nationalgrid

Stage 02: Industry Consultation

Grid Code

GC0088 - **Voltage Unbalance**

What stage is this document at?

01	Workgroup Report
02	Industry Consultation
03	Report to the Authority

This proposal seeks to homogenise the Grid Code limits on Voltage Unbalance within GB which will entail some relaxation of the limits in England & Wales to more closely align with international standards. This will help to avoid triggering unwarranted network investment.

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: **30 July 2015**
Length of Consultation: **25 Working Days**
Responses by: **3 September 2015**

National Grid recommends:
Implementation of changes to the Connection Conditions CC.6.1.5 (b) and CC.6.1.6 to allow more cost effective connections to the transmission network.

High Impact:
None

Medium Impact:
Transmission licensees
Network operators
Generators
Rail network operators

Low Impact:
None

Contents

About this document

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

Parties are requested to respond by **3 September 2015** to grid.code@nationalgrid.com.

Document Control

Version	Date	Author	Change Reference
0.1	24 June 2015	National Grid	Draft Industry Consultation for GCRP
1.0	30 July 2015	National Grid	Final Industry Consultation

Any Questions?

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Proposer:

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1 Executive Summary

1.1 This proposal is submitted to revise the existing Grid Code criteria applied to Voltage Unbalance at a Point of Common Coupling within CC.6.1.5 (b).

1.2 At present, and according to Grid Code CC.6.1.5 (b), the voltage unbalance limit for all voltage levels in Scotland is 2% whereas in England and Wales this limit is 1% for EHV systems or where equipment is owned by National Grid and 2% for equipment owned by the Distribution Network Operators and connected at 132kV or less.

1.3 Voltage Unbalance on transmission and distribution systems can lead to damage to or reduced life of rotating plant while managing and reducing the levels of unbalance requires network investment. Any limits should consider the overall cost to system users and consumers, and should be set to minimise this cost. The current Grid Code limits, particularly in England and Wales, are set at a lower level than in generally accepted international practice and are triggering addition network investments.

1.4 NGET has undertaken analysis of the impacts of modifying the Grid Code limits, considering the effects on all parties. As a result of this NGET proposed that a uniform approach, based on international standards and publications, is adopted across the electricity network in Scotland, England and Wales to:

- **set a single limit at EHV level (above 150kV) of 1.5% and**
- **set a single limit at lower voltages of 2%.**

1.5 In NGET's view, based on its analysis, this proposal will significantly reduce transmission network investment requirements in England and Wales without causing additional investment in Scotland and without adversely impacting users, including rotating plant and distribution networks.

1.6 Following discussion at the GCRP in November 2014 a workshop was held in February 2015 to consider whether a working group was necessary to develop these proposals further or if they could go straight to industry consultation. The workshop was generally supportive of the principles of the proposal and supported progressing with a consultation, but in some areas, such as the limits to be applied in Scotland, there was not a consensus on the specifics of the proposal. Section 4 of this document describes the workshop discussions and areas where differing options were considered. Section 6 requests general comments on the proposal and support for this, and includes questions around the areas lacking consensus.

1.7 Changes in the legal text of the Grid Code for CC.6.1.5 (b) and CC.6.1.6 covering the voltage unbalance limit are proposed in Annex 1.

1.8 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 and can be found on our website at the link below. Please click on the link entitled "Voltage Unbalance Report".

http://www2.nationalgrid.com/UK/Industry-information/Electricity-codes/Grid-code/Modifications/GC0088/

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2 Why Change?

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

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

2.3 Furthermore, the Grid Code limit of 1% in England and Wales also applies to a number of 132kV busbars owned by NGET. As they are part of the electricity transmission system NGET is obliged to comply with the limit at this voltage level.

2.4 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].

2.5 ENA ER P29 sets the limit of 2% for voltages 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.

2.6 As shown above, the limits for 132kV busbars are different in the Grid Code and Distribution Code, i.e. the Grid Operator is obliged to comply with 1% phase unbalance limit whereas the Distribution Network Owner is required to comply with 2% limit.

2.7 This proposal objective is to propose a uniform approach and rational for all voltage levels based on recommendations by international standards, industry practices and technical publications.

2.8 Unbalance in power system have the following impacts and therefore should be limited to or below the immunity level of equipment.

i) Increase in losses through extra loss in negative phase sequence (nps) and zero phase sequence (zps) networks, which otherwise in a balanced 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 to loss of life and possible premature breakdown.

2.9 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).

2.10 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 high UBF limit may affect 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%.

iii) High unbalance due to high power flow may require inter-trip schemes on power stations that add to the complexity of operation and affect security of supply. Inter-trip schemes have been installed 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 may be required to reconsider their demand requirement if possible.

2.11 It is therefore prudent to review the limit in the GB 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.

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

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

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

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

2.13 When these costs, excluding motor related energy costs, are combined, curves can be developed as shown in Fig 1, that indicate the annual incremental cost to the customer for various percent voltage unbalance limits. The optimal range of voltage unbalance occurs when the cost to the customer is minimized, which is implied in ANSI C84.1 [6] to be at approximately 3% as shown in Fig 1. Therefore, the cost of mitigation by utilities to reduce the voltage nps levels in the network should be weighed against the susceptibility level considered in design of equipment. This approach has led to a universally accepted maximum level of 2% for nps voltages in the supply system, although in particular networks such as those with long single phase feeders up to 3% is allowed [4, 5]. The limit is generally set lower than the cost minimum value to ensure there is a margin between system limits and plant immunity levels. According to [6] the cost of designing the network for lower nps levels at distribution voltages would be higher than the cost of improving the tolerance level of equipment.

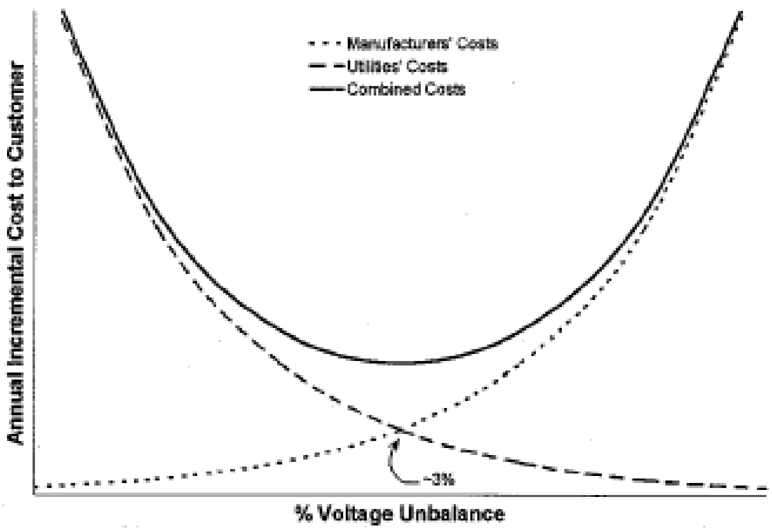

Fig 1- Annual Incremental Cost to the Customer for Various Percent Voltage Unbalance Limits

2.14 NPS levels are currently increasing on the transmission system with NGET estimating that investment in excess of £100m will be required over the next 5-10 years to meet current Grid Code requirements. Conversely, the cost to generators of increasing the limit to 1.5% in England and Wales is expected to be very low as generators are designed to withstand higher levels and, in practice, levels close to limits are experienced for limited durations. Consequently, raising the limits in

England and Wales as proposed will result in a significant overall benefit to consumers.

2.15 At any point in the network voltage unbalance arises due to one or more of three reasons:

i) Unbalanced load currents in the three phase network (unbalanced load or poor apportioning of single-phase loads or single phase traction).

ii) Unbalanced systems impedances (e.g. transmission lines not transposed in upstream network).

iii) Transfer of background nps voltage from one node to another or from one voltage level to another.

2.16 Fault conditions such as blown fuses or faulty circuit breakers leading to open circuit in one or two phases, or short circuit unbalanced faults, are the other causes of unbalance in power systems. The former are known as series faults and latter shunt faults. As such, these are categorised as faults and therefore not related to the normal system operation and should be detected and cleared in a specified time by protection devices. Hence, these are not the subject of this proposal which deals with unbalance in the normal network condition.

2.17 Due to the geometry and the phase conductor positioning of overhead transmission lines the electrical parameters are different for different phases unless transpositions are used. Even with perfect transposition unequal loading can create unbalanced voltages. One cause of unbalance, particularly in residential areas, is the uneven distribution of loads across the phases. There is often a tendency for more single-phase connection to be made to some phases due to their position in the junction box or pole cross-arm and hence reach-ability for connection.

2.18 As this proposal is related to the revision of nps voltage in the transmission network and assumes that the existing limit of 2% is accepted for HV (132kV), MV (33kV and 11kV) and LV (415V) voltage levels, the main focus will be on the sources of the unbalance in the transmission systems. The main source of unbalance in the transmission system is untransposed lines. In a perfect transposed line the impedance of all three or six conductors from the sending to receiving ends is equal. The line can be represented by symmetrical matrix where the diagonal elements, the self-impedances, are equal and off-diagonal or mutual impedances between phases are also equal. When this matrix is converted into the symmetrical component impedances using the standard phase coordinate to symmetrical component conversion operator matrix, the sequence networks will be decoupled and hence the mutual impedances between sequence networks is nil, which in turn means that the current in one sequence network does not affect the voltage in another. There is one exception for double circuit lines where there is a mutual coupling between the two circuits zero sequence networks. For untransposed line, on the other hand, this property does not exist and there are mutual effects between the sequence networks of one circuit and between circuits. This means that current in one sequence network, e.g. pps, affects the voltage in another, e.g. nps.

2.19 The other source of unbalance in transmission network is connection of high power single phase traction loads, which are increasing in MVA size and number, which in turn has forced the rail operators to prefer connection to transmission network against rather than distribution systems. This has shifted a large of the traction load from distribution to transmission network.

2.20 A technical report has been prepared presenting more technical detail about the effect of unbalance in power system and background to this proposal and its implication. The technical report is an integral part of this proposal and can be found at the link below. Please click on the document entitled “Voltage Unbalance Report”.

http://www2.nationalgrid.com/UK/Industry-information/Electricity-codes/Grid-code/Modifications/GC0088/

3 Solution

3.1 An extensive search of the CEGB archive (as far back as 60s, 70s and 80s, Chief engineer conferences/recommendations) and NGET Policies, Technical Specification 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.

3.2 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.

3.3 Scottish Network designers/operators have been considering a Grid Code limit of 2% for UBF in accordance with the Grid Code and this has not led to any published technical and design issues.

3.4 Table 1 illustrates the limit for unbalance factor in different countries.

Country	UBF (%)	Comments
England & Wales	1	[1] GB Grid Code
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 1- Limits for UBF in other Countries

3.5 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 studies 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 2.

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 emissions between unbalanced installations and various systems inherent sources of unbalance, e.g. untransposed lines, present in the system is 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

3.6 It is proposed that the compatibility limit in Grid Code clause CC.6.1.5 is changed:

- from 1% to 1.5% for 400kV and 275kV in England and Wales
- from 2% to 1.5% for 400kV and 275kV in Scotland and
- to 2% for voltages up to 150kV.

3.7 The proposed limit of 2% for voltages up to 150kV across GB 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.

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

3.9 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.

3.10 The rational for considering 1.5% for nps limit is illustrated by (1). If an equitable share of a 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:

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

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 allowance for contribution from 132kV and lower voltages is thus given by (2).

Contribution from unbalance sources in DNO =

$$\sqrt[1.4]{2^{1.4} - (0.9 \times 1.5)^{1.4}} = 1.08\% \quad (2)$$

3.11 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.

3.12 A supporting report is attached to this proposal whose title is:

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

4 Summary of GCRP and Workshop Discussions

4.1 The requirement for a workshop was as set out in the presentation, and accompanying report, made to the 19 November 2014 GCRP meeting by NGET. The recommendation from GCRP was to hold a workshop to explore the issues in more depth and with more specialised knowledge in the room.

4.2 The aim of the workshop was to determine the next steps. The options were to go straight to writing an industry consultation or to convene a workgroup to arrive at this position.

4.3 A draft copy of Terms of Reference for the Workshop was circulated amongst GCRP members. This is included in Annex 3.

4.4 A workshop was held at National Grid House on 2nd February 2015. Invitations were sent to all stakeholders. The accompanying Report to the proposal presented to GCRP was made available to all potential participants.

4.5 Representatives from Scottish Power Transmission, Enercon, Scottish and Southern Electricity (transmission), Western Power Distribution, RWE, Ofgem, National Grid Interconnectors and National Grid Transmission attended the workshop. Apologies were received from EdF, Element Power and Scottish and Southern distribution.

4.6 During the workshop all aspects of the proposal were discussed, with options for a number of them considered. Where the discussions did not reach a clear consensus, consultation questions are included in Section 6 seeking wider industry views. National Grid presented a summary of the report already submitted to the GCRP and additional information about unbalance case studies carried out by National Grid.

4.7 National Grid explained that it considers the Grid Code as a specification for the network performance and therefore it interprets it as requirements that applied to Users as well as the operators of the transmission network. As such, National Grid considers the limit for voltage unbalance (presently 1%) in planning and design as an absolute value that should be complied with all the time (100% of time). The design includes the most adverse but credible outage cases to ensure that the guaranteed level in the Grid Code is complied with. It was further emphasised that National Grid's approach gives the necessary assurance to transmission network Users for their design and assessment of installation susceptibility. It was explained that all new connections such as new power stations and traction connections are assessed against this requirement. Background voltage unbalance, caused by pre-existing network power flow and traction loads, is inherently included in the model.

4.8 It was explained that the basis for the proposal is the recommendation from IEC and CIGRE Working Group C4.07. These recommend that allowance should be made for inherent network unbalance such as untransposed lines and that emissions from different voltage levels should have an equitable share of the limit.

4.9 Using field measurements, and using IEC 61000-3-13 recommended method for aggregation, National Grid presented results of the allowance for the emission from distribution networks based on assumed 1% and 1.5% emission from EHV network and the transfer coefficients already calculated. With a 2% limit on the DNO networks at 132kV, the contribution from DNO networks would be limited to 1.507% and 1.08% for EHV emissions of 1% and 1.5%.

4.10 A question was asked whether an increase in the contribution from EHV to the aggregated level at 132 kV and lower voltages would cause the voltage unbalance level to exceed the limit at these voltages. It was explained that theoretically it is a possibility, at least in some parts of the distribution network where the voltage unbalance level is already approaching the limit of 2%, and when the depleted network condition prevails. A large number of measurements from 132kV sites were presented. The maximum levels were well below 2%, and by assuming the contribution of 1.5% from EHV network, it was shown that for all measurements the levels would still be below 2%.

Timeline

Meeting Dates

GCRP presentation – 19 Nov 2014

Workshop – 2 February 2015

4.11 A further factor considered was that nowadays most traction connections are made or applied for at the EHV levels. Considering that international standards recommend equitable allowance should be made for upper and lower voltage level contributions, in National Grid's view it is justified that the limit for EHV is increased. Furthermore, it was presented that in the majority of normal operating conditions the voltage unbalance levels are well below the limits. Scottish Power Transmission concurred and mentioned that there are usually odd onerous cases which cause the limit to be exceeded.

4.12 It was also presented that usually, in the majority of cases, depleted network states, due to line and/or generator outages, are the limiting cases for the voltage unbalance that require mitigation and hence influence the project cost. Scottish Power Transmission concurred and explained that they have similar approaches. This seemed to be in contrast to methods employed by some DNOs that consider the voltage unbalance limit in the D Code, which in turn refers to P29, as being a planning level and hence they allow 2% for intact network. It further became apparent that DNOs do not consider outages in their assessment and that the level could be above 2% for the duration of outages in some parts of the network.

4.13 Based on the method adopted by DNOs that only intact conditions are considered, the possibility of using dual limits for EHV in the Grid Code was tabled by some attendees, which included a limit of 1% for intact conditions and 1.5% for a depleted network. National Grid's view is that this would not alter the design, which would be driven by the outage conditions, and would add to the complexity of assessment. As there is currently only a single EHV limit, DNO designs at present account for the maximum unbalance on the transmission system. Increasing this single EHV limit will increase the levels that DNOs account for, but as discussed above, it is not anticipated that this will lead to non-compliances for DNO networks. National Grid believes that this approach would not solve the issues designers are facing or lead to a more efficient design for Users.

4.14 A question was asked as to why in the proposal the threshold of 150 kV had been chosen for change in the limits of 1.5% and 2% for EHV and lower voltages and whether it was arbitrary chosen and why it could not be set at 110kV. National Grid responded by referring to EN 50160 that gives limits for different distribution and high voltage levels. In this document, voltages of 150 kV and below are defined as high, medium and low voltages. Other IEC documents tend to follow the same definitions with some increasing HV to 220 kV. Therefore, National Grid adopted these standards and recommendations. Furthermore, it was discussed that if the threshold is reduced to 110 kV then the limit for 132kV would be reduced from presently 2% to 1.5% making the limit at 132 kV more onerous.

4.15 The proposal will reduce the limit in Scotland from 2% to 1.5% on the EHV system. National Grid presented that the assessment method deployed by Scottish Power Transmission inherently considers the coordination between voltage unbalance levels at different voltages and that the 2% limit at 132kV effectively limits the EHV to around 1.5%. Therefore it is envisaged that there would be no impact. Furthermore, it was mentioned that according to international recommendations, coordination between limits at different voltage levels is essential. The limit of 2% for EHV and 132 kV does not comply with this requirement. Scottish Power commented that they would need to further assess the implications of reducing the limit.

Scottish Power Transmisson (SPT) and Scottish Hydro Electric Transmission (SHET) have commented further that pending more investigation about the implication of reducing the limit in Scotland from 2% to 1.5% they would oppose the proposal although they have no objection in increasing the limit in England and Wales from 1% to 1.5%.

SSE have also suggested that in view of desired unified limit for the GB network, 2% be proposed in the Grid Code for England and Wales as well as Scotland. In NGET's view a 2% limit for EHV would not be beneficial. As described above, the EHV limit is in practice around 1.5% due to the impact of EHV levels on the DNO networks. To set a Grid Code limit that would not have any influence on system performance is not beneficial to TOs or users.

4.16 Using the results from a real fault condition in the 400 kV network the effect of voltage unbalance on the harmonic levels was presented. The fault was a single open phase condition about 25.8 km from a 2 GVA HVDC connection. It is emphasised that this was a fault and should be differentiated from a network normal operating condition which is the subject of this proposal. However the results can be used to illustrate the relationship between voltage unbalance and harmonics.

It was shown that the voltage unbalance level before the fault, obtained from simulation matched very well with the field measurement at 0.2%. During the fault the voltage unbalance increased to 9.6% at the fault location and 5.0% at the point of HVDC converter station where the measurement was done. During the fault period, there was no change in THD and other harmonics except in the 3^{rd} harmonic when it increased from 0.25% pre-fault to 0.62% during the fault. If it is assumed that the relationship between the changes in voltage unbalance and 3^{rd} harmonic is linear then an increase in voltage unbalance from 1% to 1.5% would lead to an increase of approximately 0.05% in the 3^{rd} harmonic level. This is not considered to be a significant impact.

Workshop Recommendations

4.17 All workshop attendees agreed that there was no need to set up a workgroup provided the draft consultation paper is first circulated amongst the workshop attendees and then made available to GCRP for approval before being published.

5 Impact & Assessment

Impact on the Grid Code

5.1 The text required to give effect to the proposal is contained in Annex 1 of this document. No other changes to the Grid Code are required.

Impact on National Electricity Transmission System (NETS)

5.2 None, as power quality will be maintained to correct national and international standards and practices.

Impact on Grid Code Users

5.3 Facilitate more cost effective and efficient design. Otherwise, none.

Impact on Greenhouse Gas emissions

5.4 None.

Assessment against Grid Code Objectives

5.5 National Grid considers that GC0088 would better facilitate the Grid Code objectives, as set out below:

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

(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.

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.

This proposal does not affect quality and security of supply as it is only related to the compatibility limit concerning network's normal operating conditions.

The proposed change is in accordance with the internationally recommended practices suggested by CIGRE Working Groups and adopted by other major European utilities.

Impact on core industry documents

5.6 None.

Impact on other industry documents

5.7 None.

Implementation

5.8 National Grid proposes that implementation should be carried out 10 business days after an Authority decision. Views are invited on this proposed implementation date.

6 Consultation Responses

6.1 Views are invited upon the proposals outlined in this consultation, which should be received by **3 September 2015**. Please email your responses to grid.code@nationalgrid.com.

6.2 Responses are invited to the following questions:

(i) Do you support the proposed implementation approach?

(ii) Do you believe that GC0088 better facilitates the appropriate Grid Code objectives?

(iii) Do you agree with the proposal to continue with a single limit, as opposed to limits for intact and outage conditions?

(iv) (a) Do you agree with increasing the EHV voltage unbalance limit in England and Wales from 1% to 1.5%?

(b) If in agreement with (a), do you agree with removing the regional difference between England and Wales and Scotland by reducing the existing EHV limit for Scotland from 2% to 1.5%?

(v) Do you agree to 150kV being the threshold for applying a 2% limit?

(vi) Do the proposed changes set clear limits for Voltage Unbalance? If not, what do you suggest should be modified to improve their clarity?

(vii) Can you provide any example(s) of disruption caused by the Voltage Unbalance and the mechanism by which this occurred which could be used as evidence to amend the proposal presented in this consultation?

(viii) Do you have evidence to suggest that raising the unbalance limit in England and Wales to 1.5% will lead to additional costs to generators that will outweigh the benefits?

(ix) Do you have any additional comments?

6.3 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 & Confidential", in which case 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 the proposed Grid Code modification as set out in this report which entails changes to Grid Code Connection Conditions CC6.1.5 and CC 6.1.6. The proposed new text is in red and is based on Grid Code Issue 5 Revision 13.

The proposed change refers to international standards IEC 61000-4-30 and IEC 61000-3-13 which define measurement methods and rules relevant to power quality measurements and assessments. Both are part of IEC 61xxx series standards related to power quality. IEC 61xxx series are internationally accepted as the basis for power quality measurements and reviewed regularly by the IEC. IEC 61000-4-30 outlines clear methods for the measurement of power quality parameters to ensure uniformity and repeatability of measurements. All power quality monitoring devices in the market, including those used by NGET and power industry in GB comply with these standards. Therefore it is prudent that the requirement in the Grid Code refer to these standards to ensure consistency in the measurement.

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 and lower voltages it is prudent that the GB Grid Code voltage unbalance limit for EHV network in Scotland is reduced.

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:

(a) Harmonic requirement

…

(b) Phase Unbalance

Under Planned Outage conditions, the ~~maximum~~ 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, across GB, below ~~1%~~1.5%, and ~~in Scotland,~~ 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 10-minute average, in accordance with IEC 61000-4-30.

CC.6.1.6 Across GB, 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.

Annex 2- 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.

Annex 3 – Terms of Reference for the Workshop on 2/2/15

GC0088: Voltage Unbalance

TERMS OF REFERENCE

Governance

The Voltage Unbalance Workgroup was established by Grid Code Review Panel (GCRP) at the November 2014 GCRP meeting.

The group shall formally report to the GCRP.

Membership

The Workgroup shall comprise a suitable and appropriate cross-section of experience and expertise from across the industry, which shall include:

Name	Role	Representing
	Chair	
	Technical Secretary	
	National Grid Representative	National Grid
	Generator Representative	
	Non-Embedded Customer Representative	
	Transmission Licensee Representative	
	Distribution Licensee Representative	
	Authority Representative	
	Observer	

Meeting Administration

The frequency of Workgroup meetings shall be defined as necessary by the Workgroup chair to meet the scope and objectives of the work being undertaken at that time.

National Grid will provide technical secretary resource to the Workgroup and handle administrative arrangements such as venue, agenda and minutes.

The Workgroup will have a dedicated section on the National Grid website to enable information such as minutes, papers and presentations to be available to a wider audience.

Scope

The Workgroup shall consider and report on the following:

- The costs, risks and benefits of changing the Grid Code voltage unbalance limits from 1% to 1.5% for 400kV and 275kV and 2% for 132kV so they are uniform across GB, including:
  - The recommendations from the Industry Workshop on Voltage Unbalance
  - the impact on new and existing On-Embedded Customers;
  - the impact on new and existing none-Embedded Customers
  - the impact on new and existing small, medium and large generators;
  - the impact on Network Operators and their users;
  - the impact on current outage plans and investment schemes across all onshore TOs;
  - the impact on future outage planning process
  - the impact on Harmonics
  - the costs or savings in future network reinforcements across all onshore TOs;
  - the costs or savings on consumers;
  - the costs or savings in future generation connecting in

    a) England and Wales

    b) Scotland
  - the impact on the BSC; and
  - any interactions with other Grid Code criteria
  - any impact on other standard requirements for generators e.g. harmonic limits

The scope of the Workgroup shall not include:

- Changes to Engineering Recommendation P29

Deliverables

The Workgroup will provide updates and a Workgroup Report to the Grid Code Review Panel which will:

- Detail the findings of the Group;
- Draft, prioritise and recommend changes to the Grid Code and associated documents in order to implement the findings of the Group; and
- Highlight any consequential changes which are or may be required,

Timescales

It is anticipated that this Workgroup will report back at the latest to the November 2015 GCRP meeting.

If for any reason the Workgroup is in existence for more than one year, there is a responsibility for the Workgroup to produce a yearly update report, including but not limited to; current progress, reasons for any delays, next steps and likely conclusion dates.

Annex 4 – Notes of Workshop on 2/2/15

Meeting Notes

Meeting name	GC0088: Voltage Unbalance Workshop
Date of meeting	2 February 2015
Time	10.00 – 16.00
Location	National Grid House, Warwick

Attendees

Name	**Initials**	**Company**
Mark Perry (Chair)	MP	National Grid
Forooz Ghassemi	FG	National Grid
Rob Wilson	RW	National Grid
Zain Habib	ZH	National Grid
Martin Clarke	MC	National Grid
Christopher Smith	CS	National Grid Interconnectors
Cornel Brozio	CB	SPT
Konstantinos Pierros	KP	Enercon
Campbell McDonald	CMD	SSE
Ramesh Pampana	RP	SSE
Simon Scarbro	SS	Western Power
Mark Haines	MH	RWE
Mayure Daby	MD	Ofgem
Peter Haigh	PH	National Grid
Asim Khursheed	AK	National Grid

Apologies

Andy Vaudin	AV	EDF Energy
Guy Nicholson	GN	Element Power
Trung Tran	TT	SSE Distribution

1 Introductions/Apologies for Absence MP

1. The Chair welcomed everyone to the workshop and noted the apologies.

2 Background and Workshop Objectives MP

2. NPS levels on the system are rising to the point that they are beginning to impact on investment decisions. The timing was right to look at the limits on the system, which drive investment, to consider whether they were correct, and to reflect on what the impact of increasing these would be.

3. The requirement for the workshop was as set out in the presentation made to the 19 Nov 2014 GCRP meeting which accompanied the report written by Forooz Ghassemi as presented at the same meeting. An extract from the minutes of this meeting is included in appendix A. The recommendation from GCRP was to hold an industry workshop to explore the issues in more depth and with more specialised knowledge in the room.

4. The desired outcome of the workshop is to consider what steps should be taken next and to make recommendations on these to the GCRP. Broadly, the options available are to go straight to writing an industry consultation or to convene a workgroup to arrive at this position although there will also be some requirements for further checks with GCRP during this process.

3 Proposed Modification FG

5. FG presented to the group on the following topics:
   - Reasons to change
   - International Practice
   - Effect on Industry Parties
   - Proposal

6. Existing Grid Code requirements (CC6.1.5) for NPS applying to the transmission system specify a 1% limit for E&W and for Scotland 2%. This applies to 132kV sites owned by NGET in England and Wales. CC6.1.6 details that short duration peaks of 2% are allowed in E&W.

7. The proposal is to change to 1.5% across GB above 150kV and 2% below, and to retain a 2% short term peak for above 150kV. So in summary, the E&W limit would be relaxed to 1.5% above 150kV, and would be further relaxed to 2% at 132kV. In Scotland a more onerous limit of 1.5% would be applied above 150kV.

8. CMD asked why 150kV was chosen as a differentiator? Currently 132kV cables (eg Greater Gabbard) have had to be an OFTO. Could it be 110kV which would then be the same as RfG? It was agreed by NG that this was arbitrary but pointed out that in their view 110kV would not work as it would then push 132kV into the same category as 275 and 400kV systems.

9. On the distribution system, DNOs have a limit of 2% as specified in ER P29 and referenced in the distribution code DPC4.2.3.2(c), but this is a planning rather than absolute limit. This limit would not be changed due to the modification to the Grid Code. Limits on other national transmission systems are mainly 2%. None are higher than this, but a small number are lower.

10. Rotating equipment is the most affected by NPS. There is a cost for manufacturers to reduce susceptibility of equipment and a cost to system operators in keeping the levels down. Analysis by Cigre (ANSI C84.1) indicated that a compromise between these costs would be a 3% level as having the minimum overall societal cost. In general, utilities have set lower levels than this.

11. Coordination between higher and lower voltages is needed. If a 2% limit is to be used at lower voltages it will not be possible to have a level of 2% on the EHV system since NPS present on the EHV system will generally lead to a higher level of NPS at lower voltages. Analysis presented by FG indicates that a 2% limit at lower voltages aligns with approximately 1.5% at higher voltage. SS asked what the maximum contribution from the DNOs can be if one considers the existing Grid Code limit of 1%? FG stated that assuming a transfer gain of 0.9 and a EHV limit of 1% and 132kV limit of 2% and IEC 61000-3-13 recommended component for aggregation, the possible contribution from DNOs to the limit at 132 is 1.507%. This is reduced to 1.08% if the limit at the EHV level is 1.5%.

12. SS stated that they do get customers with motors overheating because of unbalance and asked what would be the limit for these? FG replied that motors are very prone to this and are often over-rated for this reason which doesn't cost much. MC added that generators normally get into trouble at about 5%.

13. FG clarified that we are not seeking to change this because of cost to NG. NG considers that the 1% limit is unnecessarily arduous and leads to additional costs being incurred. MC added that no generators are currently built to 1% as they are all built to withstand European standards of 2%. Most of the time the system will be nowhere near this limit.

14. FG set out that the cost of connecting a new generator if NPS is an issue can be 25%+ because the connection will need to be either a double turn-in or double tee rather than a single turn-in. In several parts of the system limits are being approached which means that these decisions are having to be made. Assessment is always against the most arduous outage conditions.

15. MP summarised the changes required and also other points that need consideration being:

- What is the interaction with harmonics?
- Impact on intertrips...which will tend to be greater if the requirements get more onerous.
- Efficiency of machines
- Will there be an increase in the LV background?
- Scottish outages

	Limit		Impact on:	
	Existing	Proposed	Generators	Transmission
Scotland > 150kV	2%	1.5%	Less onerous. Reconsider intertrips?	Could cost more and trigger more complex connection schemes
E&W > 150kV	1%	1.5%	More onerous background than some international standards. Could impact harmonics, intertrips and efficiency	Cost less to invest and operate
Scotland < 150kV	2%	2%	No change	No change
E&W < 150kV	1% (2% for DNOs)	2%	Background could increase	Possibly greater costs

Fig 1 – summary of changes

16. MP stated that the report had sought to address all issues that could be foreseen as it is very detailed. In increasing the E&W figure effectively this will reduce the allowable DNO contribution to stay within limits so need to consider in the round how many sites could be pushed over the limit with a higher EHV contribution.

17. RW reminded the group that compliance at a site is arbitrary. It either is or it isn't and there is not a measurement of the reason for non-compliance. RW went on to set out the process to take a modification forward from industry consultation to implementation. CMD commented that if you don't have a workgroup it makes it harder to respond to substantive comments on consultation or if Ofgem were to send back the final report for further work. RW agreed but said that in terms of the next steps, we could use the workshop attendees to consider a draft consultation and then take this back to the GCRP for discussion again and approval of how to take it forwards. Lessons learned from other workgroups would indicate that setting off without a clear scope is not a good use of anyone’s time so it is worth going through this stage first to see what the arguments may be.

18. MD summarised Ofgem's position and stated that a report to the authority would normally need a CBA. MP stated that it was likely to be a cost in £10m's for transmission system over-design vs order of magnitude lower costs on other equipment. FG asked if the limits will be applied in an absolute manner? This is important in assessing potentially all cases [RW post-meeting comment – the answer to this is that the limits will be as now set out in the Grid Code and to go outside these by design would need a derogation] . PH set out that the difference in avoided costs for Grid design schemes is somewhere between £80 and £150m if relaxing E&W standard to 1.5%.

19. CS questioned whether a two stage approach (against intact and outage conditions) would help us to avoid an over design which could otherwise end up having to increase specification of filter banks. RW replied that a derogation is a possibility but would have to be against very specific and limited circumstances. CB stated that using a derogation as a design solution was not desirable and this should only be on the basis of a CBA. CB added that for a network that can be secured, there should not be any NPS considerations to take into account while operating the system.

20. SS explained the process and standards by which WPD carry out NPS assessment. NPS is referenced in the D Code which in turn refers to P29. WPD interpret P29 as being a planning level and hence they allow 2% for intact network. SS stated that they do not consider outages in their assessment. FG asked what would be the level if they had an outage? SS responded that this is not specified or examined but they understand the possibility that NPS levels are above 2% for the duration of the outage. FG explained that NGET consider the limit in the Grid Code (presently 1%) at planning and design stages as an absolute value which should be complied with all the time regardless of conditions. The design includes the most onerous outage cases to ensure that the guaranteed level in the Grid Code is complied with. FG pointed out that the NGET approach gives the necessary assurance to Users for their design work and assessment of installation susceptibility.

21. FG stated that in EN50160 supply voltage unbalance is allowable to 2%. The harmonic specification might need to change as well looking at both outage and non-outage scenarios. RW expressed caution in considering the outage case as it might be necessary to define which were relevant outages for every substation.

22. FG presented a synopsis of measurement and harmonics going through an actual scenario. A high level of unbalance causes an increase particularly in the 3rd harmonic. CB pointed out that for an outage situation, it is not possible to know whether the high level of 3rd harmonic came about due to the trip or due to NPS. CMD asked what this would mean potentially for existing PPMs. PH replied that what we ask for in DPD section 5 is data being submitted to Grid on likely levels of unbalance.

23. CB stated that everything is working at the moment, so he didn't really want to raise any potential non-compliance issues by changing anything in Scotland. 2% has seemed to work OK as an absolute limit although generally the actual position is well away from this limit. CB went on to say that while it would be possible to come up with good reason to increase the NG area limit it would be harder to do the Scotland part of making it more onerous. MP suggested that the requirements could be split up, although it is preferable to unify requirements and remove regional differences if possible. MP asked what the consequence for DNOs would be? SS replied probably more nuisance tripping.

24. MP considered that if we present a £100m benefit on the basis of reduce transmission system design requirements vs this would have to be assessed at the moment against intangible risks. MD pointed out though that Ofgem would not want a RIIO reopener for the DNOs here or a raft of derogations requests to be the response to this.

25. SS asked whether another approach could be to update P29 and include 275 & 400kV in this? PH stated that it was preferred to do it in the Grid Code as we are seeing a lot of unbalanced loads now. MP added that revising one of the ERs could take a long time. CMD stated that one of the key questions to ask in the consultation is going to be the voltage threshold. SS asked how P29 is referenced? PH replied that it isn't in the BCAs which only refer to the Grid Code.

5 Way Forward — All

26. MP stated that there are effectively 4 options:

    (i) Do nothing - no, the problem has been demonstrated.
    (ii) Apply a single limit
    (iii) Apply a dual limit (eg 1% for intact, planning limit of say 1.5% for outage conditions)
    (iv) Allow regional differences

    A combination of these options could also be employed. The single and dual limit options would also have sub-options of either 1.5 or 2%.

27. Summarising, RW stated that the options really are to write up the report as a draft consultation and then circulate this for comment or to set-up a workgroup. A workgroup could easily spend a long time in trying to define the scope of the issue. Writing up a consultation would probably help to get people to engage, think about the issue and submit comments.

28. The workshop agreed that writing a draft of the consultation and then circulating this for comment would be the next step. Depending on how close to consensus this then appeared, it would probably then be appropriate to circulate this to the GCRP to agree what to do next between formally going to industry consultation or considering further, possibly with the help of a workgroup.

GC0088: Voltage Unbalance

3858. MP presented on GC0088. GC0088 seeks to revise the Grid Code criteria applied to Voltage Unbalance within CC6.1.5 (b). MP ran through the key points of the proposal and advised that extensive analysis had been carried out and that a number of recommendations have been made in the paper. These recommendations align with the IEC Standards and unify the England/Wales and Scotland standards to 1.5% at EHV level (voltages above 150Kv) and 2% for lower voltages. MP advised that there are a number of reasons for changing the NPS levels, including avoiding unnecessary investment in transmission systems and resolving inconsistency across England & Wales and Scotland. MP asked the Panel for their views on the work carried out so far and whether they believe a Workgroup is required to develop further, or if the work is sufficient enough to go out to Code Administrator Consultation. SB advised that she had been working on this and felt that the starting point needs to be clearly defined and also that harmonics need to be considered as this is impacted by voltage unbalance. MP responded that they have tried to keep harmonics separate and no change is proposed in this paper as he does not believe that there is significant interaction between the two. MP added that they have tried to include a clearer definition on the measurement and calculation of the level of unbalance in the paper.

3859. CMD felt that there had not been sufficient time to review this subject and questioned the formula in the paper. He had a concern about the priority of this in relation to the number of other Workgroups that are currently on hold and also about any unintended consequences and who would benefit from this. MP responded that the benefits are ultimately for the consumer as there are lower costs in transmission and added that this has been raised because we may be building more than we need to because of the tight limits. CMD was concerned about the resources, particularly with RfG coming up. IP advised that an internal view has been taken on how this ranks amongst other subjects and it was decided to bring this forward at this current time. There are cost implications for design choices which affect consumers so that is the main driver for raising now. RL suggested that it would be useful to understand what the additional costs and delays would be if this issue was not raised now. GP echoed this suggestion and added that it would be useful to break up the costs for the consumer in the paper / report. AV voiced his concerns about this progressing without a Workgroup as the implications for existing generators needs to be looked at. JN advised that sufficient time would be required to study this for implications and so that the issues are all identified. SB advised that 2% is a standard limit but that dependencies need to be examined particularly in relation to harmonics.

3860. AT asked how the GCRP deal with ranking of issues, taking into account limited resources, in relation to CMD's point on priorities. AT advised that the Progress Tracker currently has six issues on hold and thirteen Workgroups in progress including one on hold. AT queried whether GC0088 would get sufficient Workgroup membership. RL felt that if it is deemed a priority then resources would likely be re-assigned to deal with it. RW advised that the items on hold on the progress tracker are mainly due to external issues such as waiting for RfG, and also due to waiting for National Grid internal work to be carried out. JN felt that the Panel should be able to progress standalone issues that do not interact with other codes/work. IP noted that there is an element of self-regulation. AT asked if there is anything on the tracker that could be progressed now. Some members of the Panel felt that there is not enough information on this issue yet to know whether it needs to be prioritised or not. MK advised that he is not aware of issues for DNOs but that this needs to be resolved bearing in mind the amount of activity coming up over the next 10 years. GS asked if this issue (work list) had been discussed under Open Governance. AT advised that the GC0086 Workgroup has discussed workload and resources and there is a potential Advisory Group which is being developed by National Grid, which would mean that issues get developed and potentially prioritised prior to being taken to the Panel.

3861. IP suggested having one Workgroup meeting on GC0088 to form a view on where we are in terms of level of comfort with the proposal or whether further thought is required across the industry. GP agreed with JN and CMD, in that it is good that the paper is worked up but that it also means that there is more for the Panel to digest and review, and therefore it is appropriate for a Workgroup to discuss further. NS advised that the Scottish transmission networks are not as strong as England and Wales and there is a need to reflect on the position during outages. He added that consideration needs to be given to construction work and that the Scottish TOs should be included on the 'impact' list within the paper.

3862. GS suggested having a workshop to discuss the subject further. AC agreed that this would give National Grid an opportunity to walk through the paper and have the appropriate industry experts to agree on what a Workgroup may be required for. IP agreed that this is sensible and that a meeting could be arranged for January next year. The Panel agreed to comment on the draft Terms of Reference.

3863. NR asked about consequential impacts on the BSC. IP suggested putting this in the Terms of Reference.

ACTION – Arrange a workshop for January to discuss GC0088. Send out draft Terms of Reference for 3 week review.

Annex 5 – Increase in Generator Losses Report

(prepared in response to a question from RWE)

INCREASE IN GENERATOR LOSSES DUE TO PROPOSAL GC0088

F Ghassemi and M Perry

July 2015

EXECUTIVE SUMMARY

It will be presented that setting the limit for voltage nps level at 1.5% does not mean the nps voltage level reaches the level in the normal operating conditions all the times. Reference to large number of measurements in UK and worldwide will be made to show that in majority of times the nps voltage level is lower than the declared limit. The limit may however be reached in depleted network conditions, which should nevertheless be considered at design stage to ensure compliance with the Grid Code.

It is also presented that all power quality standards, including those adopted by industry in UK, allow nps level of up 2% as a compromise between the cost of reducing nps voltage and increasing equipment susceptibility level. It is not the objective of the proposal to exceed this 2% level.

It is presented that the losses produced by nps component in generators and their transformers are proportional to the square of the nps voltage that is imposed by the network on generators. Therefore, an nps voltage level of 1.5% produces a power loss in the machine that is 2.25 times higher than the power loss for 1% nps voltage.

Using synchronous generators and their transformers data in the GB model available to NGET, analysis will be carried out to estimate the nps power loss in most generators connected to the GB grid. In total 231 generators connected to 400 and 275 kV are considered. It will be shown that for a source short circuit level of 40GVA the maximum nps power loss for nps voltage of 1.5% is 83 kW. For the same machine size the pps power loss is 4 MW.

The nps power losses will be presented in terms of percentage of the pps power losses for all machines. It is shown that for large machines this ratio is below 5% and for lower rating machine the ratio is below 7%.

It is concluded that the impact on overall generator losses resulting from the proposed change to the Grid Code nps limit from 1% to 1.5% will be small compared to the benefit of the proposal.

Table of Contents

1. INTRODUCTION

By email dated 9th July 2015, RWE raised concerns about the proposed increase in the negative phase sequence (nps) voltage limit in the Grid Code to 1.5% causing additional losses in rotating plants and hence operational costs for the generator companies. The email is given in Appendix A for ease of reference.

Below, NGET respond to this concern. The response consists of two parts. The first refers to the data and information in the Report annexed to the proposal [1] to establish the effect of the increase in the nps voltage limit on the nps voltage profile in the normal operating conditions. The second part quantifies the increase in losses and compares them to the generator positive phase sequence losses.

2. EFFECT OF GRID CODE LIMIT ON NPS VOLTAGE PROFILE

NGET has a license obligation to comply with the GB Grid Code requirements. For every connection with potential nps polluting characteristic, such as new power station and traction loads, detailed studies are performed to ensure that the Grid Code requirements are met. These studies may take from two to four months depending on location, complexity of the network at the location and size of the new connection. With reference to the GB SQSS requirements, part of the study is to consider normal operating conditions as well as depleted network when planned and unplanned (faults) outages of plants are considered. In almost all cases the depleted network conditions are the limiting conditions when the Grid Code nps limit is approached or exceeded. These severe conditions usually are cases leading to counter flow in double circuits lines and double outage cases, which are usually caused by unplanned events or managed by the National Electricity Control Centre (NECC). Therefore, usually the nps levels in the network are not sustained at the limit level for a long time. This has been proved by measurement over a long time across many substations.

Measurements in GB transmission network as well as an international survey that was carried out by CIGRE WG C4.103 were presented in Section 3 of the Report [1]. The highest 95-percentile of the nps level across a large number of substations at 400kV was shown to be under 0.65%. The same for 275 kV was under 0.45%. It was explained in Report [1] that the exact network conditions during the measurement were not known but it is considered that during at least one week and in many cases longer than one week, of measurement period for such a large number of sites there was a possibility that some outages were present in the network. The measurement results collected by the CIGRE WG C4.103 and referenced in the Report [1] also confirmed that at EHV voltage level, from 168 sites worldwide, 83.3% has nps voltage of less than 1% and more than 93% of sites had voltage nps levels below 1.5%. The nps limit for all countries participating in the survey was between 1% and 2%.

It was presented in the Report [1] that the network has a voltage nps level in the normal operating condition that is lower than the limit and the limit may be reached in very few cases when there are outages in the vicinity of the node being assessed. These credible network conditions may not by encountered everyday but must be included in the assessment to ensure that the nps voltage limit is not excessive.

Section 4 of the Report [1] described the impact of the nps voltage on rotating plants. Item i), Section 4, Page10 refers to additional losses in the nps network due to nps voltage in the network.

It was presented that ANSI C84.1 sets the voltage nps level at 3% where compromise between cost to utilities to reduce nps level and cost to manufacturer to increase equipment susceptibility is made. All international standards such as IEC 61000-3-13, EN 50160, ENA ER P29 and CIGRE WG C4.07 report agree that up to voltage nps level of 2% is acceptable despite the losses in the nps network. EN 50160 allows up to 3% voltage nps in special cases, e.g. radial long feeders to remote loads, where the mitigation cost cannot be justified. Proposal GC0088 is in line with this recommendation and has proposed the change within this framework. It is therefore inherently accepted that the increase in the network and equipment losses due to voltage nps is acceptable to avoid mitigation cost, which can not only be imposed on the network operator and owner but also the users.

3. LOSSES IN SYNCHRONOUS GENERATORS DUE TO NPS VOLTAGE

Negative phase sequence voltage or current causes additional losses in the network, which are directly proportional to the square of nps voltage or current.

If the nps voltage in the network were always at the limit level, an increase in the nps limit from 1% to 1.5% leads to 2.25 fold (or 225%) increase in the synchronous machine nps losses.

Considering availability of equipment data, Generation Companies are in the best position to assess the losses in the synchronous generators due to nps current. However, National Grid endeavour to present a quantitative analysis below.

The generator data in the GB model in Power Factory is used to assess the nps losses in generators. More than 231 generator sets and their transformers are considered in the assessment. The data submitted by generators to NGET includes stator winding resistance and nps resistance. There is some doubt about the reliability of generator nps resistance data. It is well known that the resistance presented by a generator to the nps voltage at the machine terminal is higher than the stator winding resistance due to the resistance of the rotor winding and structure, which become part of nps circuit due to reverse rotation of the nps stator flux relative to rotor motion. For the positive phase sequence (pps) component on the other hand, rotor rotation is in synchronism with the flux created by the stator currents and thus no current is induced in the rotor. Therefore the only effective resistance presented to the pps current is the stator winding resistance.

It is difficult to reliably determine the nps reactance and resistance of a synchronous machine. There are different standard test methodologies that can be used. Amongst a number of reasons, the most important ones affecting the measurement are low level harmonics generated by machines internally. As explained in the Report [1] the nps reactance is usually provided and that is assumed to be equal to the direct axis subtransient reactance or the average of the direct and quadrature axes reactances. The nps resistance of turbo-generators is between 2 and 4 times smaller than the nps reactance and for hydro-generators is between 2 and 8 times smaller than the nps reactance.

In the analysis that follows, it is assumed that the nps voltage is at the Grid Code limit all the time. It is also assumed that the ratio of nps reactance to resistance is 3. Furthermore, for the loss analysis, generators and their transformers are considered as one unit and the combined losses in the generator and transformers are calculated.

In Section 4.3 of the Report [1] analysis was carried out to determine the level of nps voltage that causes flow of 8% nps current in the machine. In that exercise it was assumed that the machine is connected to an infinite busbar with zero source impedance to consider the worst case scenario. In the analysis that follows here it is assumed that the machine is connected to a source with 40GVA fault level with a reactance to resistance ratio of 10. It is also assumed that the pps and nps impedances of the source are equal. Any reduction in the source fault infeed reduces the nps current in the machine for a given nps voltage in the network, thus reducing the nps power loss. The influence of source impedance on the reduction depends on relative ratio of source impedance to that of combined nps impedance of the generator and its transformer.

The equation used for calculating the nps current in the machine for a given nps voltage is shown in (1) below:

$$I^{-}=\frac{V^{-}}{Z_{s}^{-}+Z_{g}^{-}+Z_{Tx}^{-}} \qquad (1)$$

Where Z_{s}^{-}, Z_{g}^{-} and Z_{Tx}^{-} are respectively the nps impedances of the source, generator and generator transformer. The power loss is then calculated from (2).

$$P_{Loss}^{-}=I^{-2}\left(R_{g}^{-}+R_{Tx}^{-}\right) \qquad (2)$$

All parameters are converted to 100 MVA base.

Figure 1 shows the generator and its transformer pps resistances. It can be seen that larger machines have lower resistances and also the generator and transformer resistances are comparable.

Figure 2 illustrates the generator and transformer nps resistances. It can be seen that the machine resistance is much higher than the resistance of its transformer. Therefore the majority of the power loss occurs in the machine. Also larger machines have lower resistances.

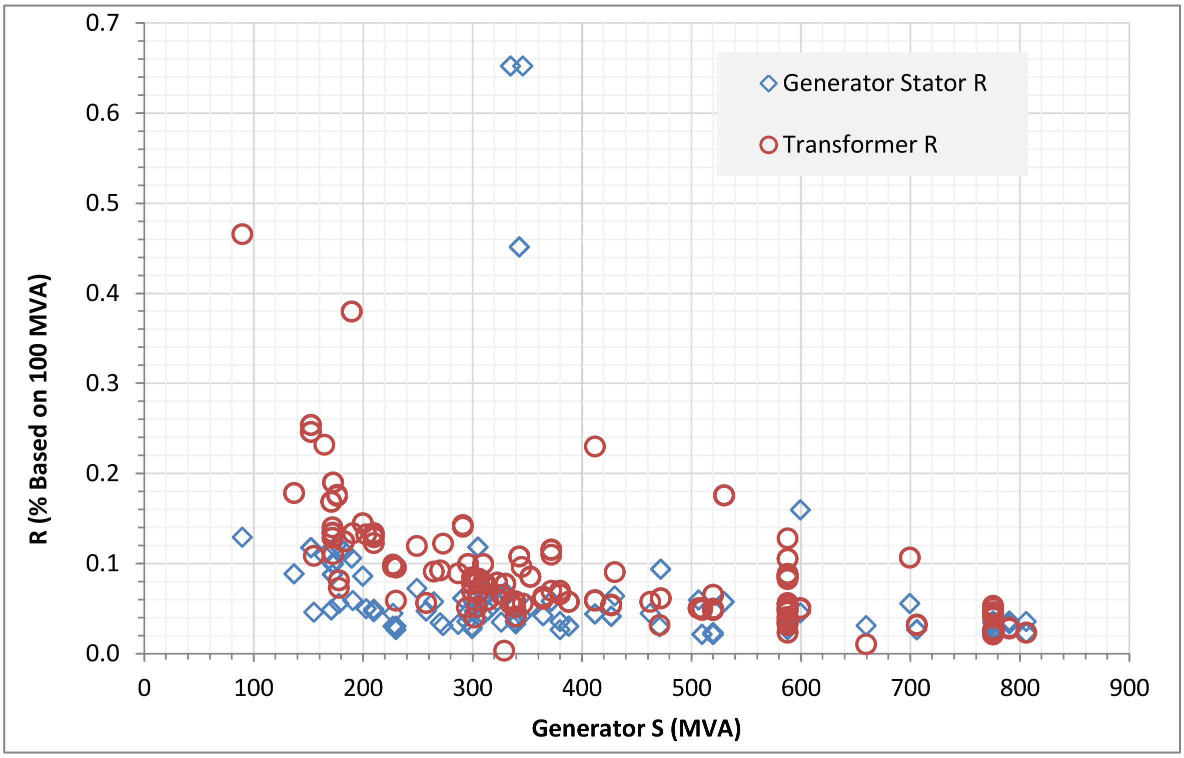

Fig 1- Generator and its Transformer PPS Resistances

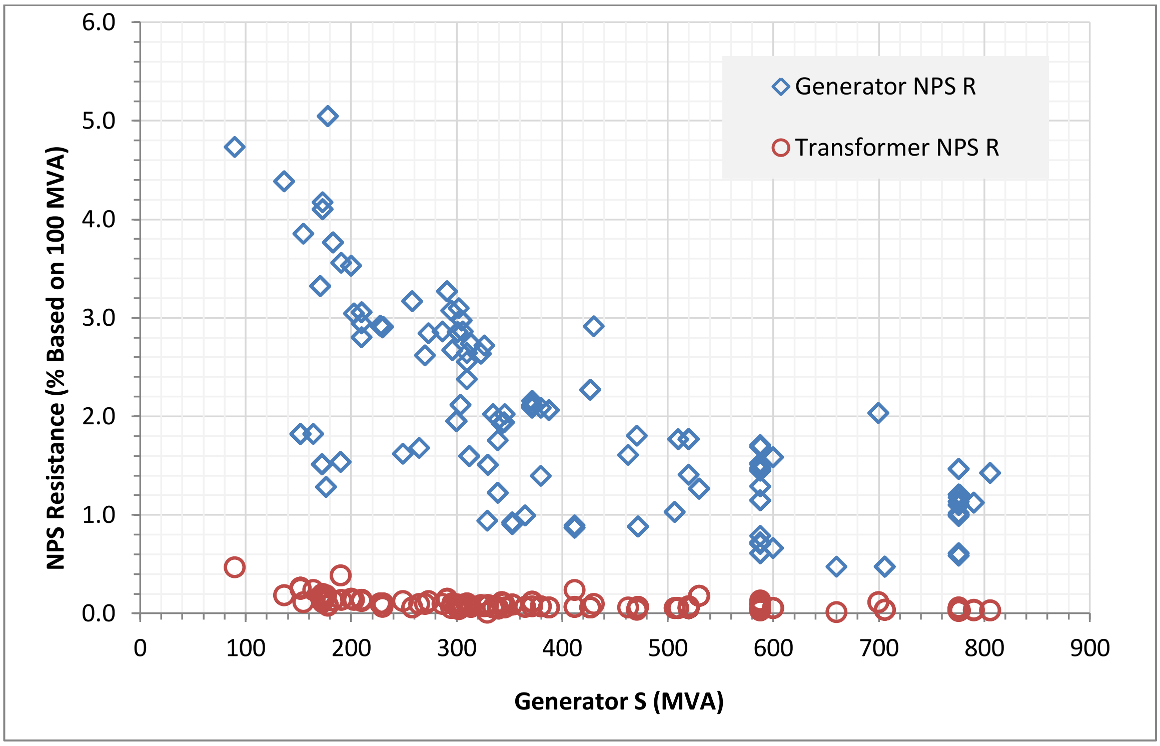

Fig 2- Generator and its Transformer NPS Resistances

Figure 3 shows the power loss in the machines and transformers considered both for nps and pps components. For calculating the pps power loss it is assumed that machine is supplying the rated apparent power. The nps power losses are shown for both 1% and 1.5% nps voltage.

Vertical left and right hand side axes respectively give the nps and pps power losses. It can be seen that the highest nps power loss for 1.5% nps voltage is less than 80 kW which occur in large machines (790 MVA) and the pps power loss for the same size machine is around 4 MW. The lowest pps power loss is about 0.35 MW (350 kW) which occurs in relatively small machines (150 MVA) and for the same size machine the nps power loss is about 22 kW.

Note that the nps power loss for nps voltage of 1.5% is 2.25 times higher than the power loss for nps voltage of 1.0%. In general the higher the machine rating the higher the nps and pps power loss.

Figure 4 illustrates the nps power loss in the generator and its transformer as percentage of the pps power loss at machine rating. It can be seen that for machines with 300 MVA rating and above the nps power loss is below 5% of the pps power loss. For most machines with lower ratings this increases to below 7% with one case only of 9.5%. This odd case may be due to data inaccuracy.

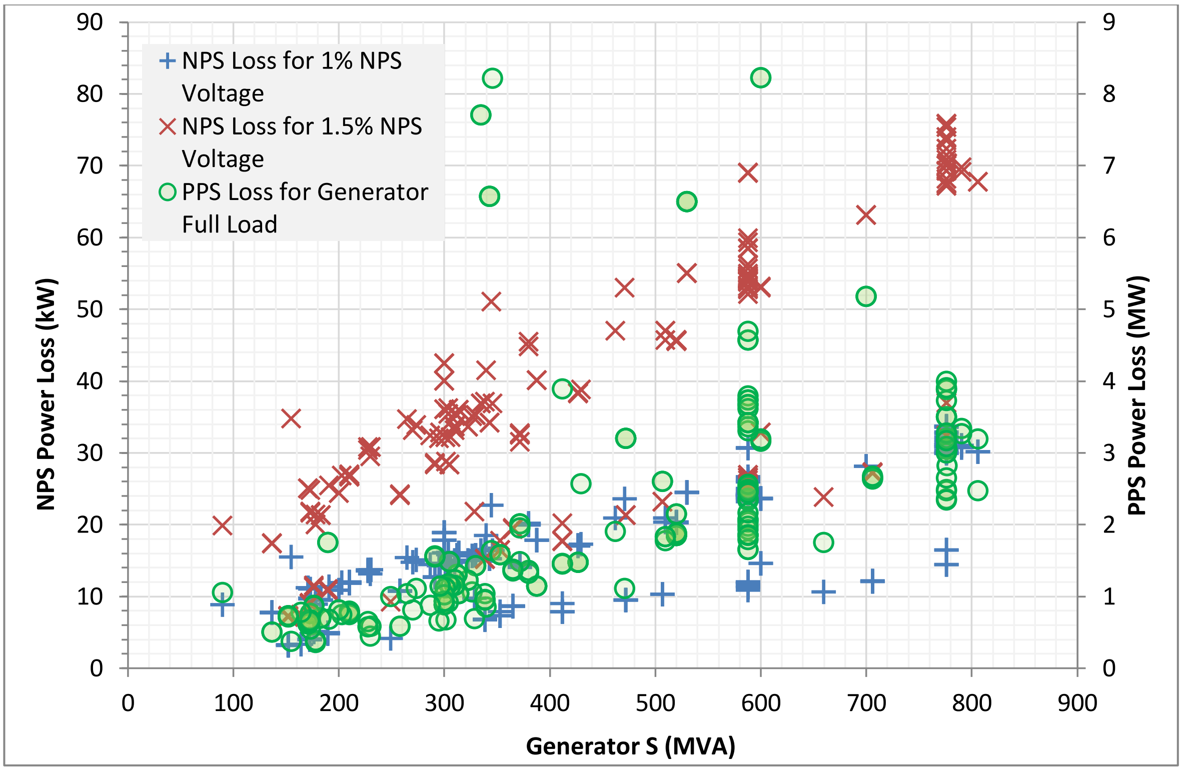

Fig 3- PPS and NPS Power Loss in Combined Generator and its Transformer

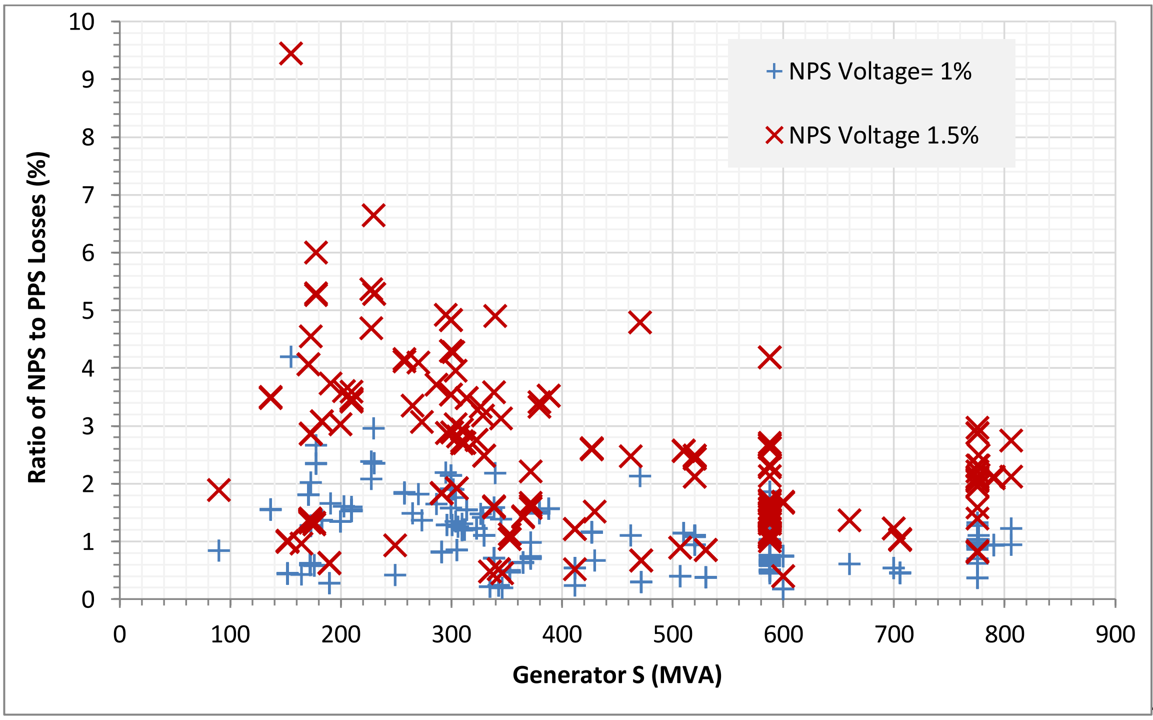

Fig 4- Ratio of NPS to PPS Power Loss

4. CONCLUSIONS

It was explained that setting the limit for voltage nps level at 1.5% does not mean the nps voltage level reaches the level in the normal operating conditions all the time. Reference to a large number of measurements in UK and worldwide was made to show that in the majority of times the nps voltage level is lower than the declared limit. The limit may however be reached in depleted network conditions, which should nevertheless be considered at the design stage to ensure compliance with the Grid Code.

It was also presented that all power quality standards, including those adopted by industry in UK, allow nps level of up 2% as a compromise between the cost of reducing nps voltage and increasing equipment susceptibility level. It is not the objective of the proposal to exceed this 2% level.

It was presented that the losses produced by the nps component in generators and their transformers are proportional to the square of the nps voltage that is imposed by the network on generators. Therefore, an nps voltage level of 1.5% produces a power loss in the machine that is 2.25 times higher than the power loss for 1% nps voltage.

Using synchronous generators and their transformers data in the GB model available to NGET, analysis was done to estimate the nps power loss in most generators connected to the GB grid. In total 231 generators connected to 400 and 275 kV were considered. It was shown that for a source fault infeed of 40GVA, the maximum nps power loss for nps voltage of 1.5% was 83 kW. For the same machine size the pps power loss is 4 MW. This power reduces if the source fault infeed is lower.

Consequently, considering the duration at which nps levels will be high, and the relatively small impact on overall losses would result from the proposed increase in the nps limit, it is concluded that the cost of the additional losses will be small when compared to the benefit of the proposal presented in [1].

5. REFERENCES

[1] Report entitled “Review of Voltage Unbalance Limit in The GB Grid Code CC.6.1.5 (b)”, Annex to Proposal GC0088, October 2014.

APPENDIX A

Email from RWE.

Sent: 09 July 2015 14:43
To: .Box.Grid.Code;

Subject: RE: GC0088 Voltage Unbalance consultation for comment

Hi Alex

Just one comment on the draft report – if the phase unbalance in England and Wales is increased from 1% to 1.5%, the negative phase sequence (NPS) currents in generating units would increase, causing additional heating, a slightly reduced efficiency and increased operating cost. Whilst the report Para 2.1.4 recognises that this cost would be minimal for generators, it is assumed from the reference to design that this refers to the generator's capital cost. Whilst Question 8 asks consultees for evidence that additional (operational) costs to generators would outweigh the benefits, the generator is unable to answer this question in isolation. It would therefore be helpful if the report gave an indication of the likely extent that the greater phase unbalance would occur on the transmission system in E&W and also an estimate of the total operational costs that would be incurred by generating units operating less efficiently.

Kind Regards