nationalgrid

Stage 02: Industry Consultation

Grid Code

01	Workgroup Report
02	Industry Consultation
03	Report to the Authority

GC0028 – Constant Terminal Voltage

This consultation seeks views on proposals to modify the Grid Code. The modifications are intended to provide clarity on the requirements related to the method by which the Reactive Power Output of a Synchronous Generating Unit is controlled. They also offer Generators the flexibility to supplement transformer tap control with terminal voltage adjustment when they respond to a MVAr instruction or a Target Voltage Level instruction.

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 12 of this document.

Published on: **13 July 2015**
Length of Consultation: **20 Working Days**
Responses by: **10 August 2015**

National Grid recommends:
Implementation of the changes proposed to the Grid Code.

High Impact:
None

Medium Impact:
Operators of Onshore Synchronous Generating Units
Transmission Licensees

Low Impact:
None

Contents

Any Questions?

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About this document

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

Parties are requested to respond by **10 August 2015** to grid.code@nationalgrid.com

Document Control

Version	Date	Author	Change Reference
1.0	10/07/2015	Bieshoy Awad, National Grid	Final – for consultation

1 Executive Summary

1.1 It is proposed to modify the Grid Code in order to clarify the requirements related to the provision of reactive power from Synchronous Generating Units; and to allow Generators the ability to supplement transformer tap changer control with machine terminal voltage adjustment when responding to a MVAr instruction. This change gives Generators some flexibility when specifying their Generating Unit Transformers; allows them to move spare transformers between different sites; and allows them to avoid the need to use transformers with excessive, potentially unrealistic, number of taps. While doing so, the proposed change retains the reactive power capability available to NGET, and has no negative implications on the Transmission System.

1.2 Synchronous Generating Units, when supplying Rated MW, are required to be able to operate continuously at any power factor between 0.95 power factor leading and 0.85 power factor lagging at the Generating Unit terminals in accordance with CC.6.3.2 of the Grid Code. They are required to be able to provide their full reactive capability within the voltage range of ±5% at 400kV, 275kV and 132kV and lower voltages in accordance with CC.6.3.4 of the Grid Code.

1.3 CC.6.3.8(a)(i), of the Grid Code requires Synchronous Generating Units to be equipped with a continuously acting automatic excitation control system to provide constant terminal voltage control of the Generating Unit without instability over the entire operating range.

1.4 BC2.A.2.6 of the Grid Code specifies that when instructed to provide a defined MVAr output from a Synchronous Generating Unit, the Generator shall achieve the MVAr level instructed, within a specific tolerance – typically ±25MVAr, although other tolerances may apply in Scotland or may be agreed on a site-specific basis – by means of tap changing.

1.5 A number of Generators have requested clarification of the requirements. They also questioned whether it is necessary to always operate at 1.0pu terminal voltage given that the Grid Code does not specify the target voltage at which a Synchronous Generating Unit is required to operate, and whether the terminal voltage may be adjusted when responding to a MVAr instruction.

1.6 It was also noted that a number of derogations are either pending or in force in relation to this issue.

1.7 In response, the Grid Code Review Panel convened a Workgroup to investigate these issues and report its findings.

1.8 The Workgroup reported its findings back to the Grid Code Review Panel in May 2015. The Grid Code Review Panel approved the findings and recommended it for consultation.

Options

1.9 To address these concerns, the Workgroup identified three options which it believed would address the issues identified in the Terms of Reference (see Annex 2).

1.10 Option 1 – Under this option, the Generating Unit terminal voltage would be controlled to its rated value (ie 1.0p.u). This would require the generator transformer to be fitted with an On Load Tap Changer (OLTC) with a sufficient number of taps to ensure the Generating Unit can deliver its full reactive capability with system voltage changes of between ±5% at 400kV, 275kV and 132kV and lower voltages whilst at the same time controlling the Generating Unit terminal voltage to 1.0p.u of rated terminal voltage. It would also necessitate that the tap step is small enough to allow the reactive output of the generator to be controlled to the tolerances detailed in BC2.A.2.6.

1.11 Option 2 – This comprises of two variants – Option 2A and Options 2B.

1.12 Option 2A – Under this option the generator transformer would have a smaller tap range that allows the Generating Unit to deliver the major part of its reactive capability for a system voltage range of ±5% at 400kV, 275kV and 132kV and lower voltages whilst at the same time controlling the generator terminal voltage to 1.0p.u of its rated value. At the extreme tap positions, any deficit in reactive capability would be made up by adjusting the Generating Unit terminal voltage. The tap step should still be small enough to meet the tolerance requirements on the MVAr output of the Generating Unit as detailed in BC2.A.2.6.

1.13 Option 2B – This is an extension of Option 2A with the terminal voltage adjustment allowed at any tap position rather that at the upper end only. This enables the size of the tap step to be increased with the target MVAr output then being achieved through adjusting the Generating Unit Terminal Voltage.

1.14 Option 3 – Under this option, the Generating Unit Terminal Voltage would be controlled to its Rated Terminal Voltage (ie 1.0p.u) and the ±5% voltage range specified in CC.6.3.4 would be relaxed. This option was quickly and unanimously discounted on the basis that it would result in a significant loss of reactive capability range available to the System Operator, especially given that there has been a trend of increasing difficulty in managing system voltage.

Review of Options

1.15 The workgroup discussed each of these options in detail. In each case, detailed study work was also completed. It was also acknowledged that the potential issues would become compounded by the increase in the value of the infrequent infeed loss risk, defined within the Licence Standards, to allow the connection of individual Generating Units with ratings of up to 1800MW (2100MVA).

1.16 System Studies identified that for an 1800MW Generating Unit connected to an infinite system, over 100 transformer taps would be required to achieve the Grid Code requirements specified in CC.6.3.2 (reactive capability), CC.6.3.4 (reactive capability at HV voltage changes), CC.6.3.8 (excitation and voltage control performance requirements) and BC2.A.2.6 (±25MVAr tolerance) if Option 1 was adopted. This results in two issues, i) the ability and cost associated with manufacturing a Generator Transformer of this size and ii) the time taken to operate each tap would typically be in the region of 30 seconds to 1 minute so it could take 50 to 100 minutes to respond to a MVAr instruction requiring a change from the maximum tap to the minimum tap.

1.17 Option 2 (both options 2A and 2B) would enable a small degree of Generator Terminal Voltage Control which would typically be between 1.0p.u and 1.03p.u but it would be proposed that the Generator would have the flexibility to control the terminal voltage above 1.0p.u with the upper limit being determined by the Generator. Based on system studies, National Grid would be reluctant to support changes to Generator terminal voltage below 1.0p.u due to the implications this would have on transient stability.

1.18 With Option 2A, Generating Units of a large MW Rating, e.g. 1800MW, connected to a strong system may have difficulties finding a transformer with a tap step that is small enough to provide the MVAr dispatch accuracy required (±25MVAr). With Option 2B the tap step needs to be restricted to prevent voltage step changes in excess of the Grid Code limit of CC.6.1.7. i.e. The largest voltage step change allowed on the 400kV system as a result of a single tap action is 4kV. When necessary, better voltage accuracy, e.g. 1kV steps, is achieved by adjusting the Generating Unit terminal voltage. It is assumed that NGET in its role as System Operator would continue to despatch Synchronous Generators to a target MVAr value with the MVAr output being achieved by the Generator through a combination of the Generator Transformer tap and a change to the Generating Unit Terminal voltage. Further work is still required in relation to offline study models but this is considered as the preferred option. Assessment has also been undertaken that this proposed requirement is consistent with the European Network Code Requirements for Generators as currently drafted.

1.19 The observations noted on all the options are summarised in Table 1.

1.20 The workgroup recommends that Option 2B should be adopted going forward as it provides Generators with flexibility to choose how to respond to MVAr instructions, allows them to use the inherent capability of a Synchronous Generating Unit to avoid the use of complex, and potentially unrealistic, OLTC; allows Generators to move spare transformers between different sites; maintains the reactive power capability available to NGET; and have no negative impacts on the Transmission System.

1.21 The Grid Code Review Panel approved the report submitted by the Workgroup and recommended it to be issued for an industry consultation.

Table 1: Summary of observations on the options considered

		Option 1	Option 2A	Option 2B	Option 3
Terminal voltage	At highest tap position	1.0pu	>=1.0pu	>=1.0pu	1.0pu
	At other tap positions	1.0pu	1.0pu	>=1.0pu	1.0pu
Reactive capability available to NGET[1]		Maintained	Maintained	Maintained	Reduced
Stability margins[1]		Maintained	Improved at terminal voltage > 1.0pu	Improved at terminal voltage > 1.0pu	Maintained
Post fault MVAr response		Maintained	Improved at terminal voltage > 1.0pu	Improved at terminal voltage > 1.0pu	Maintained
Tap range[1]		No change	Less than Option 1	Same as Option 2A	Less than Options 2A and 2B
Tap resolution[1]		No change	No change	Could be increased	No change
Tap resolution required for large units		Very Small, potentially unrealistic	Very small, potentially unrealistic	Achievable	Very small, potentially unrealistic
Number of taps required[1]		No change	Marginal reduction	Significant reduction	Marginal reduction
Number of taps required for large units		Very high, potentially unrealistic	Less than Option 1 but potentially very high	Achievable	Less than Option 1 but potentially very high
Ability to relocate spare transformers from site to site without causing compliance issues		Restricted	Potential restrictions	No restrictions	Restricted
Change to Bilateral Agreements		Not required	Yes[2]	Yes[2]	Not required
Additional Operational Metering requirements		Not required	Yes[2]	Yes[2]	Not required
Submission of additional data		Not required	Required	Required	Not required
Changes required to modelling tools and load flow algorithms		None	Some changes may be necessary	Some changes may be necessary	None

[1] Compared to the existing arrangement

[2] Only for Generators willing to vary the terminal voltage of their Synchronous Generating Units

2 Purpose & Scope of Workgroup

Overview

2.1 An issue was raised at the Grid Code Review Panel on 03 July 2013 in relation to CC.6.3.4 and the methodology used for MVAr control of Synchronous Generating Units connected to the National Electricity Transmission System. A copy of this GCRP Issue paper is included in Annex 1 for reference.

2.2 The Grid Code Review Panel recommended the formation of a Constant Terminal Voltage Control workgroup. The Terms of Reference for this workgroup is included in Annex 2 for reference.

2.3 The Workgroup was tasked to consider the following points

2.3.1 National Grid's proposal for clarification of CC.6.3.4, CC.6.3.8(a)(i) and the associated costs and benefits of implementing such a proposal;

2.3.2 Alternative proposals to provide for supplementing the synchronous generator tap changer range with Generating Unit Terminal voltage adjustments, and the associated costs and benefits of implementing such a proposal; and

2.3.3 The relevant provisions of the ENTSO-E Requirements for Generators Code to ensure that the workgroup's proposals do not conflict with future requirements;

2.4 The Workgroup also considered

2.4.1 the relevant operational requirements defined in BC2.A.2.6 of the Balancing Code and the interactions with the design requirements defined in CC.6.3.2 of the Connection Conditions;

2.4.2 data provision requirements specified in OC2.4.2 of Operating Code 2, PC.A.5.3.2 of the Planning Code;

2.4.3 Schedule 1 of the Data Registration Code; and

2.4.4 Compliance process and testing requirements defined in CP.A.3.3 of the Compliance Processes and the introduction of a new clause under OC5.A.2.7.5 of Operating Code 5.

Timescales

2.5 The workgroup was scheduled to report progress back to the Grid Code Review Panel at the January 2015 meeting.

2.6 Six workgroup meetings have been held to date.

2.7 A verbal update on progress was provided at the January 2015 Grid Code Review Panel meeting. The workgroup submitted a draft report to the Grid Code Review Panel in May 2015.

Workgroup Meeting Dates

M1 - 29 January 2014
M2 - 04 April 2014
M3 - 20 June 2014
M4 - 19 September 2014
M5 - 10 December 2014
M6 - 17 April 2015

3 Reactive Power Provision from Synchronous Generating Units

Overview of Existing Grid Code Requirements

3.1 The specifications of the Generating Unit Transformer and the Automatic Voltage Regulator for a Synchronous Generating Unit need to take into account the Grid Code Requirements on reactive range, excitation control system performance, voltage step changes, and accuracy of reactive power dispatch.

3.2 The requirements on reactive range for Onshore Synchronous Generating Units are defined in CC.6.3.2 (a). When supplying Rated MW, all Onshore Synchronous Generating Units must be capable of continuous operation at any point between the limits 0.85 Power Factor lagging and 0.95 Power Factor leading at the Onshore Synchronous Generating Unit terminals.

3.3 For Onshore Synchronous Generating Units, the reactive range specified in CC.6.3.2 (a) should be fully available over the voltage range of ±5% at the Grid Entry Point or, if Embedded, at the User System Entry Point. This is specified in CC.6.3.4 (a).

3.4 The combination of CC.6.3.2 (a) and CC.6.3.4 (a) can be visualised as a rectangular range where the Onshore Synchronous Generating Unit is required to operate. This operating requirement is shown in Figure 1.

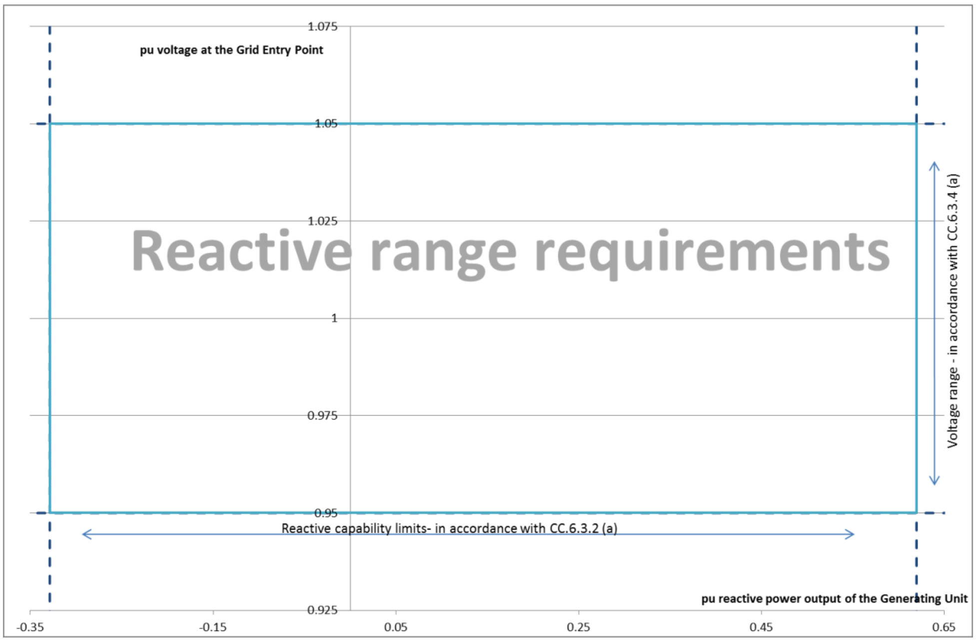

Figure 1: Reactive range requirements for Onshore Synchronous Generating Units as defined by CC.6.3.4(a) and CC.6.3.2(a)

3.5 All Onshore Synchronous Generating Units are required to have a continuously acting automatic excitation control system that provides constant terminal voltage control of the Onshore Synchronous Generating Unit over the entire operating range, in accordance with CC.6.3.8 (a).

3.6 BC2.5.4 (c) (i) specifies that the excitation control system must operate in constant terminal voltage control mode with other control modes, e.g. constant reactive power control or constant power factor control, disabled unless instructed otherwise by NGET.

3.7 BC2.5.4 (c) (i) also specifies that, in the event of any change in System voltage, a Generator must not take any action to override automatic MVAr response which is produced as a result of constant terminal voltage mode of operation of the automatic excitation control system unless instructed otherwise by NGET, immediate action is necessary to comply with stability limits, constrained by plant operational limits, or there are some safety concerns (relating to personnel or plant). This is to ensure that the automatic response of the excitation control system to a system

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disturbance, and consequently the MVAr output of the Generating Unit will assist the recovery of the system.

3.8 BC2.A.2.6 specifies that, when an Onshore Synchronous Generating Unit is connected to the Transmission System in England and Wales and is instructed to a specific MVAr output, the Generator must achieve this MVAr output within a tolerance of ±25MVAr by tap changing, unless otherwise agreed. In Scotland, this figure is the lesser of 25MVAr and 5% of the rated output. However, BC2.A.2.6, allows Generators to agree a different tolerance with NGET.

Existing Methodology for MVAr Provision

3.9 When an Onshore Synchronous Generating Unit is instructed to a specific MVAr output, the Generator manually changes the tap setting of the Generating Unit Transformer. The change of the MVAr output of the Onshore Synchronous Generating Unit will result from the response of the Automatic Excitation Control System to the transformer tap change.

3.10 The immediate effect of an increase in the tap setting of a Generating Unit Transformer, prior to any response from the Automatic Excitation Control System, is a reduction of the machine terminal voltage below 1.0pu. This, in itself, will have a limited effect on the MVAr output of the machine.

3.11 The AVR will respond to this reduction in terminal voltage by increasing the Excitation Voltage to restore the terminal voltage to 1.0pu. This will increase the MVAr output of the machine.

3.12 To illustrate this combined action, the dynamic response to a tap increase followed by a tap decrease was simulated for an 1800MW unit connected to an infinite system via a step up transformer. The results are shown in Figure 2 and Figure 3.

3.13 If there were no AVR in service, tap changes significantly affect the terminal voltage with no significant effect on the MVAr output of the machine. With an AVR, the change in terminal voltage is counteracted by a change in the excitation system voltage which changes the MVAr output of the machine.

3.14 The Generator needs to ensure that the Generating Unit Transformer is equipped with an On Load Tap Changer that allows provision of the full reactive capability over the entire range specified in CC.6.3.2(a) and CC.6.3.4(a) to the accuracy specified within BC2.A.2.6 while maintaining a constant, ideally 1.0pu, terminal voltage.

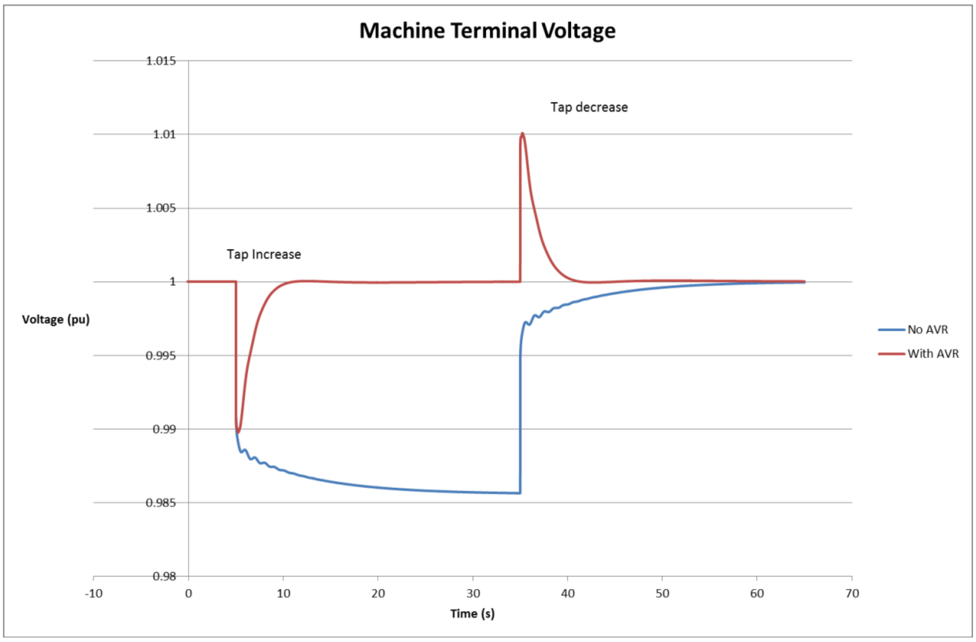

Figure 2: change in terminal voltage of a single synchronous machine connected to an infinite system via a step up transformer following a change of the transformer tap setting.

3.15 Between MVAr instructions, the Generator is required not to change the tap position. During this period, the machine will only change its MVAr output in response to a change in the voltage at the Grid Entry Point.

3.16 Figure 4 shows the reactive power output/voltage characteristics for an 1800MW machine connected to a system via a 2100MVA transformer with 13% reactance. Each characteristic corresponds to a specific tap setting. The OLTC has a 1.25% voltage/tap step.

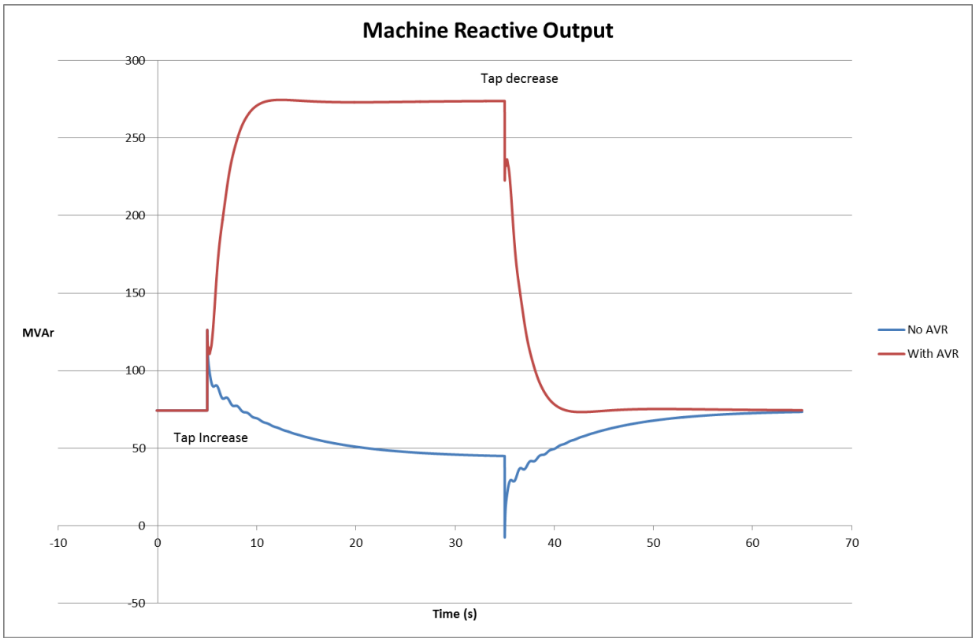

Figure 3 :Change in the MVAr output of a single synchronous machine connected to an infinite system via a step up transformer following a change of the transformer tap setting.

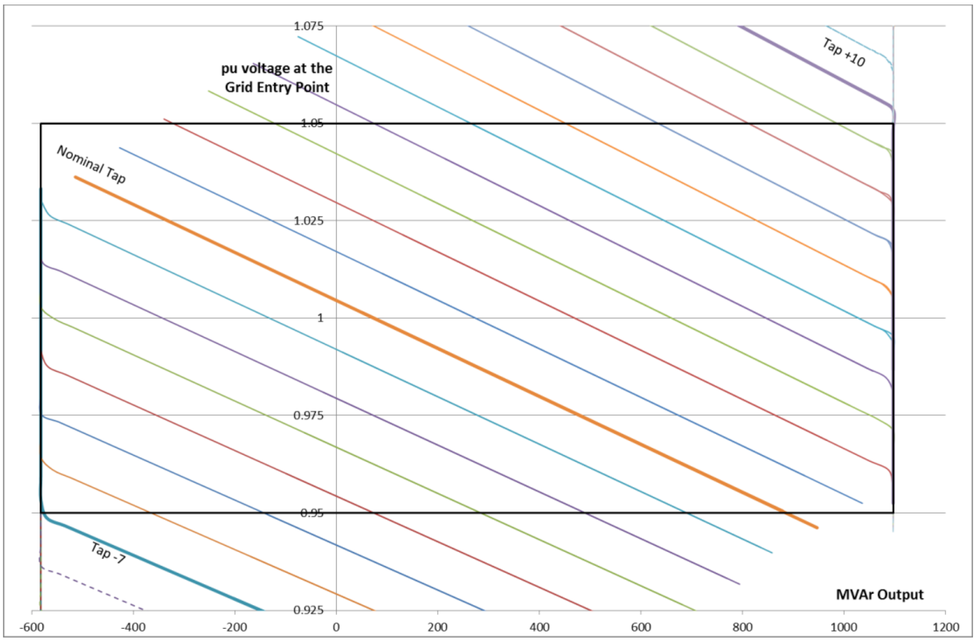

Figure 4 : Reactive power output/Voltage Characteristics for an 1800MW machine

Potential Changes to the Methodology for MVAr Provision

3.17 Another way to change the MVAr output of the machine is to alter the target terminal voltage setting while keeping the tap setting unaltered. The AVR will respond by changing the excitation system voltage to achieve the new target terminal voltage. This will change the MVAr output of the machine.

3.18 Figure 5 and Figure 6 demonstrate the response for a 0.01pu step change in the target terminal voltage setting[3] on the actual terminal voltage and the MVAr output of the machine.

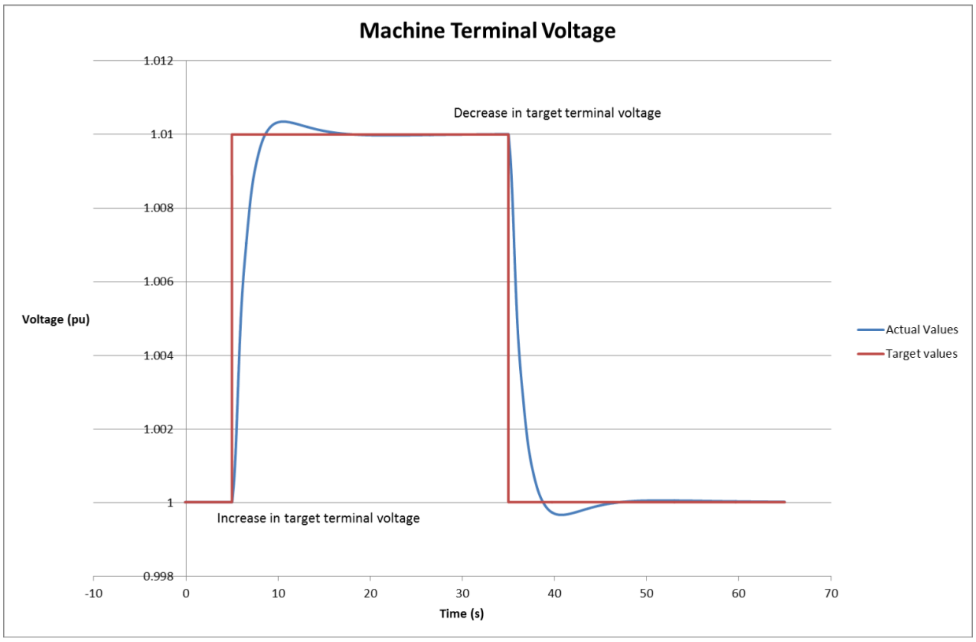

Figure 5: change in terminal voltage of a single synchronous machine connected to an infinite system via a step up transformer following a step change of the target terminal voltage.

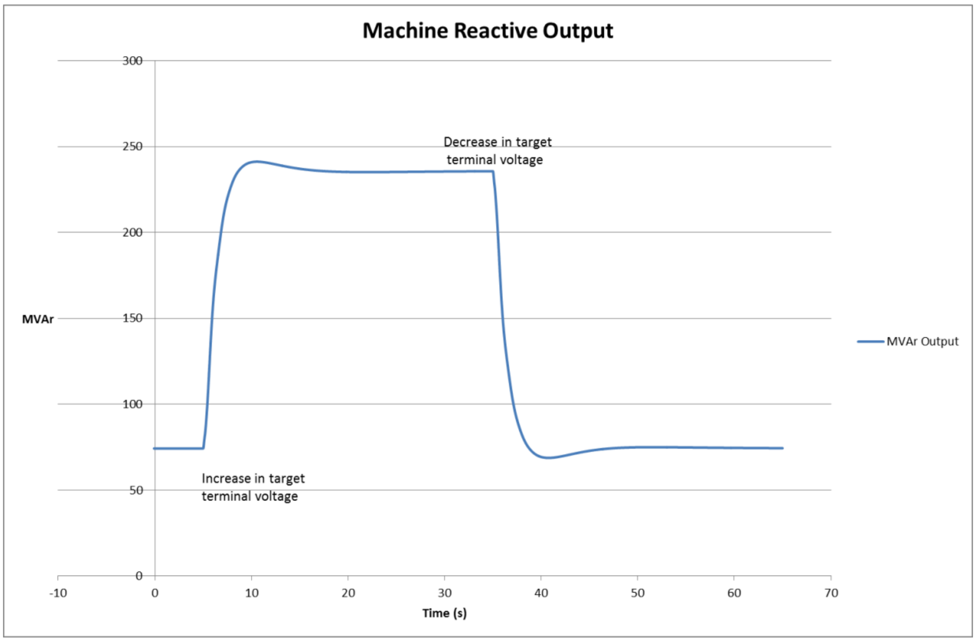

Figure 6: change in the MVAr output of a single synchronous machine connected to an infinite system via a step up transformer following a step change of the target terminal voltage.

3.19 If the full reactive range is to be made available by changing the target terminal voltage at nominal tap position, the range of terminal voltage change required would be around ±11%.

3.20 Typically, large synchronous generating units are designed to operate with the machine terminal voltage within ±5% of the rated terminal voltage. In practice, the target terminal voltage needs to be maintained within a range of ±3% of the rated value to minimise the impact on station auxiliaries. This range would not be sufficient

[3] In practice, adjustment of the target terminal voltage settings is expected to take the form of a gradual rather than a step change.

to allow the Synchronous Generating Unit to deliver the full MVAr capability at any point within the voltage range required. Hence terminal voltage control needs to be combined with tap control.

3.21 In order to assess the viability of any potential solution, three operational scenarios were defined and listed below in 3.23. The implications of operating under these scenarios were examined.

Operational Implications of Changing the MVAr Control Methodology

3.22 All examples and case studies in this section assume an 1800MW machine connected to the system at 400kV through a 2100MVA transformer with a 13% reactance. All the calculations are based on the machine delivering its rated MW output.

3.23 For the machine under consideration, there are three potential ways of reaching any operating point on any of the characteristics shown in Figure 4. That is

3.23.1 The base case with 1.0pu terminal voltage at the appropriate tap setting;

3.23.2 a tap setting higher than that in 3.23.1 with a terminal voltage below 1.0pu; or

3.23.3 a tap setting lower than that in 3.23.1 with a terminal voltage above 1.0pu.

Post fault MVAr response

3.24 In order to assess the difference between the post fault MVAr response in the base case, defined in 3.23.1, and the two other operational variations described in 3.23.2 and 3.23.3, the steps listed below and illustrated in Figure 7 were used.

3.24.1 With the machine terminal voltage controlled to 1.0pu, an operating point, Point 1, where the machine is not providing the full MVAr output is chosen. The off-nominal turns ratio required to produce this MVAr output is then determined. This is the base case.

3.24.2 Point 2 is then determined by reducing the off-nominal turns ratio to a lower value while maintaining 1.0pu terminal voltage.

3.24.3 The terminal voltage is then adjusted to achieve the same MVAr output equal to that of Point 1. This new operating point is Point 3.

3.24.4 The change in MVAr output following a disturbance in system voltage was then calculated for all the three operational points, Point 1, Point 2, and Point 3. The disturbance applied is a change in the voltage at the Grid Entry Point.

3.25 The steps described in 3.24 were applied in two Case Studies.

3.26 In Case Study 1.1, the machine is delivering lagging MVAr output. The results are shown in Table 2. In this table Q_g is the MVAr output of the machine, Q_o is the MVAr output delivered to the system, V_g is the target terminal voltage in pu, V_s is the pu voltage at the Grid Entry Point, and a is the off-nominal turns ratio.

3.27 The results in Table 2 suggest that, following a 5% reduction in voltage at the Grid Entry Point:-

3.27.1 Operating at a lower tap position improves the response of both Q_g and Q_o.

3.27.2 Operating at a higher terminal voltage improves the response of Q_g. However it has a negative impact on the response of Q_o.

3.27.3 Operating at a higher terminal voltage and lower tap position improves the response of Q_g and Q_o.

Table 2: Post fault MVAr response for Case Study 1.1 – Lagging MVAr output

	Pre fault V_s=1.05pu		Post fault Vs=1.0pu		Change	
	Q_g MVAr	Q_o MVAr	Q_g MVAr	Q_o MVAr	ΔQ_g MVAr	ΔQ_o MVAr
Point 1 a=1:1.066 V_g=1.0pu	341.21	140.07	1103.9	834.5	762.69	694.43
Point 2 a=1:1.046 V_g=1.0pu	35.117	-158.9	812.17	577.39	777.05	736.29
Point 3 a=1:1.046 V_g= 1.0188pu	341.21	147.41	1132.7	869.29	791.49	721.88

3.28 For Case Study 1.2, the machine is delivering leading MVAr output. The results are shown in Table 3.

Table 3: Post fault MVAr response for Case Study 1.2 – Leading MVAr output

	Pre fault V_s=0.95pu		Post fault Vs=0.973pu		Change	
	Q_g MVAr	Q_o MVAr	Q_g MVAr	Q_o MVAr	ΔQ_g MVAr	ΔQ_o MVAr
Point 1 a=1:0.934 Vg=1.0	-181.11	-377.08	-581.18	-796.03	-400.1	-419
Point 2 a=1:0.962 Vg=1.0	300	100.49	-88.554	-282.98	-388.6	-383.5
Point 3 a=1:0.962 Vg= 0.969	-181.11	-389.62	-557.95	-784.8	-376.8	-395.2

3.29 The results in Table 3 suggest that, following a 5% increase in the voltage at the Grid Entry Point:-

3.29.1 Operating at a higher tap position has a negative impact on the response of both Q_g and Q_o.

3.29.2 Operating at a lower terminal voltage has a negative impact on the response of Q_g. However it improves the response of Q_o.

3.29.3 Operating at a lower terminal voltage and higher tap position has a negative impact on the response of Q_g and Q_o.

3.30 A graphical illustration of Case Study 1.1 and Case Study 1.2 is shown in Figure 7. In this figure,

3.30.1 The middle two graphs show the MVAr values (Q_g and Q_o) as a function of the tap position with machine terminal voltage being controlled to 1.0pu. This is for values of V_s of 0.95pu, 1.0pu, and 1.05pu.

3.30.2 The two graphs on the right hand side show the MVAr values as a function of the machine terminal voltage with an off-nominal turns ratio of 1:1.046.

3.30.3 The two graphs on the left hand side show the MVAr values as a function of the machine terminal voltage with an off-nominal turns ratio of 1:0.962.

3.30.4 The vertical arrows point from the pre-fault operating point towards the post-fault operating point.

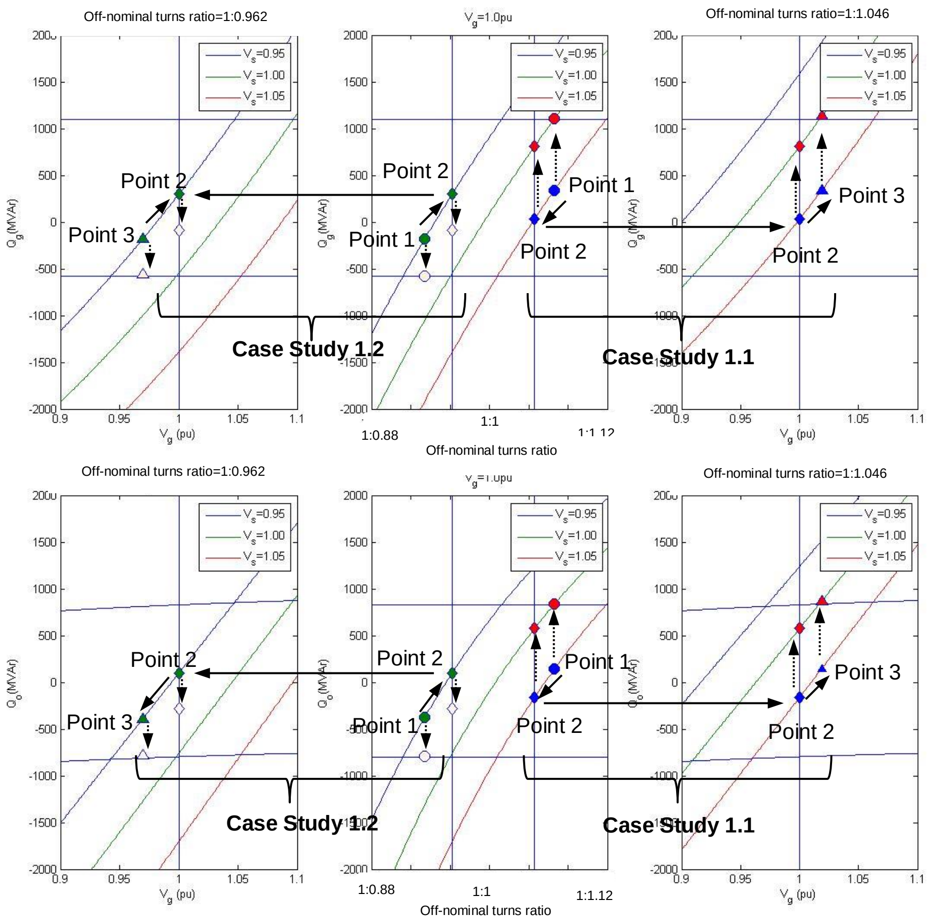

Figure 7: Post fault MVAr response at different operationg points for Case Study 1 and Case Study 2

3.31 To support the analysis, the MVAr responses for a 0.05pu reduction in the system voltage were plotted in Figure 8 as a function of the machine terminal voltage V_g for an off-nominal turns ratio of 1:1.066 and an off-nominal turns ratio of 1:1.046. The plots are in agreement with results in Table 2 and the conclusions in 3.27 and 3.29.

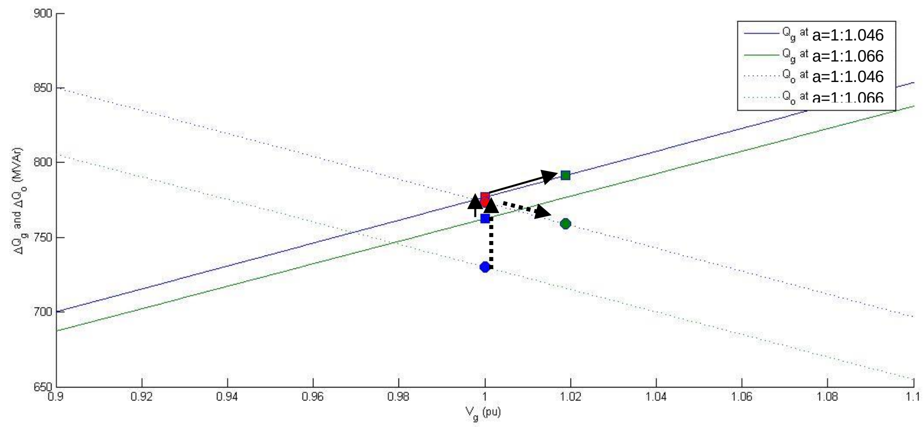

Figure 8: Variation of the machine MVAr response to a 0.05pu step change in voltage as a function of the machine terminal voltage

3.32 In conclusion, there is some benefit in operating at a terminal voltage that is higher than 1.0pu. On the other hand, operating at a terminal voltage that is less than 1.0pu is less desirable.

Implications on transient stability

3.33 In order to assess the implications on transient stability of the machine, the machine was assumed to be equipped with a typical AVR system but no Power System, Stabiliser (PSS). The short circuit level at the Grid Entry Point was assumed to be 40kA. The disturbance applied is a solid three phase short circuit fault at the HV side of the Generating Unit transformer. Following fault clearance, the system was assumed to return to its original state.

3.34 This difference was assessed at the two most extreme points of the reactive range.

3.35 In Case Study 2.1, the machine was set to inject its maximum MVAr with a 1.05pu voltage at the Grid Entry Point. A fault clearing time of 295ms was used. This is equal to the critical clearing time with the machine operating at 1.0pu.

3.36 The response was simulated for a) the machine terminal voltage controlled to 1.0pu and transformer set to the highest tap setting; and b) the machine terminal voltage controlled to 1.03pu and transformer set to a mid-range tap setting.

3.37 The simulation results are shown in Figure 9, Figure 10, and Figure 11.

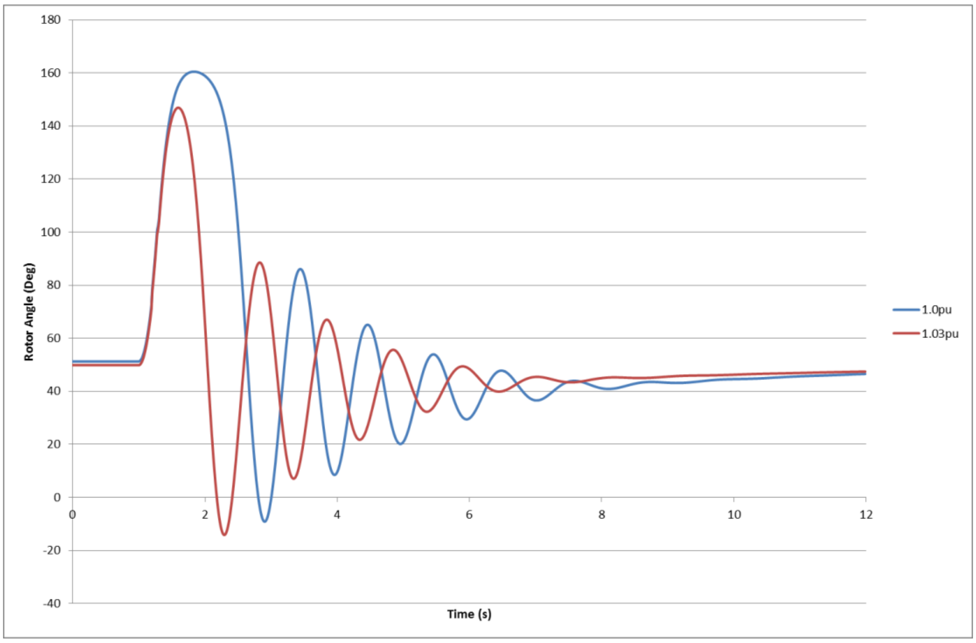

Figure 9: Transient response for Case Study 2.1 - machine rotor angle.

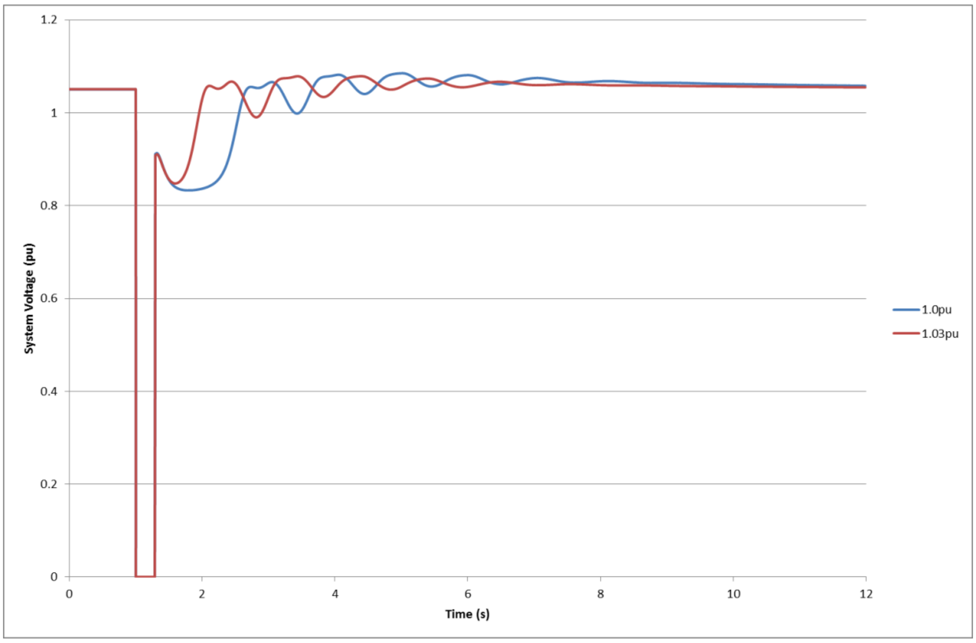

Figure 10 : Transient response for Case Study 2.1 – system voltage.

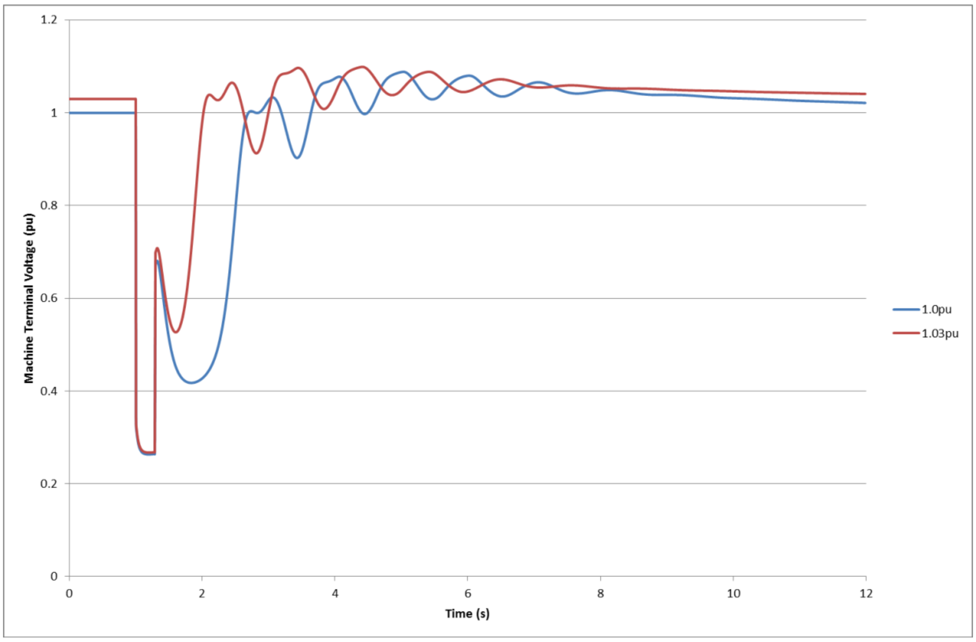

Figure 11: Transient response for Case Study 2.1 - machine terminal voltage

3.38 The simulation results indicate that the post fault transient response improves if the target terminal voltage of the synchronous machine is increased and the tap setting of the transformer is lowered.

3.39 In Case Study 2.2, the machine was set to absorb maximum MVAr with a 0.95pu voltage at the Grid Entry Point. A fault clearing time of 165ms was used. This is equal to the critical clearing time for the machine operating at a terminal voltage of 0.97pu.

3.40 The response was simulated for the two cases of a) machine terminal voltage controlled to 1.0pu and transformer set to the lowest tap setting; and b) machine terminal voltage controlled to 0.97pu and transformer set to a mid-range tap setting;

3.41 The simulation results are shown in Figure 12, Figure 13, and Figure 14.

3.42 The simulation results indicate that the post fault transient response deteriorates if the target terminal voltage of the synchronous machine is decreased and the tap setting of the transformer is increased.

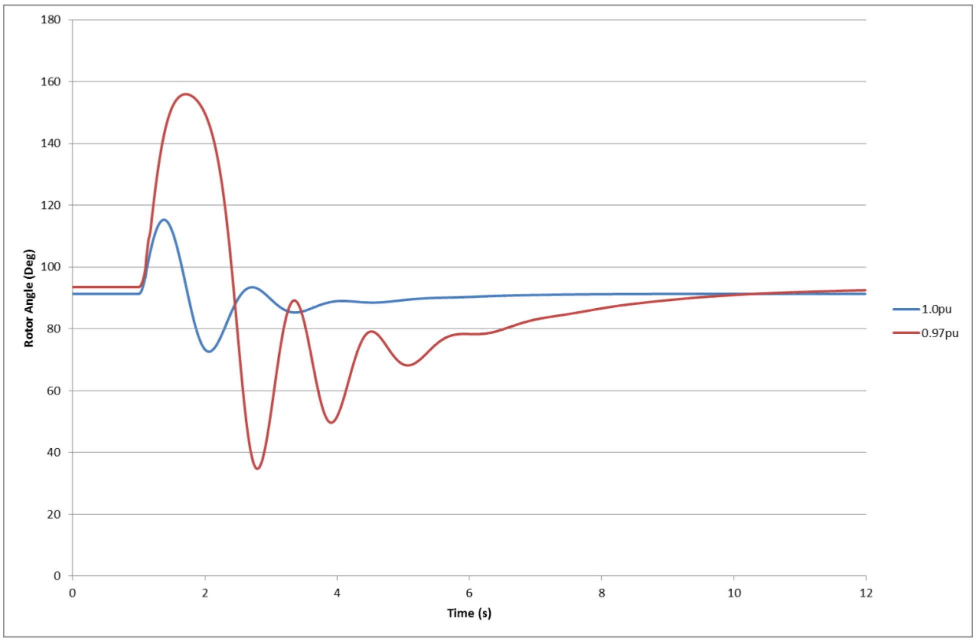

Figure 12: Transient response for Case Study 2.2 - machine rotor angle.

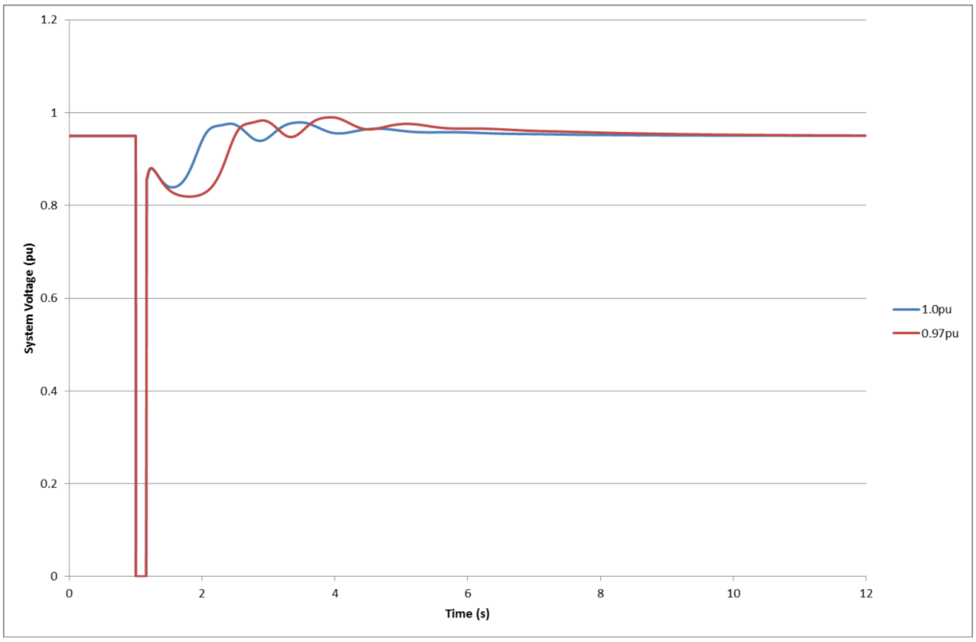

Figure 13: Transient response for Case Study 2.2 – system voltage.

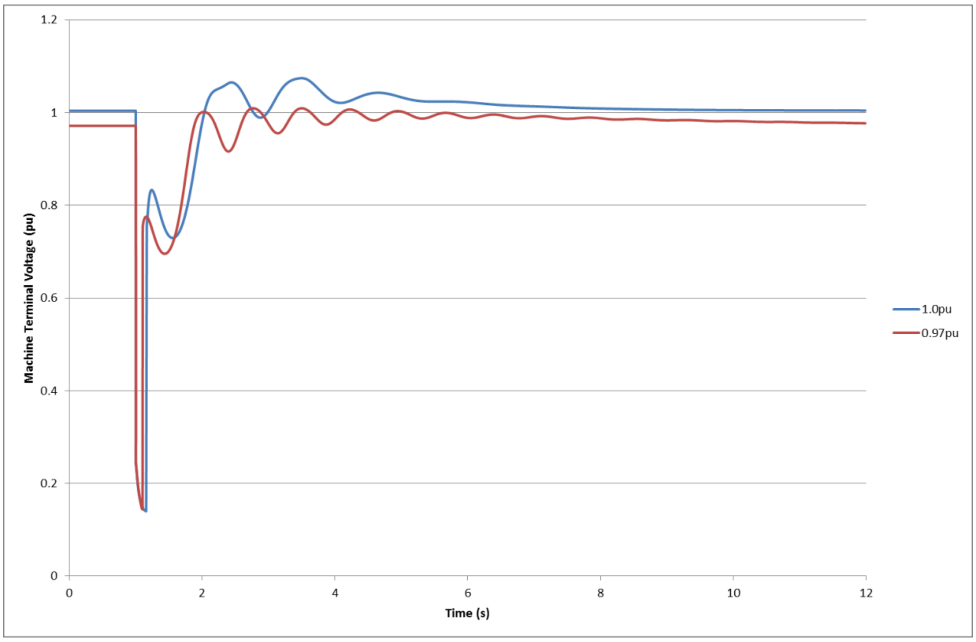

Figure 14: Transient response for Case Study 2.2 - machine terminal voltage

Design Implications of Changing the MVAr Control Methodology

Tap Range Requirements

3.43 The term "Tap Range," for the purpose of this document, is used to denote the range of turns that the tap changer spans. Its value is equal to the difference between the minimum and maximum values of the off-nominal turns ratio of the transformer. It is measured in pu voltage.

3.44 The off-nominal turns ratio required to achieve a certain level of MVAr output at a specific value of system voltage is a function of the machine terminal voltage, the MW output of the Generating Unit, and the transformer reactance. Any active and reactive demand, typically station auxiliaries, connected at the LV side of the generator transformer will also have to be taken into account.

3.45 Currently, the minimum Tap Range required needs to be large enough to cover the two most extreme points on the reactive range while the terminal voltage is controlled to 1.0pu. These are i) the point of maximum lagging MVAr output at a system voltage of 1.05pu and ii) the point of maximum leading MVAr output at a system voltage of 0.95pu.

3.46 In order to simplify the examples provided, transformer impedance was assumed to be independent of tap position; only two levels of transformer reactance were considered, 13% and 18%; no load was assumed to be connected to the low voltage side of the generator transformer. Any rounding up of the tap range resulting from any physical limitations was neglected. In reality, all these factors will have some effect on the actual tap range and will have to be considered while designing the plant.

3.47 If the terminal voltage is to be permanently controlled to a target value other than 1.0pu, the minimum Tap Range required to cover the entire reactive range will change. However, as indicated by the figures in Table 4, this effect is minor.

Table 4: Effect of a permanent change in the target terminal voltage on the transformer Tap Range required

	Target terminal voltage (pu)	Minimum off-nominal turns ratio	Maximum off-nominal turns ratio	Minimum Tap Range required (pu voltage)
13% transformer reactance	1.03	1:0.888	1:1.083	0.195
	1.0	1:0.912	1:1.119	0.207
	0.97	1:0.937	1:1.158	0.220
18% transformer reactance	1.03	1:0.873	1:1.105	0.232
	1.0	1:0.896	1:1.143	0.247
	0.97	1:0.919	1:1.184	0.264

3.48 If the terminal voltage is to be adjusted in order to control the MVAr output of the machine, the minimum Tap Range required to cover the entire reactive range will be reduced. This reduction is illustrated by the figures in in Table 5.

Table 5 Effect of varying the target terminal voltage on the transformer Tap Range

	Minimum value for target terminal voltage (pu)	Minimum value for target terminal voltage (pu)	Maximum value for target terminal voltage (pu)	Minimum off-nominal turns ratio	Maximum off-nominal turns ratio	Minimum Tap Range required (pu voltage)
13% transformer reactance	1.0	1.0	1.0	1:0.912	1:1.119	0.207
	1.0	1.0	1.03	1:0.912	1:1.083	0.171
	1.0	1.0	1.06	1:0.912	1:1.049	0.137
	0.97	0.97	1.03	1:0.937	1:1.083	0.146
	0.94	0.94	1.06	1:0.964	1:1.083	0.119
18% transformer reactance	1.0	1.0	1.0	1:0.896	1:1.143	0.247
	1.0	1.0	1.03	1:0.896	1:1.105	0.209
	1.0	1.0	1.06	1:0.896	1:1.069	0.173
	0.97	0.97	1.03	1:0.919	1:1.105	0.186
	0.94	0.94	1.06	1:0.944	1:1.069	0.125

Tap Step requirements

3.49 As the transformer tap position is changed, the operating point moves between the MVAr/Voltage characteristics of the relevant taps. The trajectory that the operating point follows is determined by the parameters of the transmission system as seen by the generator. i.e. The open circuit voltage and the short circuit impedance.

3.50 Figure 15 shows the trajectories of the operating point – dashed lines – moving between MVAr/Voltage characteristics – solid lines – as tap changes take place. Five different short circuit levels were used. In this figure, the machine terminal voltage is controlled to 1.0pu and the system's Thevenin's equivalent voltage is set to 1.0pu. A 13% transformer reactance was assumed.

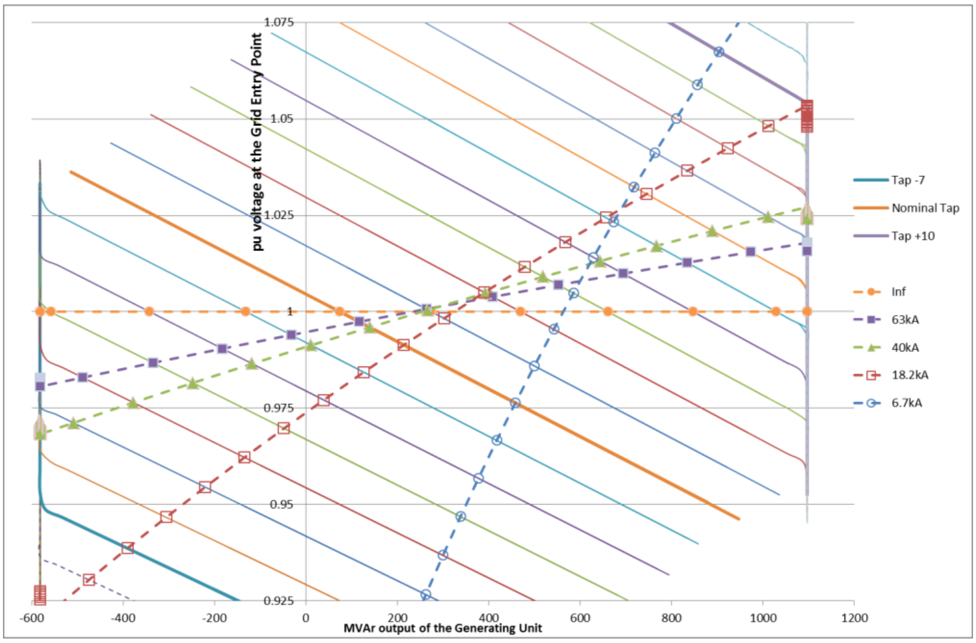

Figure 15: Effect of tap actions on the MVAr output and the voltage at the Grid Entry Point at different short circuit levels at 400kV.

3.51 Figure 15 indicates that, as the short circuit level drops, the effect of a tap action on the system voltage increases, and the effect of the same tap action on the MVAr output of the machine decreases.

3.52 Table 6 shows the maximum change in voltage and MVAr output associated with a single tap operation for different short circuit levels and different values of %voltage/tap.

3.53 In Table 6, the number of taps required was based on a 1.0pu target terminal voltage. This number would be scaled up or down in accordance with the ranges shown in Table 4 and Table 5 if this assumption changes.

3.54 The tap step size should be small enough to ensure that, at a high short circuit level, the MVAr accuracy required (BC2.A.2.6) is achieved and; at a low short circuit level the kV accuracy required (BC2.A.2.6) is achieved and the voltage step change requirements (CC.6.1.7) are not violated.

3.55 A tap step of slightly less than 0.45% voltage/tap would be sufficient to bring the MVAr step at a short circuit level of 63kA below 50MVAr. This allows the Generator to meet the ±25MVAr accuracy requirements specified in BC2.A.2.6. The same tap step will also ensure that the maximum voltage step change at a very low short circuit level, 6.7kA, is less than 0.5% (2kV). This allows the Generator to meet the ±1kV accuracy requirements specified in in BC2.A.2.6 and the 1% voltage step change specified in CC.6.1.7.

Table 6: Effect of short circuit level and tap step size on the voltage response and reactive power response to a tap change

Short circuit level		Voltage step/tap	Max tap required	Min tap required	Maximum MVAr change	Maximum voltage change[4]
kA	GVA	%			MVAr	%
Infinite System		1.25	10	-7	227	NA
Infinite System		0.625	20	-14	114.3	NA
Infinite System		0.45	27	-20	83	NA
Infinite System		0.2	60	-44	47.00	NA
63	43.6	1.25	10	-7	156.2	0.406
63	43.6	0.625	20	-14	78.3	0.205
63	43.6	0.45	27	-20	56.5	0.149
40	27.7	1.25	10	-7	131.7	0.548
40	27.7	0.625	20	-14	65.9	0.276
40	27.7	0.45	27	-20	47.4	0.199
18.2	12.6	1.25	10	-7	89.2	0.819
18.2	12.6	0.625	20	-14	44.6	0.412
18.2	12.6	0.45	27	-20	32.1	0.297
6.7	4.6	1.25	10	-7	48.3	1.059
6.7	4.6	0.625	20	-14	24.1	0.542
6.7	4.6	0.45	27	-20	17.3	0.391

Implications on the Rated Excitation Limit

3.56 In order to change the terminal voltage, the excitation system will change the rotor voltage and, consequently, the rotor current. The magnitude of this change will be a function of the machine parameters and its active and reactive power outputs.

3.57 The maximum lagging MVAr output from a Synchronous Generating Unit is usually limited by the Rotor Heating limit as shown by Figure 16[5], which depicts the performance chart of a typical 520MW machine operated at 1.0pu terminal voltage.

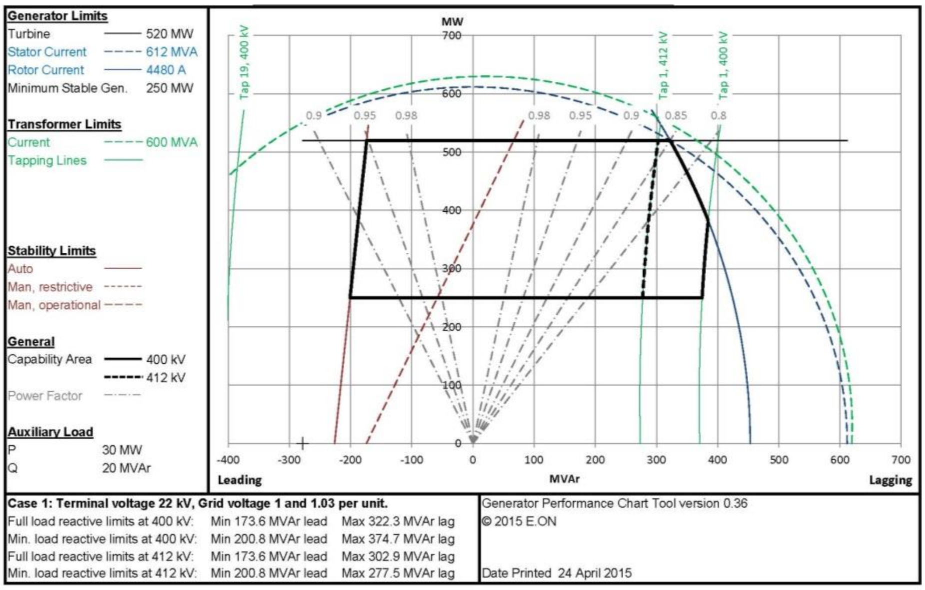

Figure 16: A typical performance chart for a 520MW machine operated at 1.0pu terminal voltage

[4] Larger voltage changes may take place at some operating points however, these points are not feasible because of pre/post fault operational restrictions.

[5] Performance charts in Figure 16, Figure 17, and Figure 18 are for a generic 520MW Synchronous Generating Unit. Charts are provided by E.ON.

3.58 As the terminal voltage is increased, and assuming that the rotor windings cannot be operated continuously at any current above the rated rotor current, that is the current required to provide the rated MW at the rated power factor and rated terminal voltage, the machine may not be able to comply with CC.6.3.2 (a) requirements. This is illustrated by the performance chart, shown in Figure 17, for the same machine operated at 1.04pu terminal voltage.

3.59 Figure 18 depicts the performance chart for the same machine operated at 1.04pu terminal voltage but with the rotor windings rated to the increased value of the rotor current.

3.60 Generators will need to ensure that the rotor windings and the whole excitation system of the Synchronous Generating Unit are rated adequately such that they are capable of meeting all the relevant Grid Code requirements, including delivering the rated power output at 0.85 power factor lagging, over the entire operating range of terminal voltage.

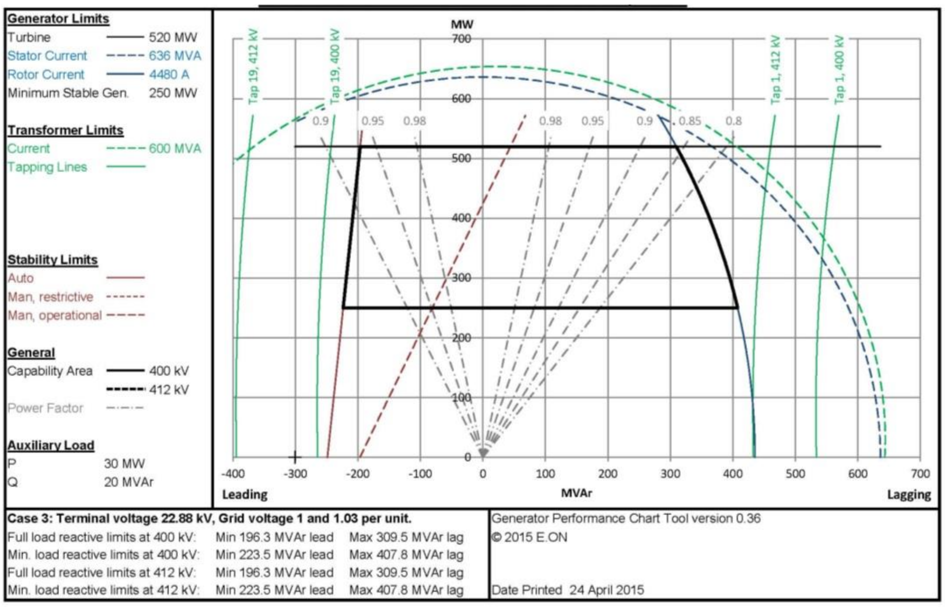

Figure 17: A typical performance chart for a 520MW machine operated at 1.04pu terminal voltage

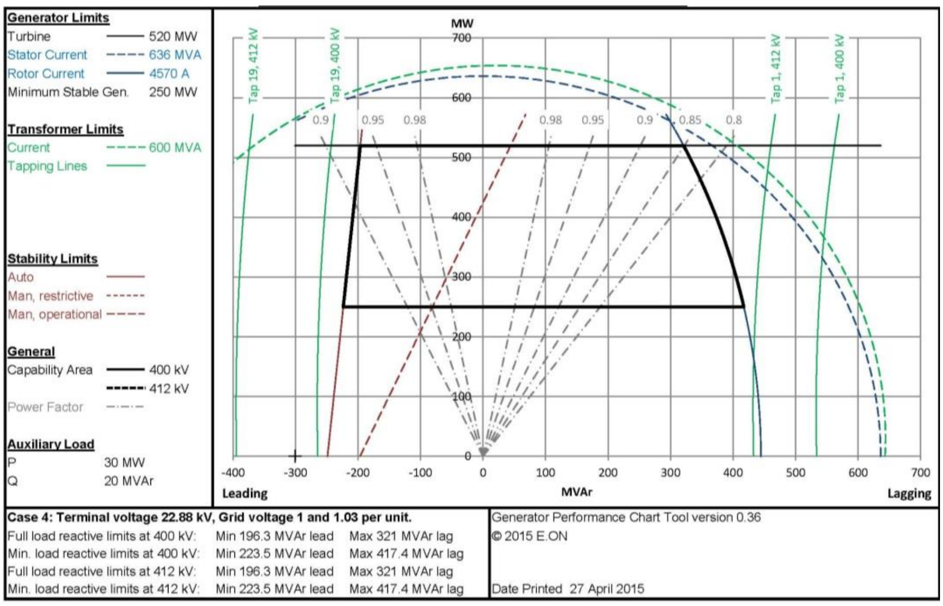

Figure 18: A typical performance chart for a 520MW machine operated at 1.04pu terminal voltage with rotor windings rating increased to enable compliance with the Grid Code 0.85 lagging power factor requirement.

4 On Load Tap Changer Technology

Number of taps

4.1 The simplest form of an On Load Tap Changer (OLTC), is shown in Figure 19, which comprises a selector switch and a diverter switch. The selector switch has two moving contacts. One of the two moving contacts moves between the odd-numbered tap positions whereas the other moves between the even-numbered tap positions. One of the two moving contacts will be at the current tap position whereas the second will be at the next tap up or down. The diverter switch is used to move the load current from the current tap into the next tap position.

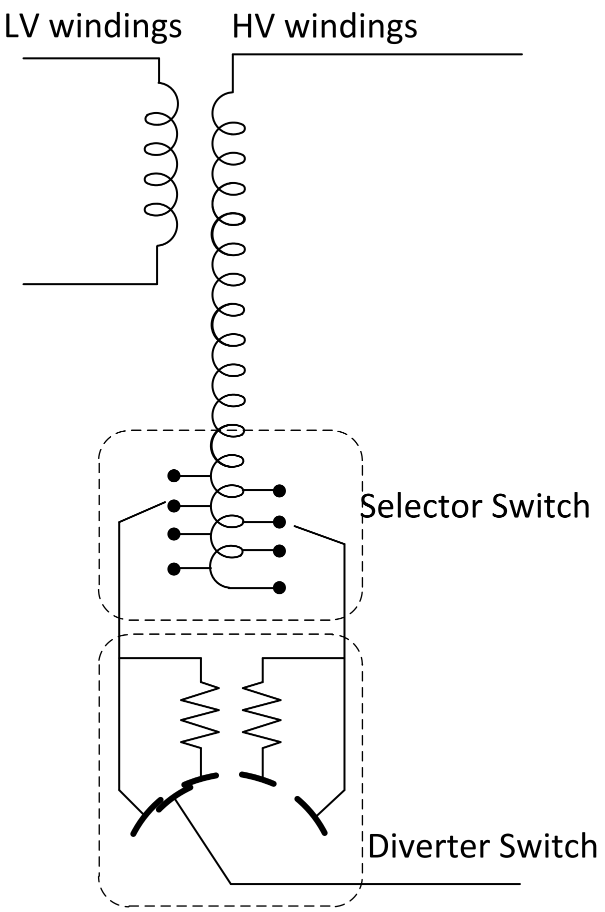

Figure 19: Basic on load tap changer

4.2 Where a large number of tap steps is required, the total number of physical taps is halved via using an OLTC with separate Buck/Boost windings.

4.3 A further reduction in the physical number of taps required to provide a large number of tap steps is achievable using two sets of taps. One set for coarse tap adjustment, whereas the other is for fine tap adjustment.

Tap resolution

4.4 Transformers of a high MVA rating have large cores. With the voltage per turn set by the size of core, these transformers will have a large voltage-per-turn.

4.5 Each tapping interval must be a whole number of turns. Even in transformers with a five-limb core, half-turns are physically difficult to achieve as the taps emerge on the wrong side of the transformer. With the smallest possible tap being one turn, the minimum tap step for a specific transformer will be set by the voltage-per-turn for that transformer.

4.6 A 2100MVA transformer is likely to have a large voltage-per-turn. Hence, it might be physically impossible to achieve a fine tap resolution for such transformer.

4.7 A potential solution would be to have a separate transformer for tapping. As this transformer will only handle a fraction of the total MVA, the core size, and the voltage-per-tap will be smaller than that of the main transformer. In this solution, coarse tapping will take place on the main transformer winding whereas fine tapping would take place on the small transformer. Workgroup members were not aware of any cases where this approach had been implemented and noted that a number of issues would need to be addressed before this solution could be considered feasible.

4.8 Even if is possible to develop a new OLTC that is capable of meeting the current requirements, the solution developed will be a new technology with a limited number of suppliers and an unproven reliability record. This will impose additional risks on Generators.

Operational Issues

4.9 The complexity of the OLTC mechanism and the large number of taps will reduce the reliability of the OLTC.

4.10 The increase in the number of taps and the number of tap actions taken will increase wear and tear on the diverter switch, necessitate more frequent oil changing, and increase the frequency of the OLTC being out of service for maintenance.

4.11 The minimum time between two consequent tap actions varies from site to site. This is governed by both the capability of the OLTC and the site operational procedures. The larger the number of tap actions required to respond to a MVAr instruction, the longer the time the Generator needs to respond to an instruction. With some Generators preferring to wait for the system to stabilise between two consecutive tap actions, the time to respond to an instruction could be in the order of 30 to 45 minutes or even longer.

5 Specific Issues for Generators

Clarity of Requirements

5.1 Although CC.6.3.8 does not specifically refer to a 1.0pu constant terminal voltage, NGET has always assumed that all synchronous machines will be operated at 1.0pu voltage. Generators felt the need that the 1.0pu voltage requirement should either be explicitly stated within the Grid Code or completely removed.

5.2 The Grid Code Connection Conditions is the main reference for Generators when specifying the design of their Plant and Apparatus, whereas the Balancing Code usually receives less attention at this stage. This increases the risk that the transformer design may not have the ability to meet the operational requirements defined in BC.2.5.4 and BC2.A.2.6. Hence, these clauses could be clarified and referred to within the Connection Conditions so it is clear to Generators what obligations they have to meet at the design stage

Derogations

5.3 Some Synchronous Generating Units are currently operating under a lifetime derogation because they cannot meet CC.6.3.4 (a). Other Synchronous Generating Units have already applied for a lifetime derogation against the same clause.

5.4 It would be beneficial if the solution proposed increases the feasible operating range of these Synchronous Generating Units such that they become compliant with the Grid Code or their non-compliance is reduced.

5.5 Once a conclusion has been determined and the Grid Code modified to reflect this solution, a review for the existing derogations may be necessary to determine if they are still required.

Reactive Range Requirements

5.6 For most of the time, Synchronous Generating Units are instructed to supply reactive power to the system when the transmission system voltage is low and conversely instructed to absorb reactive power from the system when the transmission voltage is high. On the other hand, Synchronous Generating Units are less likely to be instructed to supply reactive power to the system when the transmission voltage is high and instructed to absorb reactive power from the system when the transmission voltage is low.

5.7 Synchronous Generating Units operating at the extreme ends of the reactive range, that is when they are either absorbing the full MVAr capability at 0.95pu voltage or injecting full MVAr capability at 1.05pu voltage, will be operating at their limits and hence they need to be designed with these operating points in mind. Consequently, any reduction of the operational range may result in lower specifications of the Generating Unit and transformers and consequently some reduction in capital costs.

5.8 Moreover, Generators are interested in having flexibility with regards to the means of providing capability, as this can enable transformers from other sites (possibly including from other countries) to be used as spares, with no or reduced compliance issues, in the event of failure of existing in-service transformers.

Number of Taps Required

5.9 As the MW rating of the machine increases, the number of tap steps required to comply with the existing Grid Code requirements increases.

5.10 Most of the units currently operating have 19 taps. Some of the more recent units have up to 26 taps. Generators have indicated that, from their point of view, it is practical to procure transformers with up to ±23 taps (47 taps in total). Any number of taps in excess of the 47 taps would be considered impractical.

5.11 As described in Section 4, there are questions concerning the feasibility of building transformers with very fine tap steps and the implications of having a large number of tap steps.

5.12 In general, Generating Units of significantly large MW rating, e.g. 1800MW machines, may need to utilise new OLTC technology that has been developed specifically for their project. This use of unproven technology increases the risks Generators are exposed to.

6 Specific Issues for Transmission Licensees

Operational Issues

6.1 The reactive capability provided by Synchronous Generating Units is a key element that NGET relies on in meeting its obligations to manage transmission system voltage levels in accordance with the Grid Code and NETS SQSS requirements.

6.2 With the challenges NGET faces in managing voltage levels, it is necessary to ensure that new Synchronous Generating Units are able to provide their full reactive capability over the entire operating range that is currently specified in the Grid Code.

6.3 The requirement that Synchronous Generating Units need to be able to generate reactive power when system voltages are low and absorb reactive power when system voltage are high is intuitively understandable. On the other hand, the requirement that they need to be able to absorb reactive power when system voltages are low or generate reactive power when system voltages are high is not so obvious. However, a review of recent experience indicated several occasions when Synchronous Generating Units were instructed to absorb their maximum MVAr capability at very low voltage levels in order to ensure that, following a double circuit fault, voltage levels remain within the acceptable operational levels as specified in the NETS SQSS.

6.4 During low demand periods, the number of Synchronous Generating Units that are in merit is low. This number will drop even further as the range of size of machines increases and as the volume of non-synchronous generation increases. Hence, it is necessary to ensure that the few units that are already running are able to provide their maximum reactive capability.

6.5 It is also important to ensure that the machines are able to provide their MVAr output such that target voltage levels can be achieved with enough precision.

Monitoring Issues

6.6 In order to ensure appropriate visibility of the Transmission System, NGET continuously monitors the relevant electrical quantities at all system nodes and branches. NGET also receives Operational Metering signals from all Transmission System Users. The data collected is fed into a State Estimator that will produce a consistent set of results defining the system operating point. This data is then fed into online stability assessment and contingency analysis tools.

6.7 The algorithm used by the State Estimator requires that the number of quantities fed into it is higher than the number of variables required to be calculated. These quantities include both the Generating Unit transformer tap position and the Generating Unit terminal voltage.

6.8 The terminal voltage for all Synchronous Generating Units is controlled to a constant value at all times. This value is 1.0pu for the majority of the Synchronous Generating Units currently in service with only very few exceptions where a different value of terminal voltage has been agreed.

6.9 As the Generating Unit terminal voltage has always been controlled to a fixed value, it has been sufficient to supply this value as an input to the State Estimator with no actual monitoring. On the other hand, as the Generating Unit transformer tap position is adjusted on a regular basis, this value is constantly monitored and sent to NGET where it is fed to the State Estimator. This arrangement is reflected in the Bilateral Agreement between NGET and the Generator which requires the Generator to provide Operational Metering signals for the transformer tap position and does not generally require them to provide a terminal voltage signal.

6.10 Any change to the operational arrangements to Generators to adjust the target terminal voltage settings, would require a revision to the Operational Metering requirements specified in the Bilateral Agreement with the relevant Generators. Some hardware changes and some database updates may be required in order to ensure that the additional signals are received and routed correctly. This is to ensure that the accuracy of the State Estimator is not compromised.

Modelling Issues

6.11 Transmission Licensees have a licence obligation to design and operate the Transmission System in an economic and efficient manner. In order to meet these requirements, they need to maintain an up-to-date set of models that accurately reflect the behaviour of all plant connected to the Transmission System.

6.12 All power system models currently used by NGET assume a Generating Unit terminal voltage of 1.0pu with only very few exceptions where a different value has been agreed bilaterally with the Generator. These models assume that only tap position will be adjusted to achieve a specific MVAr value.

6.13 In order to accommodate any change to the MVAr control methodology, affected Generators will need to supply any additional data required to allow accurate modelling of their Generating Units. This includes the range of terminal voltage adjustment and the corresponding performance charts.

6.14 In addition, any change in MVAr control methodology will need to be accurately represented in the power system models and algorithms used by NGET and other Transmission Licensees. This is to ensure that NGET is able to dispatch the machine at all feasible operating points, and that, following any secured event, NGET is able to predict the behaviour of the machine and any potential interactions with other plants.

6.15 NGET is yet to determine the scope of modifications required for the power system simulation algorithms.

7 Options Overview

Option 1

Overview

7.1 Maintain the existing reactive range requirements, maintain the existing MVAr control arrangements and clearly define that the target terminal voltage must be set to 1.0pu. Additional clarification of several Grid Code clauses would also be required.

Implementation

7.2 In order to comply with Option 1, Generators need to ensure the generating unit transformer is equipped with an on load tap changer that

7.2.1 spans the full range of off-nominal turns required to cover the full reactive range with the terminal voltage set to 1.0pu; and

7.2.2 has a tap step that is small enough to meet the MVAr accuracy, kV accuracy (as defined in the Balancing Codes), and voltage step change requirements as defined in the Connection Conditions.

Reactive range

7.3 Option 1 retains the existing reactive range defined by CC.6.3.4(a) and CC.6.3.2(a). This is shown by Figure 1.

Provision of Reactive Capability

7.4 The Generator will use the same methodology described in paragraph 3.9 to 3.16 to respond to MVAr instructions from NGET.

Tap Range requirements

7.5 The Tap Range required will remain unchanged.

Tap Step requirements

7.6 The tap step and the total number of taps required will also remain unchanged.

Post fault response

7.7 The existing post fault MVAr response will be retained.

Implications on transient stability

7.8 The existing dynamic performance of the machine will be retained.

Impact on Generators

7.9 No impact on the plant auxiliaries as the target terminal voltage will be fixed at 1.0pu.

7.10 No need for additional Operational Metering signals from the plant.

7.11 No need to change any operational procedures.

7.12 No need to submit additional data.

7.13 Where the MW Rating of the machine dictates an excessive number of taps, as discussed in Section 4 and paragraphs 5.9, 5.10, and 5.11, Generators may have to procure an OLTC that uses an unproven technology, is impractical to operate, and is difficult maintain; or they may need a transformer with a tap resolution that is impossible to achieve.

7.14 The Generator will maintain the current level of flexibility in designing and operating their plant. i.e. The plant will have to be designed to operate at 1.0pu terminal voltage at all times.

7.15 Generator's ability to use spare Generating Unit transformers from different sites will be restricted due to potential non-compliance issues.

Impact on the National Electricity Transmission System

7.16 The current reactive reserves and stability margins will remain unaltered.

7.17 There will be no need to change models and simulation algorithms.

7.18 There is no need for additional Operational Metering signals.

7.19 Where the MW Rating of the machine dictates an excessive number of taps, NGET will need to allow sufficient time for Generators to respond to a MVAr instruction. Moreover, the reduced reliability and availability of the OLTC might increase the challenges of managing the voltage profile on the National Electricity Transmission System.

Impact on Derogations

7.20 Plants that are not compliant with the existing requirements will not be compliant with the requirements according to Option 1.

7.21 There is a limited number of plants that have agreed a target terminal voltage that is different to 1.0pu in order to facilitate them meeting the existing reactive range requirements. If Option 1 is to be implemented, these plants may require a derogation.

Interactions with European Codes.

7.22 No conflict has been identified between Option 1 and the European Requirements for Generators (RfG) Network Code.

Option 2A

Overview

7.23 Maintain the existing reactive range requirements and divide this range into a Tap Control region and a Terminal Voltage Control region.

7.24 In the Tap Control region, a 1.0pu terminal voltage is maintained and the MVAr output is controlled via changing the transformer tap position.

7.25 In the Terminal Voltage Control region, the transformer is set to the maximum or minimum tap position and the MVAr output is controlled via adjusting the target terminal voltage.

7.26 Figure 20 shows an example of the two operating regions for an 1800MW machine. The size of the Terminal Voltage Control region is determined by the maximum allowable change in terminal voltage. In this figure, only target terminal voltages with values greater than or equal to 1.0pu were used. Hence, the Terminal Voltage Control region is only on the upper right corner of the reactive range. If values below 1.0pu were used, the Terminal Voltage Control region would have also covered the lower left region of the reactive range.

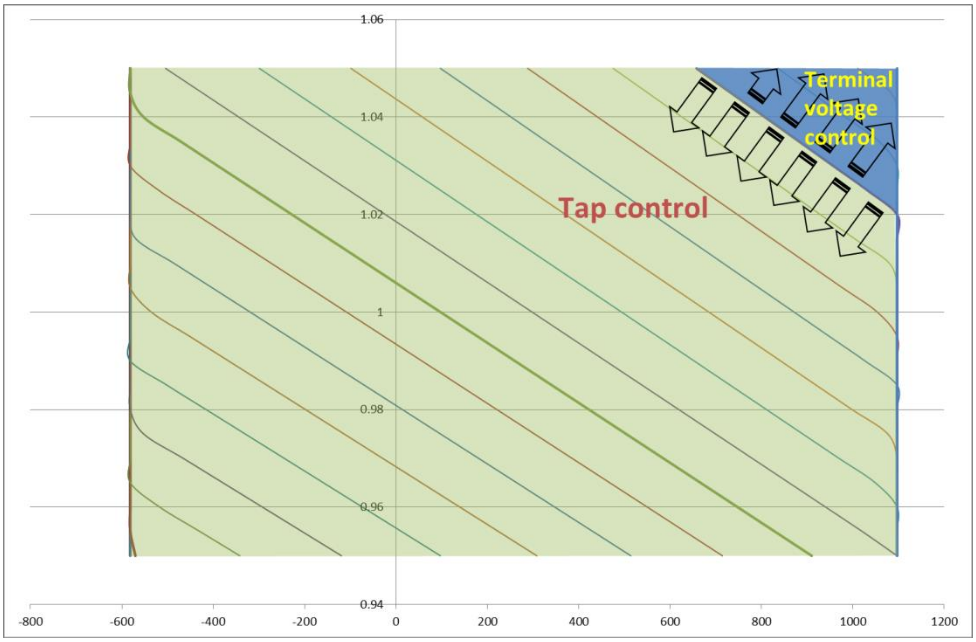

Figure 20: The different operating ranges for Option 2A for an 1800MW machine.

Implementation

7.27 In order to comply with Option 2A, Generators need to ensure the generating unit transformer is equipped with an on load tap changer that

7.27.1 spans the range of off-nominal turns required to cover the Tap Control region of the reactive range with the terminal voltage set to 1.0pu; and

7.27.2 has a tap step that is small enough to meet the MVAr accuracy, kV accuracy, and voltage step change requirements.

7.28 The Generator will then need to ensure that the target terminal voltage is adjustable within the range necessary to cover the Terminal Voltage Control region.

7.29 The Generator will also need to ensure that the Synchronous Generating Unit is able to continuously operate at the increased terminal voltage while meeting all the Grid Code requirements.

Reactive range

7.30 Option 2A retains the existing reactive range defined by CC.6.3.4(a) and CC.6.3.2(a).

Provision of Reactive Capability

7.31 The Generator will use the same methodology described in paragraph 3.9 to 3.16 to respond to MVAr instructions from NGET until the maximum tap position has been reached. Any shortfall in MVAr capability beyond this level will be achieved by adjusting the target terminal voltage.

Tap Range requirements

7.32 The Tap Range required may be reduced. The percentage reduction is largely dependent on the range of terminal voltage. This is illustrated by the figures in Table 5.

Tap Step requirements

7.33 The Tap Step required will remain unchanged. However, if the Tap Range decreases, the total number of taps required will also decrease.

Post fault response

7.34 While operating within the Tap Control region, the existing post fault MVAr response will be retained.

7.35 While operating within the Terminal Voltage Control region with a terminal voltage above 1.0pu, a marginal enhancement in steady state post fault MVAr response will be achieved.

7.36 Terminal voltage values below 1.0pu are restricted in order to prevent any deterioration in steady state post fault MVAr response.

Implications on transient stability

7.37 While operating within the Tap Control region, the existing transient and dynamic performance of the machine will be retained.

7.38 While operating within the Terminal Voltage Control region with a terminal voltage above 1.0pu, an improvement in the machines transient and dynamic performance will be achieved.

7.39 Terminal voltage values below 1.0pu are restricted in order to prevent any deterioration in the machine transient and dynamic performance.

Impact on Generators

7.40 Changing the terminal voltage in a plant where the plant auxiliaries are supplied from their generating unit terminals will affect these auxiliaries. In these plants, the auxiliary transformer may need its own on load tap changer with sufficient tap range and an adequate number of tap steps.

7.41 The Bilateral Agreement with Generators opting to use the new MVAr output control methodology may need to be updated to include additional Operational Metering signals (machine terminal voltage) and to specify that the Generator is allowed to adjust the terminal voltage.

7.42 Operational procedures may need to be changed to allow staff at the Generators' plant where the new MVAr output control methodology is to be used to adjust the terminal voltage in response to a MVAr instruction or a Target Voltage Level instruction from National Grid when the OLTC is at the maximum tap position.

7.43 Additional data will need to be submitted to facilitate modelling the plant. This includes

7.43.1 maximum terminal voltage setting;

7.43.2 resolution of terminal voltage setting; and

7.43.3 the Synchronous Generating Unit performance charts at different values of terminal voltage.

7.44 Total number of taps required will be reduced. The percentage of reduction is mainly driven by the voltage control range.

7.45 The Generator will have some flexibility in the choice of their Generating Unit transformers.

7.46 The Generator will have more flexibility in using spare Generating Unit transformers from different sites compared to Option 1.

Impact on the National Electricity Transmission System

7.47 The current reactive reserves will remain unaltered.

7.48 Stability margins will improve when the machine is running at a terminal voltage above 1.0pu.

7.49 There will be a significant change to models and simulation algorithms. The scope of these changes is yet to be determined.

7.50 The machine terminal voltage will need to be monitored and its value fed into state estimators.

Impact on Derogations

7.51 Option 2A effectively provides the option to reduce the Tap Range required to meet CC.6.3.2(a) and CC.6.3.4(a).

7.52 Provided that derogated plants are able to adjust the target terminal voltage to achieve a specific MVAr output, the degree of non-compliance will be reduced.

Interactions with European Codes.

7.53 No conflict has been identified between Option 2A and the RfG

Option 2B

7.54 Maintain the existing reactive range requirements and change the existing MVAr control methodology such that Generators are able to adjust the target terminal voltage as required to meet the MVAr instruction. Once the MVAr output instructed has been achieved, the Generator will be required to maintain this target terminal voltage until the next MVAr instruction.

7.55 The range originally proposed for the target terminal voltage is between 1.0pu and 1.03pu. However, it was eventually agreed that the upper limit would be defined by the Generator.

Implementation

7.56 In order to comply with Option 2B, Generators need to ensure that the generating unit transformer is equipped with an on load tap changer that:

7.56.1 spans the range of off-nominal turns required to cover the Tap Control region of the reactive range, as per Option 2A, with the terminal voltage set to 1.0pu; and

7.56.2 has a tap step that is small enough to meet the voltage step change requirements.

7.57 The Generator will then need to ensure that the target terminal voltage is adjustable as necessary to be able to carry out reactive power and voltage instructions within the accuracy required.

7.58 The Generator will also need to ensure that the Synchronous Generating Unit is able to continuously operate at the increased terminal voltage while meeting all the Grid Code requirements.

Reactive range

7.59 Option 2B retains the existing reactive range defined by CC.6.3.4(a) and CC.6.3.2(a).

Provision of Reactive Capability

7.60 The Generator will be able to use a combination of transformer tap control and terminal voltage adjustment to achieve the MVAr instruction. Tap control will be used for coarse control of MVAr output whereas terminal voltage adjustment will be used for fine tuning as necessary.

Tap Range requirements

7.61 Similar to Option 2A, the Tap Range required may be reduced down as illustrated by the figures in Table 5.

Tap Step requirements

7.62 For Option 2B, the only factor that limits the tap step is the 1% maximum voltage step change required by CC.6..1.7 and any impacts on the station auxiliaries. Hence, tap steps significantly larger than that required for Option 2A may be achievable.

7.63 The combined effect of a reduction in the Tap Range required and the increase in the acceptable tap step is likely to result in a significant reduction in the number of transformer taps required.

Post fault response

7.64 A marginal enhancement in steady state post fault MVAr response will be achieved when operating at a terminal voltage above 1.0pu. Otherwise, the existing response will be retained.

7.65 Terminal voltage values below 1.0pu are restricted in order to prevent any deterioration in steady state post fault MVAr response.

Implications on transient stability

7.66 The dynamic and transient response of the machine will improve when operating at a terminal voltage above 1.0pu.

7.67 Terminal voltage values below 1.0pu are restricted in order to prevent any deterioration in the dynamic and transient response of the machine.

Impact on Generators

7.68 Changing the terminal voltage in a plant where the plant auxiliaries are supplied from their generator terminals will affect these auxiliaries. In these plants, the auxiliary transformer may need its own on load tap changer with sufficient tap range and an adequate number of tap steps.

7.69 The Bilateral Agreement with Generators opting to use the new MVAr output control methodology may need to be updated to include additional Operational Metering signals (machine terminal voltage) and to specify that the Generator is allowed to adjust the terminal voltage.

7.70 Operational procedures may need to be changed to allow staff at the Generators' plant where the new MVAr output control methodology is to be used to adjust the terminal voltage in response to a MVAr instruction or a Target Voltage Level instruction from National Grid.

7.71 Additional data will need to be submitted to facilitate modelling the plant. This includes

7.71.1 maximum terminal voltage setting;

7.71.2 resolution of terminal voltage setting; and

7.71.3 the reactive power capability charts at different values of terminal voltage.

7.72 Total number of taps required will be reduced significantly.

7.73 The Generator will have some flexibility in the choice of their Generating Unit transformers.

7.74 The Generator will have more flexibility in using spare Generating Unit transformers from different sites compared to Option 1.

Impact on the National Electricity Transmission System

7.75 The current reactive reserves will remain unaltered.

7.76 Stability margins will improve when the machine is running at terminal voltage above 1.0pu.

7.77 There will be a significant change to models and simulation algorithms. The scope of these changes is yet to be determined.

7.78 The machine terminal voltage will need to be monitored and its value fed into state estimators.

Impact on Derogations

7.79 Option 2B effectively provides the option to reduce the Tap Range required to meet CC.6.3.2(a) and CC.6.3.4(a).

7.80 Provided that derogated plants are able to adjust the target terminal voltage to achieve a specific MVAr output, the degree of non-compliance will be reduced.

Interactions with European Codes.

7.81 No conflict has been identified between Option 2B and the RfG

Option 3

7.82 Modify the reactive range requirements (CC.6.3.2 and CC.6.3.4) to reduce the reactive capability required at extreme voltage conditions. There will still be a requirement to maintain the existing MVAr control arrangements with the terminal voltage set to 1.0pu.

Implementation

7.83 In order to comply with Option 3, Generators need to ensure the generating unit transformer is equipped with an on load tap changer that:-

7.83.1 spans the range of off-nominal turns required to cover the reduced reactive range specified with a terminal voltage set to 1.0pu; and

7.83.2 has a tap step that is small enough to meet the MVAr accuracy, kV accuracy, and voltage step change requirements.

Reactive range

7.84 Option 3 restricts the reactive range available in comparison to the existing requirements defined by CC.6.3.4(a) and CC.6.3.2(a). This is illustrated by Figure 21 showing the upper right corner and the bottom left corner shaded as the Generating Unit is no longer required to be capable of operating in these areas.

Provision of Reactive Capability

7.85 The Generator will use the same methodology described in paragraph 3.9 to 3.16 to respond to MVAr instructions from NGET.

Tap Range requirements

7.86 The Tap Range required will be reduced due to a reduction in the reactive range requirements.

Tap Step requirements

7.87 The tap step will remain unaltered but the total number of taps required will be reduced due to a reduction in the Tap Range required.

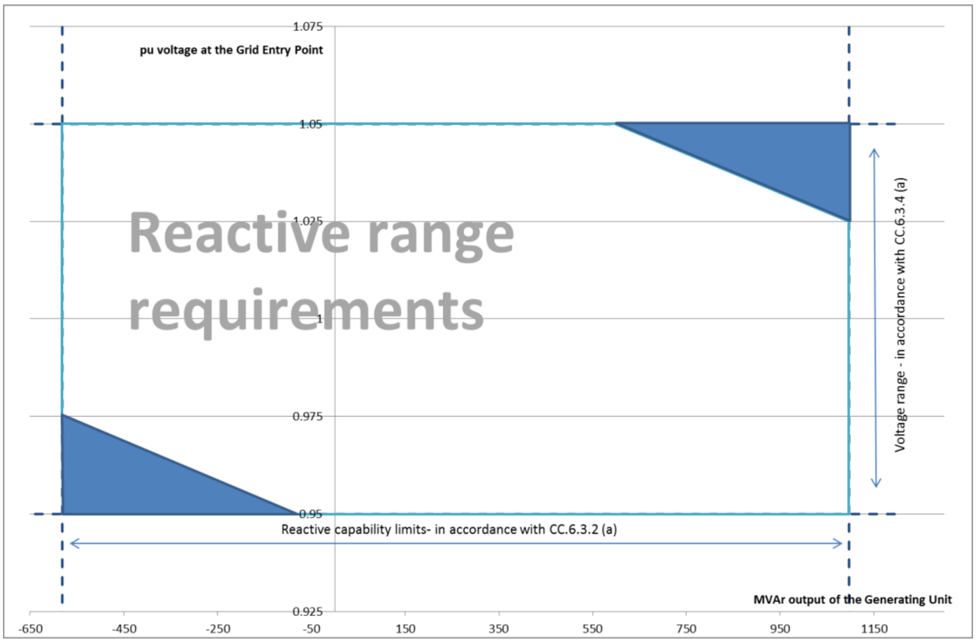

Figure 21: Reactive range requirements for an 1800MW Synchronous Generating Unit as defined by Option 3

Post fault response

7.88 The existing post fault MVAr response will be retained.

Implications on transient stability

7.89 The existing dynamic performance of the machine will be retained.

Impact on Generators

7.90 No impact on the plant auxiliaries as the target terminal voltage will be fixed at 1.0pu.

7.91 No need for additional Operational Metering signals from the plant.

7.92 No need to change any operational procedures.

7.93 No need to specify any operational arrangements in the Bilateral Agreement.

7.94 Where the MW Rating of the machine dictates an unpractically small tap step, the consequences will be in accordance with that stated in Section 4.

7.95 The Generator will maintain the current level of flexibility in designing and operating their plant. i.e. The plant will have to be designed to operate at 1.0pu terminal voltage at all times.

7.96 Generator's ability to use spare Generating Unit transformers from different sites will be restricted due to potential non-compliance issues.

Impact on the National Electricity Transmission System

7.97 MVAr margins available will be reduced. This will increase the challenges facing the System Operator to manage the Transmission System voltage profile. This will consequently trigger additional investment in static and dynamic reactive compensation to cover the difference.

7.98 There will be no need to change models and simulation algorithms.

7.99 There is no need for additional Operational Metering signals.

Impact on Derogations

7.100 Plants that are not compliant with the existing requirements may be compliant with the requirements according to Option 3. This will depend on the tap range available and the new reactive range requirements.

Interactions with European Codes.

7.101 No conflict has been identified between Option 3 and the RfG

8 Work Group Discussion

Discontinuing Option 3

8.1 NGET raised a concern that voltage management is increasingly difficult due to the loss of short circuit infeed as synchronous generation is displaced, the high penetration of embedded generation, falling levels of MW demand, and a reduction in the MW/MVAr demand ratio.

8.2 In the design and operation of the Transmission System, NGET needs to ensure that the system voltage levels are within the levels specified in the NETS SQSS and Grid Code. NGET also need to ensure that, following clearance of a secured event, voltages remain within the same levels.

8.3 Due to the timescales associated with MVAr dispatch, NGET needs to ensure that the pre-fault tap position is such that, if a secured event is to occur, the machine will respond by providing the level of MVAr required to contain voltage excursions within limits.

8.4 For example, in order to secure the system shown in Figure 22 for the double circuit fault between the system and the demand, the Synchronous Generating Unit will have to be instructed to the MVAr output that balances the demand and any reactive losses associated with the long route at prefault conditions. Depending on the system voltage, this may dictate that the machine provides maximum leading MVAr output at low voltage conditions or maximum lagging MVAr at high voltage conditions. Similar situations have materialised recently as discussed in Paragraph 6.3.

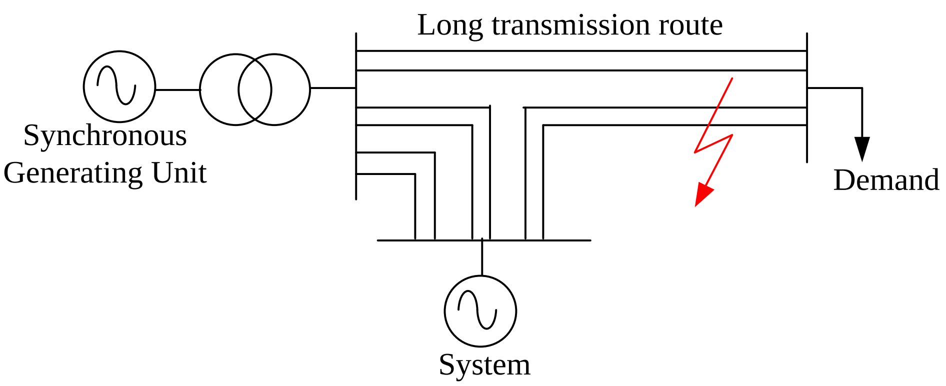

Figure 22: A generic system illustrating the need case for operation at the extreme points of the reactive range.

8.5 This condition materialised recently when a plant was instructed to produce the maximum leading MVAr output at low voltage conditions.

8.6 Although this condition is better avoided, it is credible and Transmission Licensees need to ensure they are able to secure the system for it.

8.7 Where it is mechanically feasible to do so, the incremental cost of providing additional taps to the generating unit transformer is marginal in comparison to the cost of providing dedicated dynamic reactive compensation on the Transmission System.

8.8 If Option 3 were to be adopted, the reduction in reactive capability available to NGET from Synchronous Generating Units would need to be replaced by either investment in reactive compensation or by contracting services from other Synchronous Generating Units that are less likely to be running. In both cases, the costs incurred are likely to exceed any savings on the cost of generating unit transformers. Hence, the Workgroup agreed to discontinue Option 3 as it is likely to fail to permit the development, maintenance and operation of an efficient, coordinated and economical system for the transmission of electricity.

Interactions with Other Grid Code Criteria

8.9 The analysis undertaken by different parties within the Work Group suggested that reducing the terminal voltage below 1.0pu would have a negative effect on the stability margin of the machine.

8.10 Whilst National Grid is favours an approach which requires Generators to ensure that the terminal voltage does not drop below 1.0pu, some Generators are of the view that stability margins are covered independently by the fault ride through requirements (CC.6.3.15) and specifications in the Bilateral Agreement.

8.11 However, as National Grid needs some certainty on the worst case stability condition, and where this has no adverse effects on Generators, the workgroup agreed that the minimum value for the target terminal voltage should be 1.0pu.

MVAr Tolerance Requirements

8.12 The Balancing Code requires Generators to be able to achieve a MVAr instruction within an accuracy of ±25MVAr. In Scotland, the requirement is based on an accuracy of (±5% of the rating) or ±25MVAr (whichever is smaller). This allows NGET to manage busbar voltages with reasonable accuracy.

8.13 The Balancing Code also requires Generators to be able to control the voltage at the Grid Entry Point or the User System Entry Point within a tolerance of ±1kV.

8.14 The specification of the tolerance in MVAr terms suggests that the main purpose of this value is to ensure that voltage targets are achievable and to ensure Generators are not paid for MVAr that they have not been instructed to provide. This limit also allows NGET to fine tune the voltage target of transmission busbars.

8.15 Removing the limits from the Balancing Code would allow Generators to have tap steps that are large enough to cause a 1% voltage step change on the Transmission System. This will restrict the voltage control precision on the 400kV system to 4kV. This will make it more difficult for the System Operator to achieve an adequate voltage profile.

8.16 At low short circuit levels, the MVAr step/tap is low, whereas the voltage step/tap is high. Hence, extending the ±5% of the rating applicable in Scotland to all generation would not assist in fine tuning Transmission voltage levels if the short circuit level is low.

8.17 A potential solution is i) to maintain the 25MVAr value or ii) specify a kV step change level that is stricter than the 1% allowed under CC.6.1.7. However, as the preferred option should easily allow Generators to meet these requirements, it is proposed to maintain the 25MVAr value.

Restrictions on the Range of Target Terminal Voltage

8.18 The initial view for Option 2A and Option 2B was to specify the maximum and minimum values for the target terminal voltage that Generators are allowed to use.

8.19 Generators had concerns that this specification is restrictive and does not add any extra value to the clause.

8.20 Hence, it was agreed not to specify a maximum value for the target terminal voltage. However, in line with 8.11, the minimum value of terminal voltage is to be specified as 1.0pu.

Implications on the Excitation System Positive and Negative Ceiling Voltages

8.21 If a short circuit fault occurs, the excitation system voltage will increase to its positive ceiling value. The magnitude of increase is equal to the difference between the positive ceiling voltage and the pre fault steady state voltage.

8.22 As the terminal voltage is increased, the steady state excitation system voltage will need to be increased as well. Consequently, as the terminal voltage is increased, the post fault increase in the excitation system voltage will be reduced.

8.23 The workgroup discussed that simulations suggest an improvement in post fault dynamic performance of Synchronous Generating Units when operating at a terminal voltage higher than 1.0pu. Hence, this change is not likely to have any negative implications on the transient stability of the Synchronous Generating Unit or the Transmission System as a whole. Moreover, positive and negative ceiling voltages are determined on a case by case basis as part of the connection application and hence they are not within the scope of this workgroup.

Preferred Option

8.24 Having considered all the options and the issues associated with them, the work group proposes to adopt Option 2B as by allowing Generators the flexibility to supplement transformer tap changer control with machine terminal voltage adjustment when responding to a MVAr instruction, Generators will have more flexibility when specifying their generating unit transformers; will be able to move spare transformers between different sites; and will be able to avoid the need to use transformers with excessive, potentially unrealistic, number of taps. While doing so, the Option 2B retains the reactive power capability available to NGET, and has no negative implications on the Transmission System.

9 Implementation Considerations

Retrospective application

9.1 With Option 2B, Generators are still able to operate at 1.0pu terminal voltage and remain compliant with the Grid Code. This means that retrospective application of the requirements will not raise any additional non-compliance issues.

9.2 Generators seeking to use the new MVAr control methodology for Synchronous Generating Units that are already connected to the Transmission System would have to submit a Modification Application to National Grid in order to allow for additional data submission, update the Bilateral Agreement, and arrange for additional Operational Metering requirements.

9.3 Where a different terminal voltage set point has been agreed prior to the implementation of the modification proposed, National Grid will approach the relevant Generators to reflect the operational arrangement agreed in their Bilateral Agreement.

When should new requirements apply from?

9.4 It is proposed that this Grid Code change is implemented within 10 business days of approval by the Authority.

9.5 National Grid will assess any implications on simulation tools, models, and internal procedures.

Which generation should this apply to?

9.6 The modification proposed applies to all Onshore Synchronous Generating Units.

International practice and approach taken in European Code development

9.7 The MVAr control methodology varies from one country to another. For example, in Great Britain MVAr control has always been done by changing transformer taps with the machine operating at a constant terminal voltage whereas in France, where Generating Unit transformers have no OLTC, MVAr control has always been done via changing the Generating Unit terminal voltage set point.

9.8 Whereas a complete change of concept is not practical, the modification proposed allows additional flexibility for Generators to use either of these two methodologies or a combination of both.

9.9 In addition, the workgroup has assessed the solutions against the relevant European Network Codes.

European Network Codes

9.10 The interaction between different options proposed and the Requirements for Generators (RfG) have been assessed. No conflict has been identified.

10 Solution

10.1 Some of the existing Grid Code clauses related to MVAr range and Excitation Control System performance would benefit from clarification.

10.2 The MVAr control methodology currently used in GB would dictate that the generating unit transformer of synchronous machines of high MW rating will need a large number of taps with very small voltage step/tap. This large number of taps and the small tap step may be physically impractical. It may also force Generators to use some un-proven technology for their OLTC.

10.3 Any reduction of the MVAr range or the voltage range at which this capability should be made available, constitutes a risk to the operability of the Transmission System.

10.4 In order to allow Generators to continue providing the same capability, it is recommended that the MVAr control methodology is made more flexible.

10.5 The preferred option assumes that an On Load Tap Changer will be available to provide coarse MVAr control. MVAr output will then be finely tuned via adjusting the machine terminal voltage thorough the Automatic Excitation Control System.

10.6 The preferred option allows Generators to choose between two options. Generators can choose to maintain the existing MVAr control methodology through maintaining a terminal voltage of 1.0p.u at all times and managing reactive power through tap control. Alternatively, they can choose to combine tap adjustment with terminal voltage adjustment.

10.7 The preferred option does not conflict with RfG.

10.8 In order to implement this option, significant change of modelling algorithms, metering requirements, and operational procedures will be required.

11 Assessment

Impact on the Grid Code

11.1 The work group recommends modifications to the Grid Code Planning Code, Connection Conditions, Compliance Processes, Balancing Code, and Data Registration Code.

11.2 The modifications proposed to the Connection Conditions, the Balancing Code. Operating Code 2, Operating Code 5, Planning Code, Compliance Process, and Data Registration Code are detailed in Annex 3

Impact on Grid Code Users

11.3 This modification impacts the Owners and Developers of Synchronous Generating Units.

11.4 This main implication for Users impacted is that they will be able to combine terminal voltage adjustment and tap changing in order to provide the MVAr level instructed. This will enable them to reduce the number of tap steps required for large units and allow tap steps sizes that are practical to provide. It will also enable them to use transformers from other sites as spares, with no or reduced compliance issues.

11.5 In addition, this modification may enable a number of plants that are currently operating under a derogation (against the requirements of CC.6.3.4) to meet these requirements.

Impact on National Electricity Transmission System (NETS)

11.6 The reactive range available today from Synchronous Generating Units that are compliant with the existing requirements of the Grid Code will remain available.

11.7 The System Operator will have access to additional reactive range from plants that are currently operating under, or applying for a derogation; provided that these plants are willing to adopt the new MVAr control methodology to improve their performance.

11.8 State estimators, system models and modelling algorithms will need to be changed to reflect the new reactive power control methodology.

Impact on Greenhouse Gas emissions

11.9 The proposal facilitates the connection of the new generation of capacity up to 1800MW. This includes the new nuclear units which will be able to meet the new Grid Code requirements without the complexity of having to develop a purpose specific OLTC. These new nuclear units will reduce the need for fossil fuel and consequently reduce greenhouse gas emissions.

Assessment against Grid Code Objectives

11.10 The change proposed better facilitates the Grid Code objectives:

(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.

11.11 This modification allows Generators to connect new Generating Units with a capacity of up to 1800MW and meet the Grid Code requirements without having to procure a Generating Unit transformer with an excessive number of taps, a potentially unfeasible tap step, or a procure unproven technology. This provides them with much easier access to the Transmission System and facilitates competition.

11.12 It also allows Generators to move spare transformers between some of their sites without raising significant compliance issues. This allows a flexible and efficient use of spares.

11.13 Moreover, it retains the reactive power range currently required by the Grid Code and ensures it is available for the System Operator to use when required. That is, there are no negative implications on Transmission Licensees.

11.14 The change proposed does not impact the implementation of relevant provisions of the European Commission's Connection Codes at this time.

Impact on core industry documents

11.15 The GB Grid Code

Impact on other industry documents

11.16 None

Impact on Bilateral Agreements

11.17 Bilateral Agreements between NGET and Generators wishing to adopt the new methodology will need to require the provision of terminal voltage as an additional Operational Metering signal and to stipulate that they are allowed to adjust the terminal voltage of their Synchronous Generating Units.

11.18 Bilateral Agreements between NGET and Generators wishing to continue to operate at 1.0pu terminal voltage will not need to be changed.

Implementation

11.19 The Workgroup proposes that, should the proposals be taken forward, the proposed changes will be implemented 10 business days after an Authority decision.

12 Consultation Responses

12.1 Views are invited upon the proposals outlined in this consultation, which should be received by 07 August 2015 using the proforma provided.

12.2 Responses may be emailed to grid.code@nationalgrid.com.

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

12.4 Responses are invited to the following questions:

(i) Do you support the proposed approach? Please clarify why.

(ii) Do you believe that GC0028 better facilitates the appropriate Grid Code objectives? If not, why do they fail to do so?

(iii) Do the proposed changes facilitate efficient connection and operation of new and/or existing Synchronous Generating Units? If not, why do they fail to do so?

(iv) Do the proposed changes impose any additional material risks on the System Operator, e.g. reduced stability margins, reduced reactive capability margins, or difficulty in managing transmission system voltages? If yes, please highlight these risks.

(v) Do the proposed changes impose any additional material risks on Transmission Owners, e.g. additional investment that might be neither economic nor efficient? If yes, please highlight these risks.

(vi) Do the proposed changes adequately protect the interests of all Transmission System Users? If not, why do they fail to do so?

(vii) Are there further technical considerations to be taken into account? If yes, please highlight these technical considerations.

(viii) Is there any evidence that Users will be inappropriately or adversely affected by the changes proposed? If so, please provide details.

(ix) Do the modifications proposed strike an appropriate balance between the needs of Generators, Transmission Licensees, and other interested parties? If not, why do they fail to do so?

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

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

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

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

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Grid Code Review Panel

CONSTANT TERMINAL VOLTAGE

Date Raised: 03 July 2013

GCRP Ref: ppYY/XX[6]

A Panel Paper by Graham Stein

National Grid

Summary
Constant terminal voltage requirements set out in Grid Code Connection Condition CC.6.3.4

Users Impacted
High – Generating Units, Power Park Modules, DC Converters and OTSDUW Plant and Apparatus ***Medium –*** None Identified ***Low –*** None Identified

Description & Background

Background

Grid Code Connection Condition CC.6.3.4 (a) specifies that the Reactive Power Output of any Onshore Generating Unit, Onshore DC Converter and Onshore Power Park Module or OTSDUW Plant and Apparatus under steady state conditions should be fully available within the voltage range of ±5% at 400kV, 275kV and 132kV.

The issue relates to the first part of CC.6.3.4(a) where Generating Units, Power Park Modules, DC Converters and OTSDUW Plant and Apparatus are required to satisfy the above requirement rather then the latter section which relates solely to Onshore Power Park Modules connected at or below 33kV where the requirements are slightly less onerous.

In order to design and operate the Transmission System in a safe, secure and economic manner and ensure the flow of Active Power across the network, National Grid as System Operator will need to maintain a voltage profile across the network. The principle way in which this is achieved is through the provision of Reactive Power supplied by Generators, which is sometimes referred to as pillars of voltage support.

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

Under CC.6.3.2 of the Grid Code, Synchronous Generators are required to have a reactive capability at the Generating Unit terminals of 0.85 power factor lag (overexcited) to 0.95 Power Factor lead (underexcited) at rated MW output.

The additional requirement of CC.6.3.4 effectively requires the full reactive capability of the generating unit (as specified in CC.6.3.2) to be fully available for any HV voltage change of between ±5% of nominal at 400kV, 275kV, 132kV and below (whilst noting the exception for Power Park Modules and non Synchronous Generating Units connected at or below 33kV). For example if a Synchronous Generator where to be connected to an Hv node of nominal voltage of 400kV the Generator should be capable of generating its full reactive capability (at the Generator terminals ie 0.85 Power Factor Lag to 0.95 Power Factor Lag) at a System Voltage of 380kV to 420kV.

In practice the way in which this is achieved is for a Synchronous Generator is for the Automatic Voltage Regulator (AVR) to control the terminal voltage to a constant value (typically 21kV for a 500MW Generating Unit) and the onload tap changer on the Generator Transformer to adjust the MVAr output.

The advantage of this approach is that it enables the MVAr output of the Synchronous Generating Unit to be controlled independently of the machines terminal voltage which has the advantage of reducing voltage changes at the machines terminals (an important feature for ensuring regulation of station auxiliary supplies) and provides greater MVAr reserves to the System in the event of a fault or disturbance, this latter point being an essential in fulfilling the requirements of the SQSS.

Without this requirement (in particular the absence of an on load tapping facility fitted to the Generator Transformer), there is a risk of the potential need for greater reactive reserves, particularly in the post fault period and some means of providing greater regulation of station auxiliaries for example through a station transformer, the impact being potentially greater costs at both a transmission and generation level.

The Issue

The issue has recently come to light at a number of Power Stations utilising Synchronous Generating Units where the Generator Transformer tap has been insufficiently rated to provide the full reactive capability range over an HV voltage range of ±5%. The effect of which being a depletion of MVAr reserves, and the ability of the Transmission System to recover, particularly post fault.

In some countries it is not common practice to fit on-load tap changers to the Generator Transformer, with system voltage regulation being achieved by adjusting the set point of the AVR. In this instance, a direct comparison between GB and other countries is complex as the point at which Reactive Capability is delivered (ie at HV or LV) will vary as will the security criteria to which those countries operate (ie N-1 or N-D) operate.

National Grid has run a number of generic studies and identified that for a typical generator transformer with a fixed tap, to achieve the full reactive range over a ±5% voltage range would require a terminal voltage change in excess of ±10% which would cause significant issues for the Station's auxiliary supplies. The conclusion being that it would be inappropriate not to install an onload tap changer.

There are however a number of issues worthy of further consideration. The present wording of CC.6.3.4 states that the full reactive capability range should be achieved at nominal voltages of ±5% at 400kV, 275kV, 132kV and below. There is some debate as to whether it is appropriate for the Generator to be capable of supplying full MVAr exporting capability when the System Voltage is high and equally full importing capability when the system voltage is low. For example where a generator is connected at 400kV it seems inappropriate to require the generator to generate 0.85 Power Factor lag at system voltages of 420kV and equally absorb 0.95 Power Factor lead at System Voltages of 380kV. On this basis there may be some scope for defining a voltage against Reactive Power capability diagram with some capping applied at the extreme ends. There may also be some scope for adjusting the target voltage of the AVR but this would depend on the generator topology concerned.

Under Article 13 2(b) of the ENTSO-E Requirements for Generators Code the current proposed requirements define the combined reactive capability in terms of a voltage – Q / Pmax profile at the Connection Point (ie at the HV Connection Point) rather than the Generating Unit terminals. The current ENTSO-E RfG provides little choice in respect of the National selections (other than in respect of the boundary between MVAr import and MVAr export. At the time of writing the reactive capability in GB is expected to be equal to 0.9 Power Factor Lead to 0.9 Power Factor lag at the HV Connection Point over a voltage range of ±5%. This is broadly similar to the GB requirement but provides little scope for further amendment.

The ENTSO-E RfG comitology process is expected to commence in October 2013 with completion in early 2014. From then, there will be a 2 – 3 year implementation process where the National Codes (ie the GB Grid Code) will need to be amended to ensure it is consistent with the requirements of the ENTSO-E RfG which is expected in 2016 -2017. Where National choices are available, these will be subject to the full Governance arrangements of the GB Grid Code.

In so far as the issue associated with CC.6.3.4 is concerned, the ENTSO-E RfG requirement will remain which is expected to still necessitate the installation of a Generator Transformer fitted with an On-load Tap Changer. There is some scope for National Choice around this requirement although these are limited. Notwithstanding this requirement however the ENTSO-E RfG does not mandate the requirement for a Generator to maintain constant terminal voltage.

Proposed Solution
National Grid acknowledge there are some issues associated with CC.6.3.4 of the Grid Code however any such change would need to be fully consistent with the

ENTSO-E RfG. It should be noted that the ENTSO-E RfG as currently drafted does provide for some limited National choices, but is not prescriptive in requiring the Generator to maintain constant terminal voltage.

Assessment against Grid Code Objectives
Will the proposed changes to the Grid Code better facilitate any of the Grid Code Objectives: ***(i)*** ***to permit the development, maintenance and operation of an efficient, coordinated and economical system for the transmission of electricity;*** ***(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 better facilitate objectives (i)(ii) and (iii) to ensure consistency with the ENTSO-E RfG which will be required under European law. Although there are limited National Choices under the ENTSO-E RfG in respect of Reactive Power Capability and HV Voltage variation this would not preclude the need to maintain a constant Generator terminal voltage. Any such change within the framework of the ENTSO-E RfG would provide greater certainty to Generators and manufacturers at the design and operational stages.

Impact & Assessment
Impact on the National Electricity Transmission System (NETS) On the basis that any proposed change would be consistent with the ENTSO-E Requirements for Generators no impact is identified on the National Electricity Transmission System or in respect of User's of the Transmission System. ***Impact on Greenhouse Gas Emissions*** No impacts are envisaged on Green House Gas Emissions as a result of any proposed modification.

Impact on core industry documents

The proposed modification may potentially impact on the GB Grid Code although such changes would need to included through the ENTSO-E RfG implementation process.

Impact on other industry documents

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

Supporting Documentation	
Have you attached any supporting documentation	No
If Yes, please provide the title of the attachment:	Not applicable

Recommendation

The Grid Code Review Panel is invited to:

Consider the issue and provide guidance/clarification

GC0028 CONSTANT TERMINAL VOLTAGE

TERMS OF REFERENCE

Governance

1. The GC0028 Constant Terminal Voltage Workgroup was established by Grid Code Review Panel (GCRP) at the November 2013 GCRP meeting.

2. The Workgroup shall formally report to the GCRP.

Membership

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

Name	Role	Representing
Graham Stein	Chair	
TBC	Technical Secretary	
Antony Johnson	National Grid Representative	National Grid
	Industry Representative	[Elexon]
	Industry Representative	[Grid Code User]
	Industry Representative	[Interested Parties]
	Authority Representative	Ofgem
	Observer	

Meeting Administration

4. 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.

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

6. 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

7. The Workgroup shall consider and report on the following:
   - National Grid's proposal for clarification of CC.6.3.4, CC.6.3.8(a)(i) and the associated costs and benefits of implementing such a proposal;

   - Alternative proposals to provide for supplementing synchronous generator tap changer range with terminal voltage adjustments and the associated costs and benefits of implementing such a proposal;

- The relevant provisions of ENTSO-E RfG to ensure that the Workgroup's proposals do not conflict with future requirements;

Deliverables

8. The Workgroup will provide updates and a Workgroup Report to the Grid Code Review Panel which will:
    - Detail the findings of the Workgroup;
    - Draft, prioritise and recommend changes to the Grid Code and associated documents in order to implement the findings of the Workgroup; and
    - Highlight any consequential changes which are or may be required,

Timescales

9. It is anticipated that this Workgroup will provide an update to each GCRP meeting and present a Workgroup Report to the July 2013 GCRP meeting.

10. 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.

Connection Conditions

CC.6.3.2

(f) In addition, a **Genset** shall meet the operational requirements as specified in BC2.A.2.6.

CC.6.3.8 (a)

(v) Unless otherwise required for testing in accordance with OC5.A.2, the automatic excitation control system of an **Onshore Synchronous Generating Unit** shall always be operated such that it controls the **Onshore Synchronous Generating Unit** terminal voltage to a value that is

- equal to its rated value; or
- only where provisions have been made in the **Bilateral Agreement**, greater than its rated value.

(~~v~~ vi) In particular, other control facilities, including constant **Reactive Power** output control modes and constant **Power Factor** control modes (but excluding VAR limiters) are not required. However, if present in the excitation or voltage control system they will be disabled unless the **Bilateral Agreement** records otherwise. Operation of such control facilities will be in accordance with the provisions contained in BC2.

Balancing Codes

BC2.A.2.6

MVAr Output

The individual MVAr output from the **Genset** onto the **National Electricity Transmission System** at the **Grid Entry Point** (or onto the **User System** at the **User System Entry Point** in the case of **Embedded Power Stations**), namely on the higher voltage side of the generator step-up transformer. In relation to each **Genset**, where there is no HV indication, **NGET** and the **Generator** will discuss and agree equivalent Mvar levels for the corresponding LV indication.

Where a **Genset** is instructed to a specific MVAr output, the **Generator** must achieve that output within a tolerance of ±25 MVAr (for **Gensets** in England and Wales) or the lesser of ± 5% of rated output or 25MVAr (for **Gensets** in Scotland) (or such other figure as may be agreed with **NGET**) by tap changing on the generator step-up transformer, or adjusting the **Genset** terminal voltage, subject to compliance with CC.6.3.8 (a) (v), to a value that is equal to or higher than 1.0p.u. of the rated terminal voltage, or a combination of both ~~unless agreed otherwise~~. Once this has been achieved, the **Generator** will not tap again and will not readjust the **Genset** terminal voltage without prior consultation with and the agreement of **NGET**, on the basis that MVAr output will be allowed to vary with **System** conditions.

Target Voltage Levels

Target voltage levels to be achieved by the **Genset** on the **National Electricity Transmission System** at the **Grid Entry Point** (or on the **User System** at the **User System Entry Point** in the case of **Embedded Power Stations**, namely on the higher voltage side of the generator step-up transformer. Where a **Genset** is instructed to a specific target voltage, the **Generator** must achieve that target within a tolerance of ±1 kV (or such other figure as may be agreed with **NGET**) by tap changing on the generator step-up transformer, or adjusting the **Genset** terminal voltage, subject to compliance with CC.6.3.8 (a) (v), to a value that is equal to or higher than 1.0p.u. of the rated terminal voltage, or a combination of both ~~unless agreed otherwise~~.
In relation to each **Genset**, where there is no HV indication, **NGET** and the **Generator** will discuss and agree equivalent voltage levels for the corresponding LV indication.
Under normal operating conditions, once this target voltage level has been achieved the **Generator** will not tap again and will not readjust the **Genset** terminal voltage without prior consultation with, and with the agreement of, **NGET**.
However, under certain circumstances the **Generator** may be instructed to maintain a target voltage until otherwise instructed and this will be achieved by tap changing on the generator step-up transformer, or adjusting the **Genset** terminal voltage, subject to compliance with CC.6.3.8 (a) (v), to a value that is equal to or higher than 1.0p.u. of the rated terminal voltage, or a combination of both without reference to **NGET**.

Operating Code No. 2

OC2.4.2 DATA REQUIREMENTS

OC2.4.2.1 When a **Statement** of **Readiness** under the **Bilateral Agreement** and/or **Construction Agreement** is submitted, and thereafter in calendar week 24 in each calendar year,

(m) For each **Synchronous Generating Unit** where the **Generator** intends to adjust the **Generating Unit** terminal voltage in response to a MVAr Output Instruction or a Target Voltage Level instruction in accordance with BC2.A.2.6 the **Generator Performance Chart** shall show curves corresponding to the **Generating Unit** terminal voltage being controlled to its rated value and to its maximum value.

Operating Code No. 5

OC5.A.2.7.5 The ability of the **Generating Unit** to comply with the operational requirements specified in BC2.A.2.6 and CC.6.1.7 will normally be demonstrated by changing the tap position and, where agreed in the **Bilateral Agreement**, the **Generating Unit** terminal voltage.

Planning Code

PC.A.5.3.2 The following **Synchronous Generating Unit** and **Power Station** data should be supplied:

(a) **Synchronous Generating Unit** Parameters

Rated terminal volts (kV)

Maximum terminal voltage set point (kV)

Terminal voltage set point step resolution – if not continuous (kV)

* Rated MVA

*** Rated MW**

* Minimum Generation MW

Compliance Processes

CP.A.3.3.2

In the case of a **Synchronous Generating Unit** the terminal voltage in the simulation should be the nominal voltage for the machine. Where necessary to demonstrate compliance with CC.6.3.4 and subject to compliance with CC.6.3.8 (a) (v)**,** the **Generator** shall repeat the two simulation studies with the terminal voltage being greater than the nominal voltage and less than or equal to the maximum terminal voltage. The two additional simulations do not need to have the same terminal voltage.

CP.A.3.3.3

In the case of a **Synchronous Generating Unit** the **Generator** shall supply two sets of simulation studies to demonstrate the capability to meet the operational requirements of BC2.A.2.6 and CC.6.1.7 at the minimum and maximum short circuit levels when changing tap position. Each set of simulation studies shall be at the same system conditions. None of the simulation studies shall include the **Synchronous Generating Unit** operating at the limits of its **Reactive Power** output.

The simulation results shall include the **Reactive Power** output of the **Synchronous Generating Unit** and the voltage at the **Grid Entry Point** or, if **Embedded**, the **User System Entry Point** with the **Generating Unit** transformer at two adjacent tap positions with the greatest interval between them and the terminal voltage of the **Synchronous Generating Unit** equal to

- its nominal value; and
- subject to compliance with CC.6.3.8 (a) (v), its maximum value.

CP.A.3.3.~~3~~4

In the case of a **Power Park Module** where the load flow simulation studies show that the individual **Power Park Units** deviate from nominal voltage to meet the **Reactive Power** requirements then evidence must be provided from factory (e.g. in a **Manufacturer's Data & Performance Report**) or site testing that the **Power Park Unit** is capable of operating continuously at the operating points determined in the load flow simulation studies.

SCHEDULE 1 - GENERATING UNIT (OR CCGT MODULE), POWER PARK MODULE AND DC CONVERTER TECHNICAL DATA

DATA DESCRIPTION	UNITS	DATA to **RTL** CUSC Contract	CUSC App. Form	DATA CAT.	**GENERATING UNIT** (OR CCGT MODULE, AS THE CASE MAY BE) G1	G2	G3	G4	G5	G6	STN
Rated MVA *(PC.A.3.3.1)*	MVA	□	■	**SPD+**							
Rated MW *(PC.A.3.3.1)*	MW	□	■	**SPD+**							
Rated terminal voltage *(PC.A.5.3.2.(a) & PC.A.5.4.2 (b))*	kV	□		**DPD I**							
Maximum terminal voltage set point*(PC.A.5.3.2.(a) & PC.A.5.4.2 (b))*	kV	□		**DPD I**							
Terminal voltage set point step resolution – if not continuous *(PC.A.5.3.2.(a) & PC.A.5.4.2 (b))*	kV	□		**DPD I**							
***Output Usable** (on a monthly basis) *(PC.A.3.2.2(b))*	MW			**SPD**	(except in relation to **CCGT Modules** when required on a unit basis under the **Grid Code**, this data item may be supplied under Schedule 3)						
Turbo-Generator inertia constant (for synchronous machines) *(PC.A.5.3.2(a))*	MW secs /MVA	□	■	**SPD+**							
Short circuit ratio (synchronous machines) *(PC.A.5.3.2(a))*		□	■	**SPD+**							
Normal auxiliary load supplied by the **Generating Unit** at rated MW output *(PC.A.5.2.1)*	MW MVAr	□ □		**DPD II** **DPD II**							
Rated field current at rated MW and MVAr output and at rated terminal voltage *(PC.A.5.3.2 (a))*	A	□		**DPD II**							
Field current open circuit saturation curve (as derived from appropriate manufacturers' test certificates): *(PC.A.5.3.2 (a))*											
120% rated terminal volts	A	□		**DPD II**							
110% rated terminal volts	A	□		**DPD II**							
100% rated terminal volts	A	□		**DPD II**							
90% rated terminal volts	A	□		**DPD II**							
80% rated terminal volts	A	□		**DPD II**							
70% rated terminal volts	A	□		**DPD II**							
60% rated terminal volts	A	□		**DPD II**							
50% rated terminal volts	A	□		**DPD II**							

<u>IMPEDANCES</u>:												
(Unsaturated)												
Direct axis synchronous reactance *(PC.A.5.3.2(a))*	% on MVA	□		**DPD I**								
Direct axis transient reactance *(PC.A.3.3.1(a)& PC.A.5.3.2(a)*	% on MVA	□	■	**SPD+**								
Direct axis sub-transient reactance *(PC.A.5.3.2(a))*	% on MVA	□		**DPD I**								
Quad axis synch reactance *(PC.A.5.3.2(a))*	% on MVA	□		**DPD I**								
Quad axis sub-transient reactance *(PC.A.5.3.2(a))*	% on MVA	□		**DPD I**								
Stator leakage reactance *(PC.A.5.3.2(a))*	% on MVA	□		**DPD I**								
Armature winding direct current resistance. *(PC.A.5.3.2(a))*	% on MVA	□		**DPD I**								
In Scotland, negative sequence resistance *(PC.A.2.5.6 (a) (iv)*	% on MVA	□		**DPD I**								

Note:- the above data item relating to armature winding direct-current resistance need only be provided by **Generators** in relation to **Generating Units** commissioned after 1st March 1996 and in cases where, for whatever reason, the **Generator** is aware of the value of the data item.