequence (pps) voltage multiplied by 100 [1, 2, 3, 4, 5]. This is known as Unbalance Factor (UBF).

Setting the limit low has cost implications and a balance between the immunity of equipment and

mitigation in the supply system has to be made. Below are some practical examples:

i) Assuming all other design criteria are the same, a low UBF limit may affect the connection of a new generator to the grid, e.g.

- A double turn-in may be adopted because of high UBF.
- A double turn-in is approximately 35% more expensive than a double Tee.
- A single turn-in is 25% less expensive than a double Tee connection and it is favoured if UBF is within the Grid Code limit.

ii) In parts of the network, power flow in transmission circuits are increasing to their limits, East Anglia and South Wales corridors are good examples. The UBF may approach the existing Grid Code limit of 1% even for intact conditions.

iii) High unbalance due to high power flow may impose inter-trip schemes on power stations that add to complexity of operation and affect security of supply. Inter-trip schemes have been imposed on a number of projects around Bramford.

iv) If all projects contemplated to connect around Pembroke substation are realised then unbalance around Walham, Rassau and Cilfynydd will exceed the limit.

v) A number of traction schemes have or will have limits on their demand directly because of the unbalance limit.

It is therefore prudent to review the limit in the Grid Code to allow a limit that is more in line with international standards recommendations and worldwide practices as well as considering its practicality and cost implications.

In developing this proposal for voltage unbalance, the following can be noted [6, 7]:

1) Ultimately, the customer ends up paying for the utility related costs required to reduce voltage unbalance, and the manufacturing related costs required to expand an unbalanced equipment voltage operating range.

2) Utilities' incremental improvement costs are maximum as the voltage unbalance approaches zero and decline as the unbalance is permitted to increase.

3) Manufacturers' incremental motor related costs are lowest at zero voltage unbalance and increase rapidly as the unbalance increases.

Proposed Solution

An extensive search of archive material including Technical Specifications and Technical Notes did not reveal any proposal, justification, recommendation or study as to why the limit set in the GB Grid Code is 1% in England and Wales and 2% in Scotland.

In June 1975, the Electricity Council published ER P16 entitled; EHV or HV Supplies to Induction Furnaces to outline the limits for connecting arc furnaces to the EHV and HV system. It recommended that 1% unbalance is allowed for each connection at the planning stage for voltages of 33 kV and above. This implied that the overall limit may have been allowed to be higher [8]. Clause 4.2 in [8] entitled Voltage Unbalance (single outage condition) states that 1% at 33kV and above or 1.3% below 33kV should be allowed assuming "an initially symmetrical system at this point and based on supply system single outage conditions and winter minimum generation" and "based on the consumer's worst sustained negative phase sequence component of current". The statement implies that the asymmetry introduced by the unbalance in the supply system is not accounted for within the above 1% limit.

Network companies in Scotland have been considering a compatibility level of 2% for UBF in accordance with the Grid Code and this has not led to any published technical and design issues.

Table 2 illustrates the limit for unbalance factor in different countries.

Country	UBF (%)	Comments
Scotland	2	[1], GB Grid Code.
Germany	2	[9], At transmission and distribution levels.
Australia	2	[10], At transmission and distribution levels, for short duration 3%.
France	2	[11], RTE. At transmission level.
South Africa	2	[12], For HV, MV and LV. EHV is not mentioned. Increase to 3% is being considered
Hydro Quebec	1	[13], In transmission level, based on 2 hour average (1.5% for HV and 2% for MV and LV all based on 2 hour average).
New Zealand	1	[14], Electricity Governance Rules 2003, Part C Common Quality.
Brazil	2	[15], at all voltage levels

Table 9- Limits for UBF in other Countries

The proposal to review the GB Grid Code limit for unbalance is based on the following:

i) The proposal does not intend to change the compatibility limit above the immunity level of equipment. The immunity level for all equipment is considered to be above 2%.

ii) The compatibility level for DNOs for voltages at 132kV and below is 2%. It is not intended to propose changes to this.

iii) Extensive GB system studie revealed that the transfer coefficients from EHV (400kV and 275kV) to 132kV, 33kV and 11kV are below 0.9, 0.8 and 0.6 respectively based on 99-percentiles of sites, as shown in Table 1.

iv) The above implies that any unbalance whose source is at EHV level will be transferred through the above coefficients to the lower voltages.

v) IEC 61000-3-13 recommends that an equitable share of emission between unbalanced installations and various systems inherent sources of unbalance present within the system, e.g. untransposed lines, present in the system are allowed.

vi) This provides provision for the equal contribution to the total compatibility limit of 2% from sources in the lower voltages (DNO) and in the transmission network.

	From EHV to HV	From EHV to MV33	From EHV to MV11	From HV to MV33	From HV to MV11	From MV33 to MV11
Study	0.86	0.76	0.59	1.00	0.77	0.95
Rounded	0.9	0.8	0.6	1.0	0.8	1.0

Table 1- Transfer Coefficients Based on 99% of Cases

It is proposed that the compatibility limit in Grid Code CC.6.1.5 is changed from 1% to 1.5% for 400kV and 275kV and 2% for 132kV.

The proposed limit of 2% for 132kV is in line with the present limit used by DNOs in accordance with P29 and EN 50160, which allows 2% for voltages up to 150kV.

The compatibility level of 1.5% for 400kV and 275kV is based on the recommendation in IEC 61000-3-13 that allowance to be made for inherent network unbalance created by un-transposed lines.

If 2% is considered to be the aggregated emission limit at 132kV and 1.5% to be the compatibility

level at 400/275kV then the available headroom for emissions from unbalance sources at 132kV and DNOs is 1.08%, just more than 50% of the limit.

The rationale for considering 1.5% for nps limit is illustrated by (1). If an equitable share of the compatibility level of 2% is assumed at 132kV for sources at EHV levels and imposed from lower voltages as well as 132kV itself, then the allowance for the EHV can be calculated as shown below:

$$\text{Limit for UBF\%} = \frac{\sqrt[1.4]{2^{1.4} - 1^{1.4}}}{0.9} = 1.58\% \qquad (1)$$

Where 1.4 is the exponent for aggregation of nps voltages from different sources recommended by [5], 2% is the compatibility level at 132kV, 1% is the 50% of the compatibility level allowed for the contribution from 132kV and lower voltages and 0.9 is the transfer coefficient from EHV to 132kV as given in Table 1. The compatibility level allowed for UBF at EHV network given by (1) is rounded down to 1.5%. The allowed contribution from 132kV and lower voltages is thus given by (2).

$$\text{Contribution from unbalance sources in DNO} = \sqrt[1.4]{2^{1.4} - (0.9 \times 1.5)^{1.4}} = 1.08\% \qquad (2)$$

For the lower voltages more headroom is available for sources in the MV and LV as the transfer gains for unbalance from EHV network to MV and LV are lower.

Therefore, it is recommended that the text of the Grid Code Connection Condition CC.6.1.5 (b) and CC.6.1.6 are changed to that given below. When marked as (No change) it means that no change to the existing text in the Grid Code is proposed. Conversely, the text in red highlight the proposed new insertions and changes.

Voltage Waveform Quality

CC.6.1.5 All Plant and Apparatus connected to the National Electricity Transmission System, and that part of the National Electricity Transmission System at each Connection Site or, in the case of OTSDUW Plant and Apparatus, at each Interface Point, should be capable of withstanding the following distortions of the voltage waveform in respect of harmonic content and phase unbalance: **(No change)**

(a) Harmonic requirement **(No change)**

(b) Phase Unbalance

Under Planned Outage conditions, the weekly 95 percentile of Phase (Voltage) Unbalance, calculated in accordance with IEC 61000-4-30 and IEC 61000-3-13, on the National Electricity Transmission System for voltages above 150kV should remain, in England and Wales and Scotland, below 1.5%, and for voltages of 150kV and below, below 2%, unless abnormal conditions prevail and Offshore (or in the case of OTSDUW, OTSDUW Plant and Apparatus) will be defined in relevant Bilateral Agreements.

The Phase Unbalance is calculated from the ratio of root mean square (rms) of negative phase sequence voltage to rms of positive phase sequence voltage, based on the 10-minute average, in accordance with IEC 61000-4-30.

CC.6.1.6 In England and Wales and Scotland under the Planned Outage conditions stated in CC.6.1.5 (b) infrequent short duration peaks with a maximum value of 2% are permitted for Phase (Voltage) Unbalance for voltages above 150kV, subject to the prior agreement of NGET under the Bilateral Agreement and in relation to OTSDUW, the Construction Agreement. NGET will only agree following a specific assessment of the impact of these levels on Transmission Apparatus and other Users Apparatus with which it is satisfied.

It is noted that the proposed change results in a reduction from 2% to 1.5% in Scotland. In order to follow the recommendations in [5] and other publications for the need for coordination between limits in EHV networks and lower voltage networks it is prudent that the GB Grid Code voltage

unbalance limit for EHV network in Scotland is reduced.

Assessment against Grid Code Objectives

Will the proposed changes to the Grid Code better facilitate any of the Grid Code Objectives:

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

The proposal will improve design efficiency and cost effectiveness by eliminating imposition of un-necessary cost on network owners, operators, generators and other Users in mitigating voltage unbalance or limiting power flows in the transmission network.

(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);

(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; and

(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.

Impact & Assessment

Impact on the National Electricity Transmission System (NETS)

None as power quality will be maintained to current national and international standards and practices.

Impact on Greenhouse Gas Emissions

None.

Impact on core industry documents

None.

Impact on other industry documents

None.

Supporting Documentation

Have you attached any supporting documentation [**YES**]

If Yes, please provide the title of the attachment:

Review of Voltage Unbalance Limit in The GB Grid Code CC.6.1.5 (b)

Report references and glossary.

Recommendation

The Grid Code Review Panel is invited to:

Approve this issue for progression to an industry workgroup

Document Guidance

This proforma is used to raise an issue at the Grid Code Review Panel, as well as providing an initial assessment. An issue can be anything that a party would like to raise and does not have to result in a modification to the Grid Code or creation of a Working Group.

Guidance has been provided in square brackets within the document but please contact National Grid, The Code Administrator, with any questions or queries about the proforma at grid.code@nationalgrid.com .

References

[1] The Grid Code, Issue 5, Revision 7, 31st March 2014.

[2] The Distribution Code and the Guide to the Distribution Code of Licensed Distribution Network Operators of Great Britain, Issue 21, January 2014.

[3] ENA Engineering Recommendation P29, Planning Limits for Voltage Unbalance in the United Kingdom, 1990.

[4] BS EN 50160, Voltage characteristics of electricity supplied by public distribution systems.

[5] IEC/TR 61000-3-13: Electromagnetic compatibility (EMC): Limits - Assessment of emission limits for the connection of unbalanced installations to MV, HV and EHV power systems.

[6] ANSI C84.1-1995, Electric Power Systems and Equipment—Voltage Ratings (60 Hertz).

[7] A von Jouanne, B Banerjee, “Assessment of Voltage Unbalance”, IEEE Trans. PWRD, Vol. 16, No. 4, Oct. 2001.

[8] E.H.V or H.V. Supplies to Induction Furnaces, ER P16, The Electricity Council, Chief Engineers’ Conference, System Design & Development Committee, June 1975, Classification ‘C’.

[9] 50 Hertz Transmission GmbH, Netzanschluss Und Netzzugangsregeln, Technisch-organisatorische Mindestanforderungen, Mai 2008.

[10] Customer Guide to Electricity Supply, Energy Supply Association of Australia Limited, March 2002 (reprinted November 2004).

[11] Conditions Générales du Contrat d’Accès au RPT pour les Consommateurs, Documentation Technique de Référence Chapitre 8 – Trames types, Article 8.11 – Trame type du Contrat d’Accès au Réseau Public de Transport pour les Clients Consommateurs Conditions Générales, Version 1.1 (Turpe 4) applicable à compter du 8 août 2014.

[12] NRS 048-2:2003, Second edition, ELECTRICITY SUPPLY — QUALITY OF SUPPLY, Part 2: Voltage characteristics, compatibility levels, limits and assessment methods.

[13] TransEnergie, Characteristics and target values of the voltage supplied by Hydro-Québec transmission system Études de réseau et Critères de Performance Direction Planification et Développement des Actifs TransÉnergie, Translated July 5, 2001, Original in French dated June 15, 1999.

[14] New Zealand Electricity Engineers’ Association in conjunction with University of Canterbury and the EPE Centre (Revision 3.8), “Power Quality (PQ) Guidelines”, 2013.

[15] Joint Working Group Cigré C4.07/Cired (formerly Cigré WG 36.07), POWER QUALITY INDICES AND OBJECTIVES, Final WG Report, January 2004, Rev. March 2004.