

WORKING GROUP REPORT

Frequency and voltage operating range

**Prepared by the Working Group
for submission to the Grid Code Review Panel**

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1.0 INTRODUCTION AND SUMMARY

- 1.1 At the GCRP meeting of 21 May 2009 it was agreed¹ that a review of the Grid Code requirements for frequency and voltage operating range should be added to the Outstanding Issues list of the GCRP for subsequent review.
- 1.2 A paper (pp09/40²) was submitted to the November 2009 Grid Code Review Panel (GCRP), in which it was noted that existing GB Grid Code requirements for the frequency operating ranges that generating units must remain connected continuously to the transmission system appear more stringent than those required internationally. This is against a background where large frequency perturbations have rarely occurred on the GB transmission system and have been transitory in nature.
- 1.3 Similarly voltage range is specified in combination with frequency capability with specific limited time operation at more extremes.
- 1.4 PP09/40 proposed to initiate such a review via a GC Working Group to ensure timely consideration based on the amount of new synchronous generating plant expected to be connected in the next ten years. The Panel recommended that a Grid Code Working Group is established in order to complete the Terms of Reference as shown in Annex 1, and report back to the May 2010 Panel meeting.
- 1.5 The Working Group agreed on a proposal to express grid voltage variations more clearly than in the current Grid Code by tabulating the existing criteria. It also agreed to modify the under-voltage tripping times in CC6.3.15.3 which apply to Non-Synchronous Generating Units in Scotland to align with the current fault ride through profile.
- 1.6 The Working Group also agreed that benefit would be gained by introducing duration limited operation requirements in certain frequency bands. Differences of opinion remain over one specific aspect of this, which is the starting point of the 'continuous' operating criteria. This report recommends the adoption of a proposal which both delivers benefits and has been assessed to have no impact on system security.
- 1.7 The Working Group discussed the benefits of a more explicit specification of a combined frequency and voltage range requirement. The group was unable to derive a comprehensive requirement and evaluate its compatibility with all currently available technologies.

2.0 BACKGROUND AND CURRENT POSITION

- 2.1 The GCRP paper pp09/40 summarised some of the current Grid Code clauses relating to Frequency and Voltage and is shown in Appendix Three. An overview of the current position is provided below.

Frequency

¹ Minute 1228

² <http://www.nationalgrid.com/uk/Electricity/Codes/gridcode/reviewpanelinfo/2009/>

- 2.2 CC.6.1.2 specifies that the frequency of the National Electricity Transmission System shall be controlled within the limits of 49.5-50.5Hz unless exceptional circumstances prevail.
- 2.3 CC.6.1.3 states system frequency could rise to 52Hz or fall to 47Hz in exceptional circumstances and that users plant must be capable of operating within the range as follows:
- | | |
|-----------------|-------------------------------|
| 47.5Hz – 52 Hz | Continuous operation |
| 47 Hz – 47.5 Hz | At least 20 seconds operation |
- 2.4 There are other frequency related Grid Code clauses (e.g. CC. 6.3.3, BC.3.7.1 and BC.3.7.2) which are mainly associated with power profile to frequency variations.
- 2.5 Since 1976/77 the frequency has fallen below 49.5 Hz on 43 occasions, with two below 49.0 Hz. For the same period, there was one incident with frequency rising above 50.5 Hz. Although most of these frequency excursion incidents appeared to be rare and short-lived, NGET has expressed concern in the past³ that future incidents could be more frequent and could take longer to recover because of the developments in plant operation including significant change of generation mix.
- 2.6 The international standard relevant to steam and gas turbine driven synchronous generating plant IEC 60034-3:2007 paragraph 4.6 recognises the differences between continuous operation at maximum output and frequencies where limited time operation is more appropriate unless output could be lowered for longer term operation. However, no details are given regarding relative time limits and loading levels. Some Transmission System Operators have derived their own requirements, for example see RTE specifications⁴ or Nordic Grid Code⁵.

Voltage

- 2.7 CC.6.1.4 states that at 400 kV the voltage limits are normally maintained within $\pm 5\%$ of nominal value unless abnormal conditions prevail. In addition the minimum and maximum voltages are $\pm 10\%$ unless abnormal conditions prevail, but voltages between $+5\%$ and $+10\%$ will not persist for more than 15 minutes, unless abnormal conditions prevail. At 275kV and 132kV, the voltage limits are normally maintained within $\pm 10\%$ of nominal value unless abnormal conditions prevail.
- 2.8 Since 1990 abnormal voltage outside $\pm 10\%$ has occurred seven times in England and Wales and such instances are limited in geographic scope.
- 2.9 Clause CC6.3.15.1 sets out the need for the plant to ride through defined voltage disturbances without tripping and Clause CC6.3.15.3 includes voltage limits beyond which plant should be disconnected from the system.

³ Energy Executive Emergency Committee Frequency Obligations for Small Generators Working Group (http://www.nationalgrid.com/uk/Electricity/Codes/gridcode/workinggroups/E3C_Small_Embedded+Generation+Frequency+Obligations_Working_Group/)

⁴ RTE Gestionnaire du reseau de transport d'electricite – Documentation technique de reference V2

⁵ Nordic Grid Code 2007 Part 4 Connection Code

3.0 SUMMARY OF WORKING GROUP DISCUSSIONS

3.1 The inaugural meeting was held on 29th January 2010 and the Working Group agreed and accepted the Terms of Reference. NGET introduced and discussed the scope of work which was subdivided into the following four key areas:

- Current Grid Code Obligations;
- System Performance;
- Generator Design Criteria; and
- Comparative European Obligations.

3.2 These categories will be used as a basis for the summary of all subsequent Working Group discussion below:

Current Grid Code Obligations – Frequency

3.3 The existing Grid Code obligations were discussed. A generator shall not disconnect owing to changes in system frequency in the range 47.5Hz to 52Hz, and for the period of 20 seconds in the range 47.0 to 47.5Hz (CC6.1.3).

3.4 To avoid excessive generation reduction during low frequency excursions, CC6.3.3 sets out the minimum MW output profile requirement for generating plant.

3.5 BC3.7.2 and BC3.7.1 describe the required plant behaviour during high frequency excursions when a plant is in Limited Frequency Sensitive Mode and Frequency Sensitive Mode respectively.

3.6 It was confirmed that if system frequency goes above 52Hz the plant is not obliged to remain connected. It was observed that the obligation on generators to remain connected up to 52Hz needs to be considered in the context of the obligations on generators to respond to high frequencies, in that generators would not be expected to operate at rated output as frequency approached 52Hz.

3.7 NGET confirmed that CC 6.3.12 allows for specific exceptions to be made to frequency obligations, although historically this clause had been used to manage plant risks retrospectively. Such a principle could be applied to future projects if a clear technical justification could be presented and any frequency control risks managed. The Working Group accepted that this principle could be applied in exceptional technically justifiable cases, but highlighted the need to justify any application of this principle as opposed to either pursuing a derogation or a change to the Grid Code.

Current Grid Code Obligations - Voltage

3.8 The Working Group discussed the voltage control performance expected at a connection site as described by CC6.1.4, including the concept of abnormal conditions. NGET confirmed that since 1990 there have been seven occurrences of an abnormal, local voltage outside statutory limits in England and Wales.

3.9 The advisory nature of the clause CC6.1.4 was discussed and how it related to the Generating Unit obligations in CC6.3. NGET confirmed that in order to permit

- generation flexibility, the voltage operating range is set at the transmission interface point, not at the generator's terminals.
- 3.10 The 400kV voltage obligations under CC6.1.4 were considered by some Working Group members to be potentially confusing and ambiguous as there is a +/- 5% normal range and a +/- 10% abnormal conditions range. The normal operating range for 132kV and 275kV connected generators is +/-10%. The Working Group initially concluded that such ranges are advisory of system performance, to aid technical design, and therefore this may be generally acceptable.
- 3.11 CC6.3.4 describes active and reactive power obligations under specific voltage ranges, by referring back CC6.1.4.
- 3.12 NGET System Operation procedures have only two references to timescales for voltage restoration. The first is applicable at 400kV, where if the voltage rises above +5%, up to a maximum of +10%, then they must be restored to below +5% within 15 minutes. The second reference states that at a Grid Supply Point, following a secured event, the voltage must be restored to within 95% of nominal within 20 minutes. These are specified in the Security and Quality of Supply Standards and NGET's internal procedures and not within the Grid Code. That withstanding, the 15 min restoration time is referred to within 6.1.4 where abnormal events are broadly analogous to non secured events.
- 3.13 The Group considered if clarity was needed as to whether a generator could trip in the event that voltage exceeded 'normal' conditions and if it was necessary for definitions for 'Normal' and 'Abnormal' conditions to be included in the Grid Code.
- 3.14 CC 6.3.15.3(iv) relates to requirements on Non-synchronous Generating units and Power Park Modules on the Scottish part of the system and are mainly to ensure that a plant will trip if frequency or voltage goes substantially outside a specified range.
- 3.15 The Working Group discussed a potential conflict in the Grid Code between the obligation to trip if the voltage drops below 80% for >2s, whereas the Fault Ride Through obligations CC.6.3.15 require a generator to stay connected for 2.5s. It was agreed that CC. 6.3.15.3 (iv) item (3) should be amended from "is below 80% for more than 2.0 secs" to "is below 80% for more than 2.5 secs".
- 3.16 Figure 5 of CC.6.3.15.1 contains a voltage/ duration chart illustrating the lower voltage limits during system fault conditions. It was suggested that as no upper voltage limits were shown, the requirements to remain connected under high voltage conditions are potentially unclear and open to interpretation. NGET suggested that this clause is focused on plant riding through voltage dips in the system and the upper limit is therefore irrelevant. However, NGET undertook to consider if clarity could be improved. Further discussion within the Working Group confirmed that the current text is sufficiently clear and no change is required.
- 3.17 Current Grid Code obligations require operation at simultaneous extremes of both frequency and voltage ranges whereas some European Transmission System Operators (see Annex 5) specify frequency obligations that are a function of both frequency and voltage. The Working Group considered whether simultaneous extremes were plausible. The group identified one specific issue

for consideration, which was related to over fluxing. In this case the dedicated protection would prevent damage. Control actions or the action of protection systems to maintain plant integrity, due to system concurrent voltage and frequency events, are not precluded by the Grid Code.

- 3.18 Working Group members asked for more clarity in this area. However, the Working Group was unable to derive the parameters required to determine a complete specification of concurrent frequency and voltage range requirements and to assess the risk of unnecessarily constraining plant design and procurement.

System Performance

- 3.19 Since 1976/7 there were 43 frequency excursions outside statutory limits, 2 below 49Hz and 1 high frequency event and their duration was short lived. A system split incident occurred on 5th August 1981, where the frequency of the import group dropped to 47.3Hz, recovered to 49Hz but remained at 48.5Hz for 20min. The export group had a frequency above 50.5Hz for 20 minutes.

- 3.20 NGET cited a number of specific factors that introduce uncertainty over future frequency control performance at this time, namely:

- An increase in the size of individual loss risks (by virtue of a larger unit size) which will increase the impact of multiple, unsecured, losses;
- Changes to system inertia which will occur where conventional synchronous plant is displaced by machines coupled to the networks by power electronics,
- The increasing volume of small embedded plant which is less visible and controllable than large transmission connected generation;
- Changes in demand patterns, driven either by price signals or active control (eg smart meters); and
- Despatch uncertainties of intermittent generation.

- 3.21 Clearly, as the above changes to the background conditions become manifest, NGET would be expected to implement appropriate changes to the relevant performance requirements to mitigate the effects on such things as frequency control performance within the criteria of secured events as defined in the NETS SQSS.

- 3.22 Some Working Group members stated that these suggested risks had not been examined quantitatively and it is reasonable to conclude that as long as sufficient reserve was held, and other measures adopted, there should be no increased risk of frequency excursion outside current limits. Members also highlighted the degree of uncertainty around future developments in generation and demand.

- 3.23 NGET confirmed that voltage excursions are only reported when voltage goes outside statutory limits; this has occurred seven times in the last 20 years. Records are not kept for events where voltages come close to, but do not exceed, statutory limits.

Generator Design Criteria

- 3.24 The relevant British Standard for steam and gas turbine driven synchronous generators (BS EN 60034-1:2004) contains two operating zones (see Annex 6);

- an inner zone, from 49Hz to 51Hz, where the machine can operate at rated output; and an outer zone, from 47.5Hz to 51.5Hz, where operation can occur but subject to restrictions (e.g. reduced output, limited duration, number of occurrences). NGET explained that whilst the Grid Code currently requires output to be maintained continuously within both zones, and beyond (up to 52Hz), the Grid Code does not specifically prohibit protection to operate if damage could occur such as via vibration, temperature or over fluxing. A Working Group member responded that the machine would still require to be specified to fulfil the full ranges and this leads to issues with procurement from the global market.
- 3.25 It was argued that the UK is no longer a significant enough player in the global market to influence generator design and therefore as off-the-shelf plant does not meet Grid Code obligations, a significant additional cost is added, which is hard to predict. In addition, it was identified that modern generation plant does not necessarily trip when operated outside the specified frequency and voltage range but additional maintenance and inspection may be required in order to keep within warranty. NGET confirmed that in exceptional circumstances CC6.3.12 allows such bilateral issues to be taken into account and develop alternative operating ranges.
- 3.26 Working Group generator representatives provided feedback from generator suppliers regarding the current frequency and voltage obligations. One representative stated that at a high level there were not any fundamental issues with procuring plant that could operate at the extremes of the frequency and voltage obligations, although alarms would be triggered and post event remedial actions would be required at the extremes of operation. In addition the manufacturers do not assume continuous operation and one would not guarantee continuous operation at maximum output outside the range of 49.0 - 51.0Hz.
- 3.27 Another Working Group member provided feedback from two gas turbine manufacturers. Manufacturer 'A' will generally operate continuously between 49.0 and 51.0Hz without triggering a requirement for additional maintenance. Operation outside this range will require additional maintenance and inspection and could lead to increased wear and tear and risk of failure. For Manufacturer 'B', continuous operation capability was indicated between 47.5Hz and 52.0Hz although operation between 51.5Hz and 52.0Hz accelerated 'use of life'. Operation between 47.0Hz and 47.5Hz also increases use of life and is limited to 20 sec per event and 30 minutes over the total plant lifetime.
- 3.28 The Group considered whether the addition of a time limit to the obligation to operate between 51.5Hz and 52.0Hz would match internationally available plant more closely. Whilst the Working Group thought this may be a more realistic expectation, NGET reiterated that the situation where generation arbitrarily trips for no practical reason is undesirable, i.e. before the capability of the generator is reached.
- 3.29 Three capability data sheets from various generators were considered and the Working Group concluded that it would be difficult to draft a unified requirement from the data and assess this against its impact on system security.
- 3.30 A generator representative fed back that one steam turbine manufacturer who was consulted informally did not report any issues with meeting frequency range

obligations and has recently constructed a new generator for use within Great Britain. That withstanding, another manufacturer stated that they are not willing to supply the GB market because their equipment has not been designed to meet current Grid Code requirements. The manufacture is supplying the European market.

- 3.31 A further steam turbine manufacturer commented that it would not offer its preferred design with the largest blades due to concerns with the lowest part of the frequency range namely 47.0Hz – 47.5Hz. The Working Group deduced that this inferred that continuous operation between 47.5 - 52.0Hz appears to be possible.

Comparative European Obligations

- 3.32 A diagram comparing the frequency operating range across some chosen European TSOs was discussed⁶, where all systems had unique ranges and time limits and Great Britain appeared to have more stringent requirements than other TSO Codes.
- 3.33 It was noted that European TSOs were currently discussing frequency and voltage related requirements as part of the ENTSO-E European Grid Code development programme, and that the GB Grid Code would ultimately need to work within any finalised requirements.

Other issues

- 3.34 At the February 2010 GCRP meeting the Panel requested the Working Group to consider whether rate of change of system frequency, and potential associated Grid Code obligations, should be added to the Working Group Terms of Reference. The Working Group concluded that this work did not fit comfortably within the current scope of the Working Group. Additionally, the Working Group did not believe it had sufficient membership representing for instance DNOs and/or protection experts to consider the area sufficiently. It was reported that another Working Group working in parallel, on the Future of Frequency Response, were anticipating making the recommendation for a further, specific Working Group to be established to consider the issue of the rate of change of frequency. The Frequency and Voltage Operating Range Working Group considered this to be an efficient way forward.
- 3.35 The Group considered the SQSS Review Group developments. The SQSS Working Group considered whether the frequency and voltage operating ranges should be increased but had provisionally concluded that no significant benefit would be delivered by changing from the current levels.

Option Analysis

- 3.36 The Working Group assessed potential proposals under three headings against the Grid Code Relevant Objectives:
- Clarify voltage requirements
 - Time limited frequency range – several subset criteria
 - No code changes

⁶ As shown in Appendix 5

- 3.37 **Clarify voltage requirements:** It was agreed that the voltage requirements would benefit from clarification and alternative text suggested. The Working Group discussed what exactly should be changed.
- 3.38 It was clear to the group that the clauses 6.1.3 and 6.1.4 had evolved through a number of previous changes and now contained a mix of advice on system performance and direct obligations. It was noted that the two clauses now apply to different classes of party.
- 3.39 The Working Group agreed to the addition of a table to clarify the system voltage ranges. It was also noted, that although this would be clearer, there is a risk that the forthcoming NETS SQSS review will alter this area of the code.
- 3.40 In conclusion, the group agreed to include a table in CC 6.1.4 summarizing the normal operating range at different grid voltage levels.
- 3.41 **Time limited frequency range:** The Working Group considered introducing time limits to operation at various frequency bands. Such a relaxation should facilitate procurement from the global market although there is a risk that this could lead to unnecessary protection operation in the event that automatic protection is set to meet these limits. The NGET initial proposed bands were:
- 47.0Hz to 47.5Hz – 20 seconds
 - 47.5Hz to 48.5Hz – 90 minutes
 - 48.5Hz to 51.0 Hz – Continuous
 - 51.0Hz to 51.5Hz – 90 minutes
 - 51.5Hz to 52.0Hz – 90 seconds
- 3.42 These proposed bands were compared to the IEC ranges. Under the IEC guidance the machine could run continuously in the frequency range 49.0Hz to 51.0Hz though not necessarily at full export. NGET reminded the Group that in practice the system is not operated continuously outside the statutory limits. Generator representatives responded that if it were, plant may require additional maintenance and be subject to increased risk of failure and therefore it does not seem correct to continue with the current frequency obligations given that they are not realistic.
- 3.43 Working Group members again highlighted that there had only been a single event in thirty years which had got close to the proposed time ranges. The Working Group agreed there is insufficient experience of current generating plant operating under abnormal frequency conditions to be certain of the impact. There is a degree of evidence that some modern generating plant may not fully comply with all the current voltage and frequency obligations as these are untested and largely un-testable.
- 3.44 The Group debated whether the continuous band should start at 48.5Hz or 49.0Hz.
- 3.45 Some Working Group members argued that by using the band of 49Hz-51Hz, to set a continuous operating requirement, this would be consistent with both the IEC and with the capabilities declared by plant manufacturers, and therefore may be beneficial for the procurement of generation plant. Below 49Hz, the plant

- would not trip instantly, but would be required to have a minimum capability of 90 minutes which should be adequate to safeguard system security and enable the frequency to be restored to within the 49Hz to 51Hz continuous band. NGET argued that a continuous operation limit starting at 48.5Hz was appropriate to avoid the risk of interaction with the first stage of the demand disconnection scheme (set at 48.8Hz).
- 3.46 The Working Group discussed whether there was a genuine interaction between Low Frequency Demand Disconnection (LFDD), which is intended to operate instantaneously once a frequency threshold is reached, and a duration limited frequency range requirement based on many minutes. The group examined a number of scenarios which could result in extended operation at the frequency level around the first stage of LFDD (48.8Hz) but did not reach a consensus on the probability of this occurring. This debate is key to the Working Group's proposal as its outcome would determine whether 48.5Hz or a higher value is the appropriate setting for the start of the 'continuous' frequency band.
- 3.47 The 90 minute system restoration time was proposed during the recent work of the E3C Small Generators Frequency Obligation Working Group. It had been derived from the maximum estimated time that NGET would take to react to extreme system events. Expressed in general terms, this breaks down to 30 minutes to establish conditions and develop a plan, 30 min to implement plus a 30 min safety margin to cover additional inherent complexity and uncertainty. NGET did not believe this duration could be reduced without introducing significant risk of being unable to ensure system restoration. The Working Group agreed that the proposed 90 minute limit is appropriate.
- 3.48 For the range of 51.5 Hz to 52 Hz, National Grid proposed to change the original 90 sec to 15 minutes because any system split condition could cause the export group generators to accelerate beyond 51.5 Hz and it may take the governor longer than 90 secs to bring frequency under control below 51.5 Hz. This temporary speed overshoot could trip all these generators in 90 seconds resulting in an unnecessary risk. To minimise this risk, the Working Group agreed to put forward the 15 minutes proposal for this frequency range.
- 3.49 **No Code Changes:** The Working Group concluded that such a recommendation would be valid only if all the other options were discounted, which was not the case.

4.0 RECOMMENDATIONS OF THE WORKING GROUP

Working Group recommendations:

- 4.1 Amend CC 6.1.4 to include a summary table showing normal operating range for each voltage level.
- 4.2 To maintain the current concepts of voltage requirement specifications, with the exception of changes to CC6.3.15.3 (iv) to align the under-voltage tripping time to that of the fault ride through profile.
- 4.3 The Working Group agreed that there would be benefits from the definition of a minimum capability profile (ie voltage versus frequency possibly including additional limiting boundaries such as over fluxing limits) for all plant. However,

- given the wide ranging plant characteristics and protection criteria, careful consideration is required to specify a boundary which caters for all plant design without compromising system security. The Working Group was not able to specify Grid Code criteria for a combined frequency and voltage range requirement and ensure there were no adverse implications on current well established industry practices on plant protection in these areas.
- 4.4 The Working Group also acknowledges that there is European wide code development in this area and it will be useful to keep track on this changes and review if this could be adopted in the Grid Code in the future.
- 4.5 Regarding frequency operating range, the Working Group agreed on all the proposed elements of change with the exception of the lower limit on the continuous operating range. NGET recommend that this should be set at the lower frequency of 48.5 Hz while some Working Group members believe 49 Hz is more appropriate.
- 4.6 Working Group discussions concluded that a change in the frequency operating range requirements could deliver benefits in transmission user plant procurement. All group members agreed that system security would not be adversely affected by introducing duration limited requirements as specified below as Frequency Option 1:
- 4.7 Frequency Option 1 - Amend CC.6.1.3 to introduce time limited operation as below:
- | | |
|--------------------|-------------------------------|
| ▪ 51.5 Hz – 52 Hz | At least 15 mins operation |
| ▪ 51 Hz – 51.5 Hz | At least 90 mins |
| ▪ 48.5Hz – 51 Hz | Continuous operation |
| ▪ 47.5 Hz – 48.5Hz | At least 90 mins |
| ▪ 47 Hz – 47.5 Hz | At least 20 seconds operation |
- 4.8 Some working group members concluded that further benefits could be delivered by aligning the lower limit on the continuous operation band with the threshold specified with the IEC standards at 49.0Hz, and that system security would not be adversely impacted by such a proposal. This proposal is shown as Frequency Option 2:
- 4.9 Frequency Option 2 - Amend CC.6.1.3 to introduce time limited operation as below:
- | | |
|--------------------|-------------------------------|
| ▪ 51.5 Hz – 52 Hz | At least 15 mins operation |
| ▪ 51 Hz – 51.5 Hz | At least 90 mins |
| ▪ 49.0Hz – 51 Hz | Continuous operation |
| ▪ 47.5 Hz – 49.0Hz | At least 90 mins |
| ▪ 47 Hz – 47.5 Hz | At least 20 seconds operation |
- 4.10 NGET representatives did not conclude that system security would not be adversely impacted by this proposal as the risk of interaction with the first stage of Low Frequency Demand Disconnection had not been assessed. Frequency Option 1 and Frequency Option 2 are mutually exclusive therefore the Working Group Chair recommends Frequency Option 1.

5.0 IMPACT ON GRID CODE

- 5.1 Amend the following clause of the Connection Conditions: CC.6.1.3 and CC.6.1.4 and CC.6.3.15.3 (iv)
- 5.2 The associated legal text for the Working Group recommendations is outlined in Annex 2.

6.0 IMPACT ON INDUSTRY DOCUMENTS

Impact on Core Industry Documents

- 6.1 The proposed changes to the frequency and voltage obligations must be replicated within the SO-TO Code so as to be implemented in the Scottish Transmission Owner areas.

Impact on other Industry Documents

- 6.2 No Impact envisaged.

7.0 IMPACT ON NATIONAL ELECTRICITY TRANSMISSION SYSTEM

- 7.1 No impact is envisaged on the National Electricity Transmission System (NETS) from the Working Group's proposal. Specifically, the security and integrity of the operation of the NETS will not be detrimentally affected.

8.0 IMPACT ON GRID CODE USERS

- 8.1 The proposed changes to the Grid Code frequency and voltage operating range obligations ensure that the capabilities required from transmission connected generation can continue to be widely available from the global generator supplier market, whilst maintaining the existing high levels of system security. In addition, the proposals provide clarity to the obligations.

9.0 ASSESSMENT AGAINST GRID CODE OBJECTIVES

- 9.1 The proposed changes outlined in the Working Group would better facilitate Grid Code Objectives:

- (i) to permit the development, maintenance and operation of an efficient, co-ordinated and economical system for the transmission of electricity;
- (ii) to facilitate competition in the generation and supply of electricity;
- (iii) to promote the security and efficiency of the electricity generation, transmission and distribution systems in Great Britain as a whole.

- 9.2 The amendment of the frequency and voltage operating ranges to better meet the standard capabilities of globally available generation plant, whilst avoiding any detrimental affect on to the security of the transmission system, avoids over investment in future generation equipment and avoids introducing a barrier to market entry and therefore better meet Grid Code objectives (i), (ii) and (iii).

ANNEX 1 – WORKING GROUP TERMS OF REFERENCE

Review of Grid Code Connection Conditions for Frequency and Voltage Operating Range

Final Terms of Reference

Objective

At the GCRP meeting of 21 May 2009 it was agreed that a review of the GC requirements for Grid frequency and voltage variations should be undertaken as this can have a significant bearing on design of User's Plant and Apparatus. These draft terms of reference accompany the associated GCRP Paper pp09/40 presented to the November 2009 GC Review Panel.

The objective of the group is to discuss the issues and proposals under 'Scope of Work' and agree a way forward for possible modification to the Grid Code Connection Conditions on Grid frequency and voltage variations.

Membership

The membership of the working group will be drawn from the GCRP or their nominated representatives, the CUSC or their nominated representatives, the Relevant Transmission Licensees and Ofgem.

Scope of Work

The group will consider the following, as agreed by the GCRP:

- Establish the historic frequency and voltage performance of the transmission system, specifically in relation to operation at abnormal voltages and frequencies. Consider how future generation and demand changes may affect transmission system performance in these areas.
- Establish the relevant generation design criteria and standards, and the impacts of operation at abnormal voltages and frequencies on generating units.
- Consider whether the current Grid Code frequency and voltage requirements are appropriate, taking account of system security requirements, the capabilities of generating units, and the industry costs and benefits of implementing them.
- If required, draft proposals to revise the Grid Code requirements to ensure they are appropriate.

Deliverables

The working group will produce:

- a report to the GCRP recommending a way forward on the above issues, reflective of the group discussions
- draft legal text of any proposed Grid Code changes
- identify any consequential changes to other related documentation, codes or standards.

Timescales

The working group will aim to update the May 2010 GCRP meeting on its progress.

ANNEX 2 – PROPOSED GRID CODE CHANGES

CC.6.1.3 The **System Frequency** could rise to 52Hz or fall to 47Hz in exceptional circumstances. Design of **User's Plant** and **Apparatus** must enable operation of that **Plant** and **Apparatus** within that range in accordance with the following:-

<u>Frequency Range</u>	<u>Requirement</u>
<u>51.5Hz - 52Hz</u>	<u>Operation for a period of at least 15 minutes is required each time the Frequency is above 51.5Hz.</u>
<u>51Hz - 51.5Hz</u>	<u>Operation for a period of at least 90 minutes is required each time the Frequency is above 51Hz.</u>
<u>47.5Hz - 51.2Hz</u>	Continuous operation is required
<u>47.5Hz – 48.5Hz</u>	<u>Operation for a period of at least 90 minutes is required each time the Frequency is below 48.5Hz.</u>
47Hz - 47.5Hz	Operation for a period of at least 20 seconds is required each time the Frequency is below 47.5Hz.

For the avoidance of doubt, disconnection, by frequency or speed based relays is not permitted within the frequency range 47.5Hz to 51.5Hz, unless agreed with NGET in accordance with CC.6.3.12.

Grid Voltage Variations

CC.6.1.4 Subject as provided below, the voltage on the 400kV part of the **GB Transmission System** at each **Connection Site** with a **User** will normally remain within $\pm 5\%$ of the nominal value unless abnormal conditions prevail. The minimum voltage is -10% and the maximum voltage is +10% unless abnormal conditions prevail, but voltages between +5% and +10% will not last longer than 15 minutes unless abnormal conditions prevail. Voltages on the 275kV and 132kV parts of the **GB Transmission System** at each **Connection Site** with a **User** will normally remain within the limits $\pm 10\%$ of the nominal value unless abnormal conditions prevail. At nominal **System** voltages below 132kV the voltage of the **GB Transmission System** at each **Connection Site** with a **User** will normally remain within the limits $\pm 6\%$ of the nominal value unless abnormal conditions prevail. Under fault conditions, voltage may collapse transiently to zero at the point of fault until the fault is cleared. The normal operating ranges of the GB Transmission System are summarised below:

<u>GB Transmission System Nominal Voltage</u>	<u>Normal Operating Range</u>
<u>400kV</u>	<u>400kV $\pm 5\%$</u>
<u>275kV</u>	<u>275kV $\pm 10\%$</u>
<u>132kV</u>	<u>132kV $\pm 10\%$</u>

NGET and a **User** may agree greater or lesser variations in voltage to those set out above in relation to a particular **Connection Site**, and insofar as a greater or lesser variation is agreed, the relevant figure set out above shall, in relation

to that **User** at the particular **Connection Site**, be replaced by the figure agreed.

CC.6.3.15 Fault Ride Through

- (a) Short circuit faults at **Supergrid Voltage** up to 140ms in duration...

- (b) **Supergrid Voltage** dips greater than 140ms in duration

In addition to the requirements of CC.6.3.15 (a) each **Generating Unit** or **Power Park Module** and / or any constituent **Power Park Unit**, each with a **Completion Date** on or after the 1 April 2005 shall:

- (i) remain transiently stable and connected to the **System** without tripping of any **Generating Unit** or **Power Park Module** and / or any constituent **Power Park Unit**, for balanced **Supergrid Voltage** dips and associated durations anywhere on or above the heavy black line shown in Figure 5. Appendix 4 and Figures CC.A.4.3 (a), (b) and (c) provide an explanation and illustrations of Figure 5; and,
- (ii) ...
- (iii) ...
- (iv) To avoid unwanted island operation, **Non-Synchronous Generating Units** in Scotland or **Power Park Modules** in Scotland shall be tripped for the following conditions:-
 - (1) Frequency above 52Hz for more than 2 seconds
 - (2) Frequency below 47Hz for more than 2 seconds
 - (3) Voltage as measured at the **Connection Point** or **User System Entry Point** below 80% for more than 2.5 seconds
 - (4) Voltage as measured at the **Connection Point** or **User System Entry Point** above 120% (115% for 275kV) for more than 1 second.

The times in sections (1) and (2) are maximum trip times. Shorter times may be used to protect the **Non-Synchronous Generating Units** or **Power Park Modules**.

ANNEX 3 – GCRP PAPER

pp09/40
Nov 2009

**Review of Grid Code Connection Conditions
for Frequency and Voltage Operating Ranges**

Paper by NGET

Introduction

It has been noted that existing GB Grid Code requirements for frequency operating ranges that synchronous generating units must remain connected continuously to the transmission system appear more stringent than those required internationally. This is against a background where statistically large frequency perturbations have rarely occurred on the GB transmission system and have been transitory in nature.

Similarly voltage range is specified in combination with frequency capability with specific limited time operation at more extremes.

At the GCRP meeting of 21 May 2009 it was agreed (minute 1228) that a review of the GC requirements should be added to the Outstanding Issues list of the GCRP for subsequent review. This paper proposes to initiate such a review via a GC Working Group to ensure timely consideration based on the amount of new synchronous generating plant expected to be connected in the next ten years.

Performance of Transmission

Frequency

CC.6.1.2 specifies that the frequency range of the National Electricity Transmission System shall be controlled within the limits of 49.5-50.5Hz unless exceptional circumstances prevail.

CC.6.1.3 states system frequency could rise to 52Hz or fall to 47Hz in exceptional circumstances and that users plant must be capable of operating within the range as follows:-

47.5Hz – 52 Hz	Continuous operation
47 Hz – 47.5 Hz	At least 20 seconds operation

Since 1990 the frequency has fallen below 49.5 Hz on 12 occasions and fallen below 49.0 Hz once in this period and not risen above 50.5 Hz since a system split in 1981^{2,3}. On all these occasions frequency was quickly restored to within the normal limits and hence only existed transiently.

The international standard⁴ relevant to synchronous generating plant IEC 60034-3:2007 paragraph 4.6 recognises the differences between continuous operation at maximum output and frequencies where time limited operation is more appropriate. Individual transmission system operators may use the IEC standard as a basis for defining the time

periods for operation in exceptional circumstances, for example see RTE specifications⁵ or Nordic Grid Code⁶.

Voltage

CC.6.1.4 states that at 400 kV the voltage limits are normally maintained within $\pm 5\%$ of nominal value unless abnormal conditions prevail. In addition the minimum and maximum voltages are $\pm 10\%$ unless abnormal conditions prevail, but voltages beyond $+5\%$ and $+10\%$ will not persist for more than 15 minutes unless abnormal conditions prevail.

Since 1990 abnormal voltage outside $\pm 10\%$ has occurred six times in England and Wales and such instances are limited in geographic scope.

Recommendation

It is recommended that a GC Working Group is convened based on the draft terms of reference and based on this commence a review of the frequency and voltage range defined in the Grid Code.

Impact on Other Documents

There is a potential interaction with the BSSG working group on frequency response, the Relevant Electrical Standards and SQSS.

References

1. The Grid Code Issue 4
2. Review of Studies Assessing frequency and Duration of Loss of Off-Site Power at Nuclear Power Stations NGC/MASD/19.2.4/028/A:May 2001
3. A Review of the Performance of Connections to Nuclear Power Stations owned by BE and NDA, Annual Report 2009, NG/AM/ENI/15.68/117/P
4. IEC 60034-3 Requirements for synchronous generators driven by steam turbines or combustion gas turbines
5. Nordic Grid Code 2007 Part 4 Connection Code
6. RTE Gestionnaire du reseau de transport d'electricite – Documentation technique de reference V2
7. UCTE Requirements
8. European Utility Requirements for LWR nuclear power plants.

ANNEX 4 – INAUGURAL WORKING GROUP PRESENTATION MATERIAL

Frequency & Voltage Operating Range GCRP Working Group - Meeting No 1

William Hung, System Technical Performance, 29 January 2010



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Discussion Topics

- Relevant Existing Grid Code Obligations
- Historic System Frequency Performance
- Future Uncertainties on Frequency Performance
- Relevant Guidance from IEC Documents and Practices from other European Countries
- Generating Plant Frequency Operating Range Constrains
- Next Steps

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Relevant Existing Grid Code Obligations (1)

- CC.6.1.3

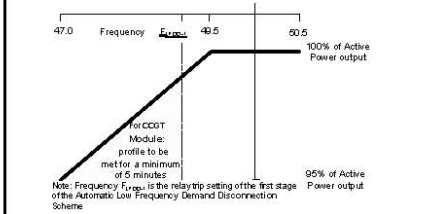
The **System Frequency** could rise to 52Hz or fall to 47Hz in exceptional circumstances. Design of **User's Plant and Apparatus** must enable operation of that **Plant and Apparatus** within that range in accordance with the following:-

Frequency Range	Requirement
47.5Hz - 52Hz	Continuous operation is required
47Hz - 47.5Hz	Operation for a period of at least 20 seconds is required each time the Frequency is below 47.5Hz.

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Relevant Existing Grid Code Obligations (2)

- CC.6.3.3



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Relevant Existing Grid Code Obligations (3)

- BC.37.2

Plant in Limited Frequency Sensitive Mode

(b) (i) The rate of change of Active Power output must be at a minimum rate of 2 per cent of output per 0.1 Hz deviation of System Frequency above 50.4 Hz

- BC.37.1

Plant in Frequency Sensitive Mode Instructed to provide High Frequency Response

(c) In addition to the High Frequency Response provided... must continue to reduce Active Power output in response to an increase in System Frequency above 50.5 Hz at a minimum rate of 2 per cent of output per 0.1 Hz deviation above that level

- The above implies that the plant output is required to be reduce under high frequency conditions at a rate of not less than 2 per cent of output per 0.1 Hz deviation

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Grid Voltage Variations set out in the Grid Code

- **Grid Voltage Variations**

CC.6.1.4 ... the voltage on the 400kV part of the **GB Transmission System** at each **Connection Site** with a **User** will normally remain within $\pm 5\%$ of the nominal value unless abnormal conditions prevail. The minimum voltage is -10% and the maximum voltage is $+10\%$ unless abnormal conditions prevail, but voltages between $+5\%$ and $+10\%$ will not last longer than 15 minutes unless abnormal conditions prevail. Voltages on the 275kV and 132kV parts of the **GB Transmission System** at each **Connection Site** with a **User** will normally remain within the limits $\pm 10\%$ of the nominal value unless abnormal conditions prevail.


- Since 1990 abnormal voltage outside $\pm 10\%$ has occurred six times in England and Wales and such instances are limited in geographic scope

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Recent Summary of Frequency outside Statutory Limits (since 1995)


Date of incident	Generation loss (MW)	Minimum freq (Hz)	Time below 49.5 Hz (minutes)
27/05/08	1993	48.795	9
26/05/03	1260	49.416	<1
19/02/96	1000	49.038	3
13/12/95	1480	49.48	<1
17/11/95	1485	49.184	3
25/09/95	1400	49.4	<1
26/04/95	2000	49.457	<1


Last time frequency went outside 50.5 was in 1972





Summary of Frequency outside Statutory Limits - taken from historic System Technical and Operational Characteristics

System Frequency Range (Hz)	Last 5 yrs (to 1996/7)	Last 10 yrs (to 1996/7)	Last 20 yrs (to 1996/7)
47.0-49.0	0	0	1
49.0-49.5	9	18	40
50.5-52.0	0	0	1
>52.0	0	0	0



- ### Historic Frequency Excursions Appeared to be Rare and Short-lived
- ◆ More low frequency excursion than high (since 1996/7)
 - ◆ 43 Low frequency incidents with 2 below 49 Hz
 - ◆ 1 high frequency incident
 - ◆ The frequency of large excursion appeared to be rare and duration short lived
 - ◆ The system split incident on 5/8/1981 indicated possibility of extreme frequency with extended duration
 - ◆ Import group -down to 47.3 recover to 49 Hz but sustained at 48.5 Hz for 20 minutes
 - ◆ Export group -up to 50.7 Hz but sustained above 50.5 Hz for 20 minutes
- 

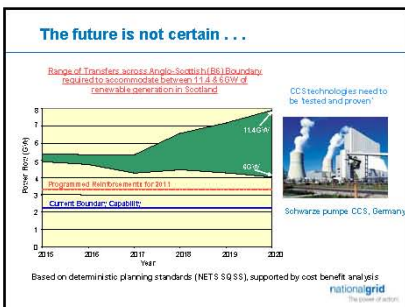
Potential Future Developments / Challenges





OUR ELECTRICITY TRANSMISSION NETWORK: A VISION FOR 2020

A Report by the Electricity Networks Strategy Group
March 2009

★ Significant Proportion of Onshore Wind Quasiing in Constrained Area of the Network ★



- ### But, Future Frequency Incidents could be More Frequent ...
- ◆ The number of large excursions could increase **because of**
 - ◆ increased generation loss risk
 - ◆ increased risk of tripping of large and new technology plant during commissioning and early stage of operation
 - ◆ the system inertia will change significantly both year on year and within the year depending on the plant mix running (restriction of inertia energy from wind farms during frequency fall period)
 - ◆ uncertainties of frequency response provisions from generation and demand.
- 

And, could take Longer to Recover

- The duration of incident could be extended **because of**
 - increased volume of embedded generation which are not visible to and controlled by System Operators (eg unpredictable generation level and time of re-connection as in the Nov 2006 UCTE system split incident)
 - significant increase of wind farm generation (30GW by 2020 and 40GW by 2030) and their intermittency nature including high wind shut down characteristics could make the system much more difficult to manage for its recovery
 - significant increase of dynamic demand and active demand side management could add further uncertainties on system recovery
- System restoration considerations
 - increased uncertainties during system restoration after a blackout

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BS EN 60034-1:2004 Rotating electrical machines – Part 1 : Rating and performance

Key:
 1: 2000 A
 2: zone B (outside zone A)
 3: rating point

Note: turbo-generators rated at or above 10 MVA are covered by part 3 of the standard

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BS EN 60034-3:2005 Rotating electrical machines – Part 3: Specific requirements for cylindrical rotor synchronous machines

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Overview of operating frequency limits imposed by Grid Codes

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Generating Plant Frequency Operating Range Constrains

- Plant Type and applications
 - Conventional turbine cylindrical rotor synchronous generating plant
 - Conventional turbine salient-pole rotor synchronous generating plant
 - Nuclear plant
 - Gas turbine based plant
 - Asynchronous plant (eg induction generators)
 - Partial converter fed plant
 - Full converter fed plant
 - Hydropump storage plant
 - Diesel plant
 - Combined Heat and Power
 - Etc
- Other Considerations?

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Next Steps?

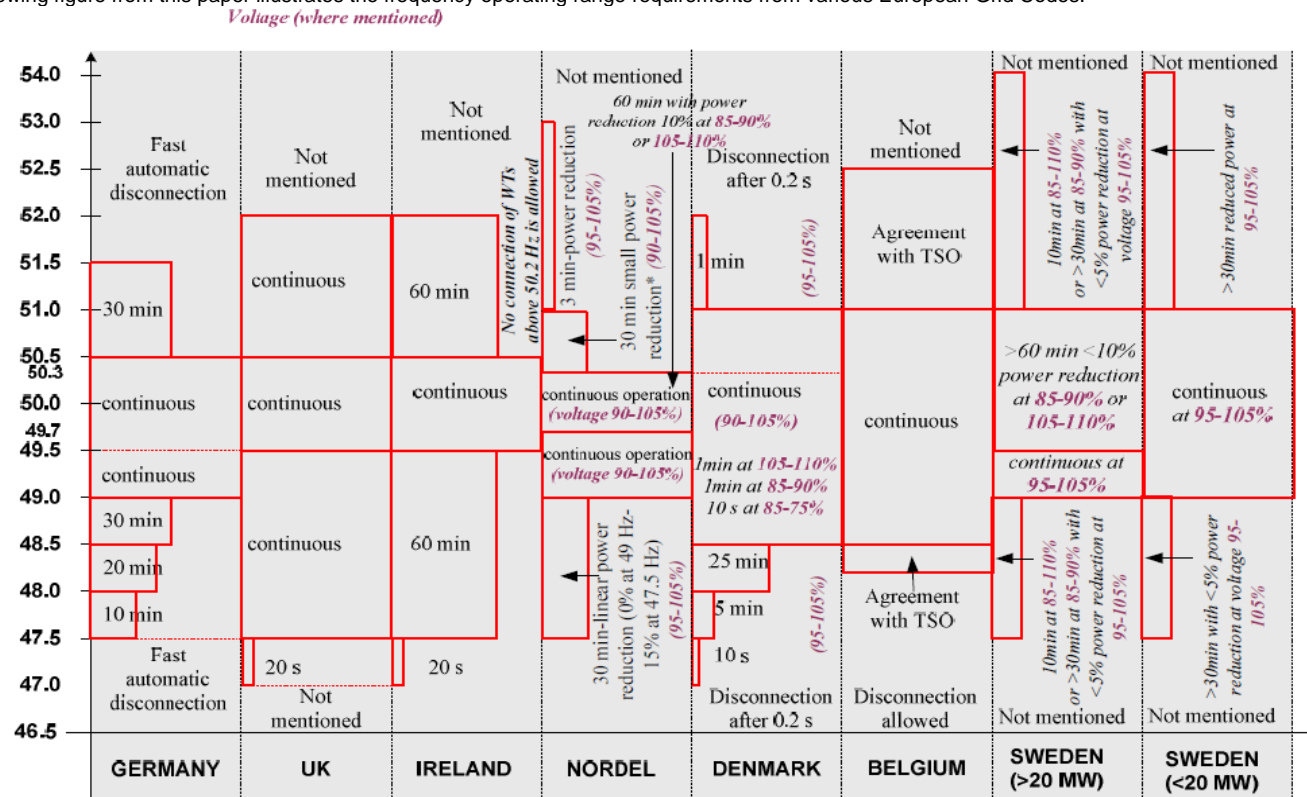
- Summarise views on
 - frequency implications
 - voltage implications
 - Combined effect
- Seek justification for the change
- Identify change options
- Assess if the associated risk can be managed

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ANNEX 5 – EUROPEAN TRANSMISSION SYSTEM OPERATOR FREQUENCY AND VOLTAGE OPERATING RANGE COMPARISON

A comparison of the requirements in various Grid Codes was presented in the following paper at EWEC 2008: *Grid Code Requirements for Large Wind Farms: A Review of Technical Regulations and Available Wind Turbine Technologies* by M. Tsili, Ch. Patsiouras, S. Papathanassiou, School of Electrical & Computer Engineering, National Technical University of Athens (NTUA)
(<http://www.ewec2008proceedings.info/index2.php?page=info2&id=133&id2=144&ordre=2&tr=&searchin=&what=&searchtext=&day=&top=&fil1=&fil2=&fil2&ord1=&sess=103#top>)

The following figure from this paper illustrates the frequency operating range requirements from various European Grid Codes.



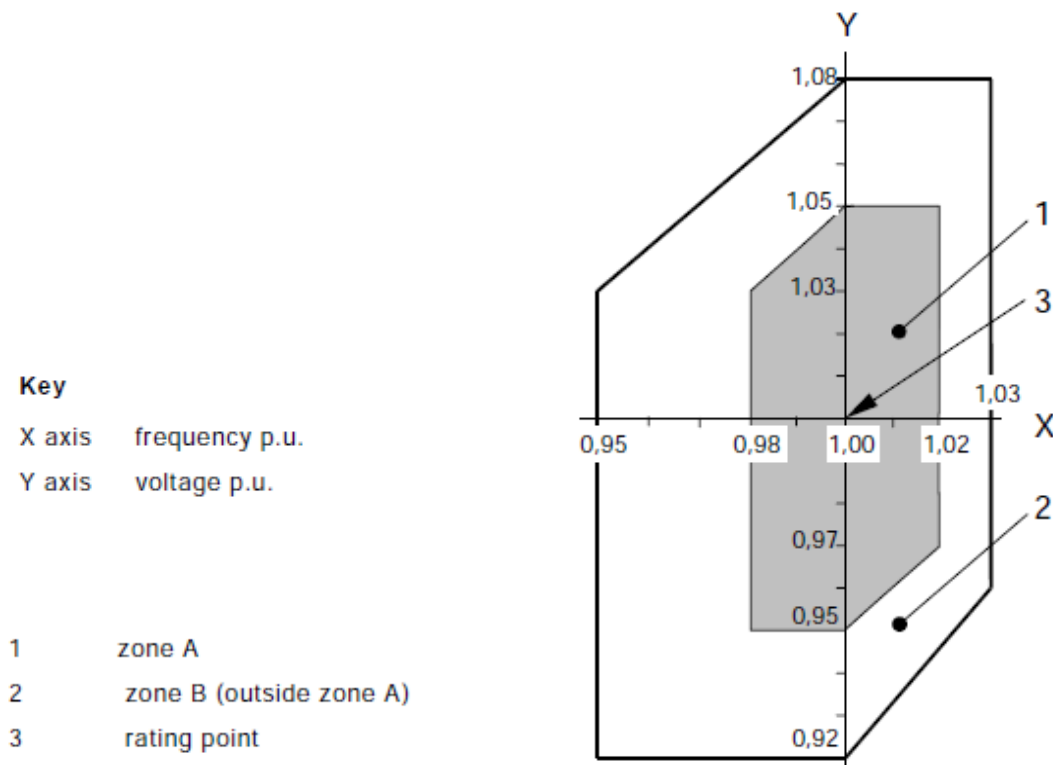
* the total duration of these operating conditions must not exceed 10 hours/year

ANNEX 6 – Relevant British Standards

BS EN 60034-1:2004 Rotating electrical machines – Part 1: Rating and performance

Covers rotating electrical machines less than 10 MVA

Capability outside zone A (whether at rated or reduced output) is not quantified and should be regarded as infrequent and short-term.



BS EN 60034-1:2008 Rotating electrical machines – Part 3: Specific requirements for synchronous generators driven by steam turbines or combustion gas turbines

