THE DISTRIBUTION CODE OF LICENSED DISTRIBUTION NETWORK OPERATORS OF GREAT BRITAIN

Stage 04: Report to the Authority

DC0079 Frequency Changes during Large Disturbances and their Impact on the Total System

The purpose of this document is to assist the Authority in its decision to implement the proposed modifications to the Distribution Code and Engineering Recommendations G59. The proposed modifications were subject to industry consultation in August 2017. Responses from this consultation show that the industry is in favour of these modifications.

What stage is this document at?

01	Proposal Form
02	Workgroup Report
03	Industry Consultation
04	Report to the Authority

Published on: 17/10/2017

Recommendation

The Distribution Code Review Panel recommended that the following modifications are made to the Distribution Code and Engineering Recommendations G59 to ensure that all embedded generators with a commissioning date on or after 1 February 2018 comply with the following:

a) That where rate of change of frequency (RoCoF) protection is used as Loss of Mains protection, the applied setting should be 1Hzs-1 with a definite time delay of 500ms.

b) That all generation using discrete relays (non- type-tested) as part of their loss of mains technique should demonstrate stability for appropriate RoCoF and vector shift disturbances

c) That vector shift protection technique should not be used as Loss of Mains protection for generators using discrete relays as part of loss of mains protection scheme.

High Impact:

Medium Impact:

New developers of embedded generation installations as vector shift cannot be used as Loss of Mains protection and 1Hzs^{-1} with 500ms time delay should be used if RoCoF is chosen.

Low Impact:

None identified.

Contents

Any Questions?

Contact:

First Last

David Spillett

+44 (0) 20 7706 5124

Proposer:

First Last

National Grid

Document Control

Version	Date	Author	Change Reference
0.1	22/09/2017	National Grid	Draft Report
1.0	17/09/2017	National Grid	Report to the authority

1 Executive Summary

1.1 Engineering Recommendations G59 and G83, which form part of the Distribution Code, require embedded power stations to be fitted with Loss of Mains (LoM) protection. This is to ensure that these power stations, following disconnection of all or part of the local distribution system to which they are connected from the rest of the distribution system, do not sustain an island with the local demand. The two most common forms of LoM protection are vector shift (VS) and rate of change of frequency (RoCoF).

1.2 The principle of RoCoF protection operation is based on the assumption that disconnection of an embedded generator and local network from the main distribution network will result in the local frequency changing at a rate that is higher than the RoCoF that is expected to be seen on the total system under a range of normal operational conditions. RoCoF relays measure this rate within the generator's installation and once it exceeds the pre-defined threshold for the required period of time, the relay disconnects the generating plant from the network. The RoCoF pre-defined threshold level has historically been $0.125Hzs^{-1}$. The Distribution Code was changed in 2014 to define this threshold to be $1Hzs^{-1}$ with definite time delay of 500ms for power stations of registered capacity of 5MW and above, based on the recommendations of the industry workgroup GC0035.

1.3 The principle of VS protection operation is based on the assumption that a disconnection of an embedded generator and local network from the main distribution network will result in a change in the phase angle of the AC voltage waveform in the islanded system. VS relays monitor change of phase angle between two successive cycles and if it exceeds the pre-defined threshold, the relay disconnects the generating plant from the network. The current VS threshold level stated in the Distribution Code is 6 degrees for low impedance networks and 12 degrees for high impedance networks.

1.4 On several occasions, it has been suspected that a transmission system fault that did not result in islanding resulted in the inadvertent tripping of embedded generation plants by their LoM protection. A definite event was recorded on 22 May 2016 following a single transmission circuit fault. Further investigation of this event showed that a significant number of embedded generation plants had tripped as a result of the operation of VS protection. This event resulted in a loss of infeed and a frequency excursion that was bigger than that which was anticipated.

1.5 Recognizing the general decline in inertia and volatility of system frequency, in 2012 GC0035 was appointed by the Grid Code Review Panel and the Distribution Code Review Panel to review the suitability of RoCoF protection. The workgroup recommended that, for embedded generation of 5MW capacity and above, the minimum RoCoF relay settings should be changed to $1Hzs^{-1}$ with a definite time delay of 500ms. The increase in the risk of islanding due to this change was found to be acceptable. The cost of applying the change retrospectively was found to be less than the cost of managing the risk of that generation tripping in real time. The Authority accepted the GC0035 workgroup recommendation that the modification be applied retrospectively.

1.6 This industry workgroup (WG), GC0079, was then appointed by the Grid Code Review Panel and the Distribution Code Review Panel with the aim of extending the same considerations of the GC0035 workgroup to embedded generation with a registered capacity less than 5MW.

1.7 Following the May 2016 incident, the Grid Code Review Panel and the Distribution Code Review Panel requested that the workgroup specifically assess the suitability of VS protection. Analysis carried out by the workgroup suggests that the risk of inadvertent operation of VS protection during a transmission system fault is significant (although it varies based on the network topology and the type of fault) yet the risk of VS protection being unable to detect genuine islanding events remains high compared to that where RoCoF protection is deployed. Hence, the workgroup recommends that VS protection should no longer be used as means of LoM protection.

1.8 The workgroup further recommends that where a LoM is provided via a relay, this should be a RoCoF relay with a setting of $1Hzs^{-1}$ with a definite time delay of 500ms. The WG noted that the risks associated with applying this setting are higher than that associated with the present settings of $0.125Hzs^{-1}$. However the risks are significantly lower than those associated with VS protection. Hence the recommendation is expected to result in a reduction in the overall risk of islanding in GB.

1.9 In reaching this conclusion the workgroup took into account that over the past 25 years no documented incident associated with out-of-phase auto-reclosure has ever been reported or any attempts made to record them. This is an important measure of the underling risk especially taking into account the current prevalence of ineffective VS protection with inferior island detection characteristic that is in use.

1.10 While this recommendation is forward looking, the workgroup has yet to determine whether this should apply retrospectively or not. A decision will have to take into account both the costs of managing the risk in real time and the costs of manually changing the settings on existing protection.

1.11 The workgroup noted that the rate at which new embedded generation plant is being connected to distribution network is currently high and likely to remain so. This increases the risks of increasing volumes of generation capacity being inadvertently tripped by operation of RoCoF or VS protection as a consequence of transmission faults. Continuing to use VS protection or RoCoF protection with the current settings will also increase the costs required to apply the change retrospectively, depending on the final recommendation of the workgroup at the conclusion of its mandate. Hence, the workgroup recommends that the changes to the settings are applied as soon as reasonably practicable for all new installations and prior to concluding on whether retrospective application would be necessary or not.

1.12 The workgroup recommends that, as a first stage, Engineering Recommendations G59 should be modified to specify that the RoCoF threshold for embedded generation of registered capacity below 5MW commissioned on or after 1 February 2018 should be $1Hzs^{-1}$ with a definite time delay of 500ms and that all embedded generation commissioned after this date shall not be fitted with VS protection.

1.13 The workgroup had also recommended, during consultation, that type tested generators should comply with the same recommendations by 1 February 2018. However no feedback was received from manufacturers of type tested embedded generators. The WG then decided to carry out a post consultation inquiry targeting manufacturers of type tested plant.

1.14 While most of the manufacturers approached in the post consultation enquiry did not respond at all, the few that did respond were split between stating that there would probably be no problem in complying and other stating that they would need more time. Two manufacturers with an estimated UK market share of over 30% have begun to engage at a detailed level and have requested more time to analyses the implications of this change. From this interaction it has been concluded that more time and further engagement with manufacturers of type tested embedded generation will be needed before Engineering Recommendation G83 is modified. This modification will require the manufacturers to undertake, at least, repeat type testing of their plant, and may involve redesign, to ensure compliance.

1.15 This report recommends that generating plant with a commissioning date on or after 1 February 2018 comply with the following:

a) That if rate of change of frequency (RoCoF) protection is used as Loss of Mains protection, the applied setting should be $1Hzs^{-1}$ with a definite time delay of 500ms;

b) That all generation using discrete relays as part of their loss of mains technique should demonstrate stability for appropriate RoCoF and vector shift disturbances;

c) That vector shift protection technique should not be used as 'Loss of Mains' protection for generators using discrete relays (non-type tested type).

1.16 The workgroup will continue their investigation, as a second stage, to determine the benefit of applying this change retrospectively and how to apply these recommendations to type tested embedded generators. This could result in a further modification to Engineering Recommendations G59, and the Distribution Code as well as Engineering Recommendations 83.

1.17 The workgroup believes that the terms of reference have not yet been completely discharged and will continue to pursue other issues within its terms of reference in parallel with this recommendation.

1.18 At the meeting of the Distribution Code Review Panel (the Panel) held on 26 October 2017, the Panel unanimously agreed to the submission of the Report to Authority as the Panel agreed that the Modification proposal better facilitated the objectives of the Distribution Code.

2 Purpose & Scope of the Workgroup

2.1 The Frequency Changes during Large Disturbances and their impact on the Total System Workgroup was established by the Grid Code Review Panel (GCRP) and Distribution Code Review Panel (DCRP) in 2012.

2.2 The reasons and background for the formation of the workgroup are covered in Chapter 3 (Workgroup discussion) of the Phase 1, GC0035 document to the authority available on National Grid's website. Further to this, the same workgroup was reconstituted under GC0079 with the aim of extending the recommendations of GC0035 to embedded generation with a registered capacity less than 5MW.

2.3 The following are the workgroup objectives relevant to this workgroup consultation:

2.3.1 To deliver proposals concerning RoCoF based protection on embedded generators with a registered capacity of less than 5MW.

2.3.2 To investigate and recommend on the suitability of VS protection as an alternative to RoCoF, taking into account its possible unsuitability for transmission fault ride through requirements.

Terms of Reference

2.4 A copy of the Terms of Reference can be found in Annex 1

Timescales

2.5 The GC0079 workgroup held a sequence of 37 meetings, the first on 14 June 2013 with the most recent meeting being on 26 September 2017. These meetings are likely to continue until the workgroup has fully executed its mandate.

3 Why Change?

Background

3.1 It is predicted that the installed capacity of embedded generation will continue to increase over the next two decades. This is illustrated by Figure 1 which depicts the total capacity of embedded Medium Power Stations and embedded Small Power Stations in Great Britain according to Future Energy Scenarios 2016 – Gone Green scenario. The total capacity of embedded generation will be higher than that shown in Figure 1 as the figure does not include embedded Large Power Stations.

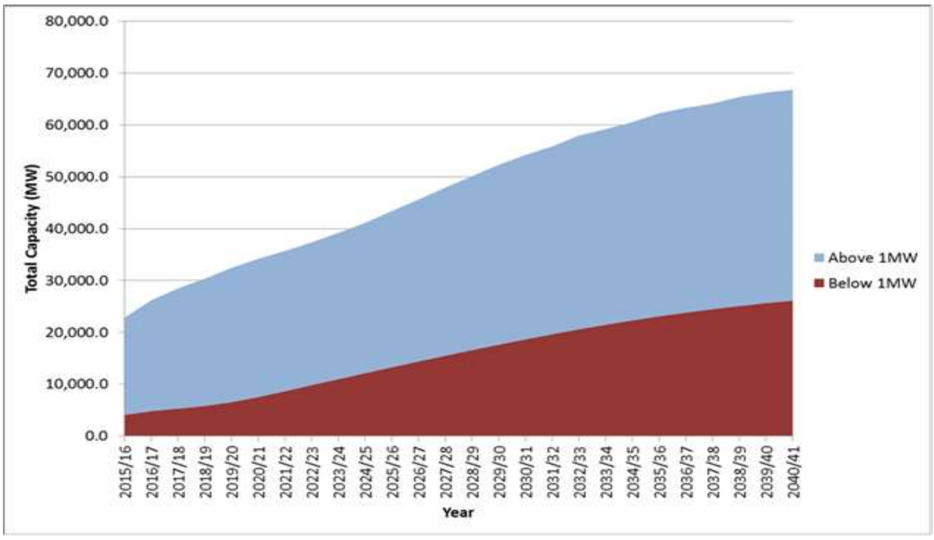

Figure 1

3.2 In order to avoid a scenario where, following disconnection from the main distribution network, embedded generation forms an island of a local distribution network together with its local demand, Engineering Recommendations G59 and G83, which form part of the Distribution Code, requires that all embedded generation is equipped by some form of LoM protection. This protection could be in the form of RoCoF relays, VS relays, direct intertripping, or for type tested units based on other techniques.

3.3 As the total installed capacity of embedded generation increases, it is increasingly important that embedded generation rides through and remains connected to the system following disturbances on the transmission system that do not require it to be disconnected. This is to ensure that the System Operator, National Grid, is able to meet its licence obligation of ensuring that the frequency remains within the limits specified within the Grid Code and the National Electricity Transmission System Security and Quality of Supply Standard (NETS SQSS) and that tripping of demand by low frequency demand disconnection protection is minimised. Hence, it is necessary to ensure that the LoM protection settings, including those on both RoCoF relays and VS relays, are such that these relays only respond to genuine islanding events.

3.4 System inertia continues to decrease due to changes in the GB generation mix. This has been driven by the government target to supply electricity from renewable sources and the decommissioning of large coal and gas fired plant. This has increased the risk that loss of generation or demand could result in a RoCoF that exceeds the current settings of RoCoF protection. This would unnecessarily trigger the additional loss of generation and could eventually lead to demand being tripped by the low frequency demand disconnection protection.

3.5 To manage the risk in real time, National Grid continuously monitors the system inertia and the largest generation/demand loss that is required to be secured and uses both numbers to calculate the RoCoF associated with this loss. If this value of RoCoF is higher than 0.125Hzs-1, National Grid takes balancing actions to reduce the largest loss and/or increase the system inertia to bring this level below the 0.125 Hzs-1, removing the risk that such a loss would result in the operation of RoCoF protection. The cost of these balancing services is approximately £30M/annum.

3.6 Further analysis of the generation mix in the System Operability Framework (SOF) 2016 report suggests that the system inertia will continue to decrease over the next 20 years. The inertia probability density is shown in Figure 2. This decrease, along with the increase anticipated in the largest generation loss of 1800MW, will increase the costs of the balancing services required to ensure that RoCoF remains within 0.125 Hzs^{-1}.

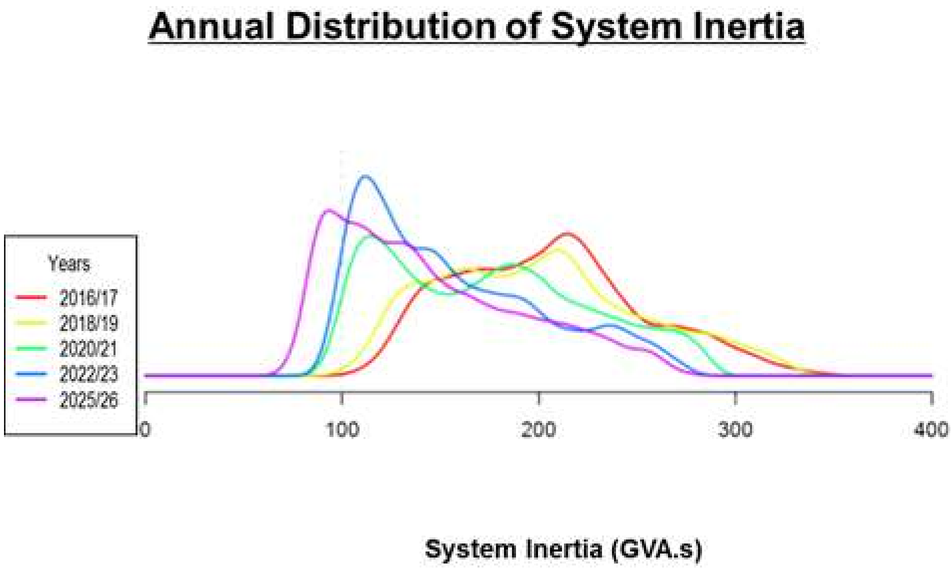

Figure 2

3.7 To reduce the risk of inadvertent tripping of embedded generation, a joint Grid Code/Distribution Code workgroup was setup to revise the LoM protection settings. A two stage approach was implemented by the workgroup. In Phase 1, the GC0035 workgroup chose to look at the settings of RoCoF protection for embedded generation with a registered capacity of 5MW and above. In Phase 2, the GC0079 workgroup was tasked to monitor the implementation of the GC0035 workgroup recommendations and to look at extending these recommendations to embedded generation with a registered capacity of less than 5MW. At the time of the workgroup inception, inadvertent operation of VS protection was not considered to be a significant risk.

3.8 The GC0035 working group agreed that, based on the anticipated drop in system inertia and the increase of the largest loss of infeed risk, and in order to minimise the risk of inadvertent tripping of embedded generation by RoCoF protection, the protection on generation plant with a registered capacity more than 5MW should not operate unless the RoCoF measured by them exceeds 1Hzs^{-1} for 500ms. The risk that RoCoF relays set according to these settings could fail to detect islanding was assessed. From the analysis, the expected number of islanding events was found to be $5.7x10^{-4}$ per annum. The risk of members of the public subjected to an electric shock was estimated to be $2.37x10^{-9}$ incidents per annum in GB which is “as low as reasonable practicable” and resides within the ‘‘broadly acceptable'' region of personal risk accepted as consistent with the Health and Safety at Work Act 1974. The number of out-of-phase auto-reclosure was estimated to be 4.56×10^{-4} incidents per annum.

3.9 Based on the interpretation of the analysis, the GC0035 workgroup recommended that Engineering Recommendations G59 be modified to specify that, for embedded power stations of registered capacity of 5MW or above, RoCoF protection should not operate unless the measured RoCoF exceeds 1 Hzs^{-1} for more than 500ms.

3.10 Following an Industry Consultation, the modification proposed by the GC0035 workgroup to Engineering Recommendations G59 was implemented and a programme to revisit the settings of all RoCoF protection for generation of registered capacity 5MW and above was been agreed and is now substantially complete.

3.11 In Phase 2, the GC0079 workgroup agreed that, in order to achieve the full benefit of the modification proposed by the GC0035 workgroup, the RoCoF protection for all embedded generation should have uniform settings. Hence it was agreed that the workgroup would assess the risks and benefits of extending the same settings proposed in GC0035 to apply to all embedded generation.

3.12 On 22 May 2016, a single circuit 400kV transmission fault triggered an approximate 400MW increase in the net transmission system demand in the South West Peninsula. Further investigation of this event attributed this increase in demand to the disconnection of a significant number of embedded power stations as a result of their VS protection operating. This incident highlighted the risk that vector shift protection imposes on the transmission system.

4 Workgroup Discussions

4.1 The first workgroup meeting on Frequency Changes during Large System Disturbances Workgroup (under GC0079) was held on the 14/06/13.

Risks Arising from Changing the Settings of RoCoF Relays

4.1 The Workgroup commissioned the University of Strathclyde to extend the assessment it had carried out under GC0035 to generators whose registered capacity is less than 5MW. The assumptions, methodology, and the detailed results of this work are documented in ‘Annex 5 Strathclyde Report 1’ of this workgroup report. The assumptions made are believed to represent the worst case scenarios.

4.2 The Workgroup notes a view that the absolute numbers quoted in the results of both reports and in this document represent a very pessimistic estimate of islanding risks and should be considered in the context of observed events. However, the real value of the analysis is in establishing the relative effectiveness for all the protection settings considered compared to each other. The logic behind this view is discussed in later sections.

4.3 The different RoCoF protection settings that were assessed and the indices that quantify the risk for each of these settings, if applied to the total population of affected generators, are tabulated in Table 1. Note that the risk figures quoted in Table 1 and in the abovementioned Strathclyde report, do not account for the Workgroup’s subsequent assessment of the relative risks arising from the use of Vector Shift techniques, which are discussed below.

<table>
<tr><th>Setting Option</th><th>RoCoF [Hzs^{-1}]</th><th>Time Delay [s]</th><th>N_{LOM}</th><th>P_{LOM}</th><th>IR_E</th><th>N_{OA}</th></tr>
<tr><td>1</td><td>0.13</td><td>0</td><td>1.66E-01</td><td>8.06E-08</td><td>8.06E-10</td><td>1.33E-01</td></tr>
<tr><td>2</td><td>0.20</td><td>0</td><td>3.29E-01</td><td>1.95E-07</td><td>1.95E-09</td><td>2.64E-01</td></tr>
<tr><td>3</td><td>0.50</td><td>0.5</td><td>2.96E+01</td><td>1.87E-05</td><td>1.87E-07</td><td>2.37E+01</td></tr>
<tr><td>4</td><td>1.00</td><td>0.5</td><td>5.66E+01</td><td>3.57E-05</td><td>3.57E-07</td><td>4.53E+01</td></tr>
<tr><td rowspan="2">9</td><td colspan="2">No LOM protection UV/OV, UF/OF according to G59/3</td><td>9.91E+01</td><td>6.28E-05</td><td>6.28E-07</td><td>7.93E+01</td></tr>
<tr><td colspan="2">Percentage risk increase compared to setting option 4</td><td>75%</td><td>76%</td><td>76%</td><td>75%</td></tr>
</table>

Table 1

N_{LOM} expected national number of undetected islanding incidents in 1 year

P_{LOM} overall probability of the occurrence of an undetected island within a period of 1 year

IR_E annual probability related to individual risk (injury or death of a person) from the energised parts of an undetected islanded network

N_{OA} annual rate of occurrence of any generator being subjected to out-of- phase auto-reclosure during the islanding condition not detected by LOM protection

Option 9 No dedicated LOM protection

4.4 In general, changing the settings of RoCoF relays on embedded generators with a registered capacity less than 5MW from 0.125Hzs^{-1} to 1Hzs^{-1} with a delay of 500ms increases the risks associated with islanding by two orders of magnitude.

4.5 Even with the pessimistic assumptions made in the report, the risk related to accidental electrocution (IRE) for the proposed RoCoF settings 1Hzs^{-1} with 500ms time delay is in the region of 10^{-7} per annum, and therefore lies within what is termed as the "broadly acceptable" region of personal risk accepted as consistent with the Health and Safety at Work Act 1974.

4.6 A comparison between RoCoF at 1Hzs^{-1} with a time delay of 500ms (option 4) and having no loss of main (Option 9) has been made in Table 1. It can be seen that the risk increases by over 75% across all indices. This highlights the benefit of retaining RoCoF at proposed settings as part of the overall G59 protection requirements.

Inadvertent Tripping of Embedded Generation by VS Relays

4.7 The Workgroup discussed the results of the power system studies that were carried out by National Grid to assess the risk of inadvertent tripping of embedded generation by VS relays. These studies included EMT simulations on a small power system and dynamic simulations on both the small power system and the GB system. Consistency checks were carried out by the University of Strathclyde.

4.8 The changes in phase angle calculated following an event on the transmission system at busbars that are within close electrical proximity to the event are shown in Table 2. The change in phase angle following a three phase short circuit is sufficiently large to trigger the operation of VS relays. On the other hand, desynchronising a generating unit or switching out a super grid transformer does not result in large changes in phase angles.

	3 Phase fault	**Switching Event**	
Location	**[°]**	**Generating Unit[°]**	**SGT[°]**
Landulph 400kV	57.48	1.453	0.017
Landulph 132kV	33.15	1.436	5.633
Plymouth 33kV	33.45	1.23	0.13
Hayle 33kV	32.78	1.299	0.58
Exmouth 33kV	20.72	0.997	0.025
Barnstaple 33kV	25.14	1.037	0.349
Langage 400kV	33.25	1.514	0.201

Table 2: Change In Voltage Phase Angle [in degrees]

4.9 The changes in phase angle computed at different busbars following a three phase short circuit at the Landulph end of a Langage/Landulph 400kV circuit are shown in the map in Figure 3. The Workgroup noted that the fault causes a widespread change in phase angle. This change reduces as the electrical distance between the busbar and the fault increases.

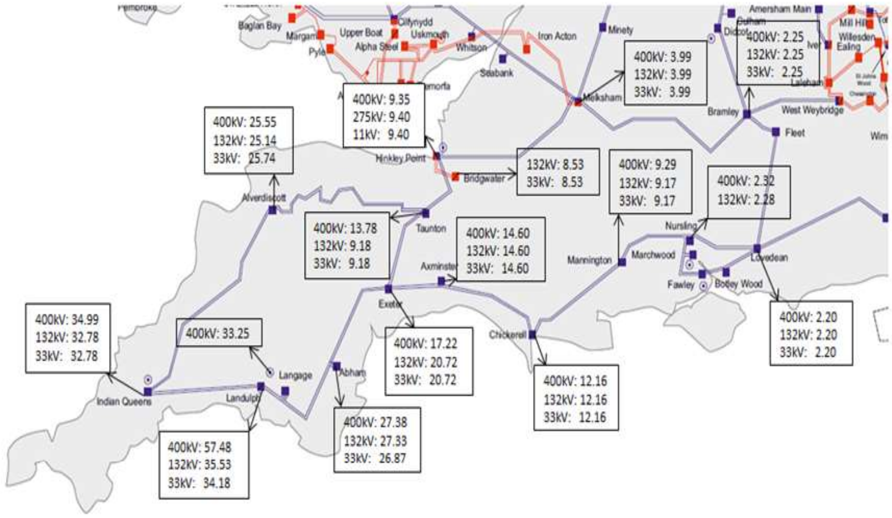

Figure 3 Change in Voltage angle Across the Transmission system

4.10 Table 3 below shows that generation and demand background will have only a minor effect on the calculated phase angle change. This change in the phase angle is calculated at Landulph 400kV substation following a three phase short circuit at the Landulph end of the Langage/Landulph 400kV circuit. The same conclusion has been drawn for other substations shown in Table 2.

	Change of Voltage phase angle [°]
Base case	57.48
One Langage machine out of service	61.30
40% increase in demand	56.60
40% decrease in demand	58.22
Winter peak demand	55.83

Table 3: Change in angle for different loading conditions.

4.11 The same studies were repeated at other parts of the system and the same observations were noted. Comparing the results of different areas with each other, it was not possible to define a consistent criterion that could be used to assess the reduction in the change in phase angle as the electrical distance from the point of fault increases.

Managing the Risk of Inadvertent Tripping of Embedded Generation by VS Relays

4.12 In order to ensure that, following the secured event of a three phase short circuit, the frequency remains within the limits specified in the Grid Code and the National Electricity Transmission System Security & Quality of Supply Standards (NETS SQSS), the system operator will have to procure sufficient frequency response service to cover the loss of any generating unit that would be disconnected following the fault and any additional embedded generation that could reasonably be expected to be tripped by their VS relays following such fault.

4.13 Where the total loss is larger than the largest loss allowed to ensure that RoCoF does not exceed 0.125Hzs^{-1}, the system operator will have to accept the bids submitted by the power stations and interconnectors that contribute towards this largest loss. Once the total output of embedded generation with VS relays connected in any specific area exceeds this largest loss, there will be no commercial mechanism available to manage this risk.

4.14 As the capacity of embedded generation connected with VS relays increase, the cost of managing the risk of inadvertent tripping of this generation will increase.

4.15 The costs required to secure certain events, eg a three phase short circuit affecting a nuclear generating unit in an area with high capacity of embedded generation, could be prohibitive and this could lead to a large loss of supply due to the operation of low frequency demand disconnection relays.

Effectiveness of Vector Shift Relays

4.16 The Workgroup commissioned the University of Strathclyde to assess the effectiveness of VS relays in detecting islanding situations compared with:

4.16.1 RoCoF relays with 1Hzs^{-1} – 500ms settings; and

4.16.2 No LoM protection.

4.17 The methodology and the results of this work are documented in the report “Assessment of Risks Resulting from the Adjustment of VS Based LoM Protection Settings - Phase II.” A copy of this report is included as Annex 6 Strathclyde Report 2.

4.18 The comparison between the risk levels failing to detect islanding for various settings for VS relays compared to option 4 RoCoF relay setting (1 Hzs^{-1} with 500ms delay) are shown in Figure 4. In this figure, a ratio higher than 1 indicates that the VS relay is less likely to detect an islanding situation than the RoCoF relay. The “no fault” category is where the disconnection is upstream of the local network, and therefore no fault on the local islanded network.

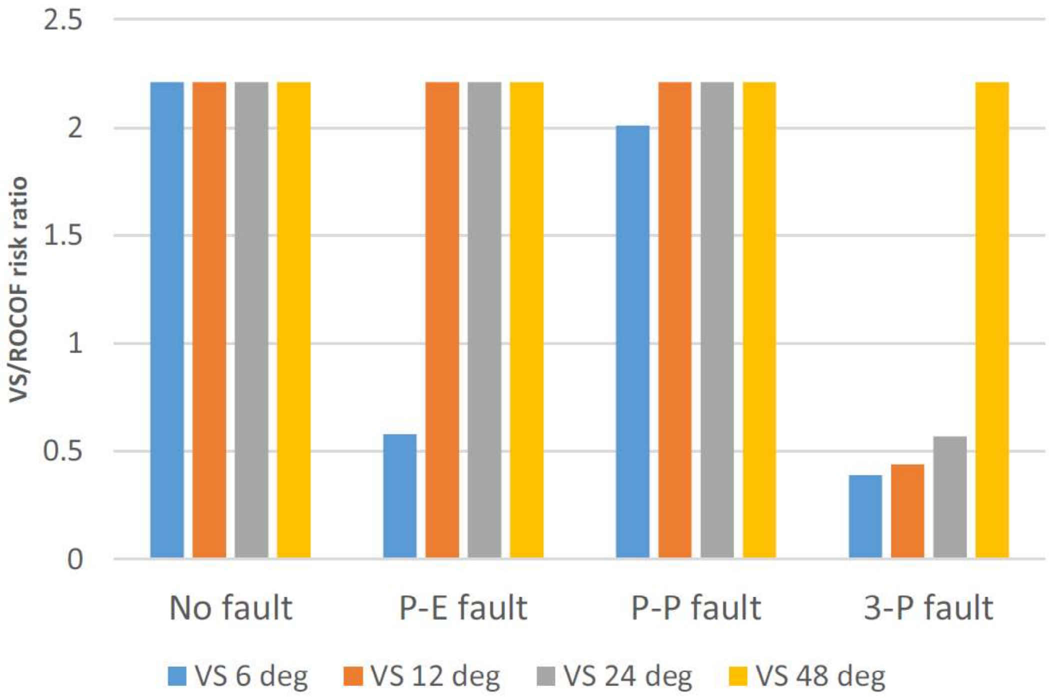

Figure 4

4.19 The comparison within Figure 4 suggests that RoCoF relays are more than twice as effective, in detecting islanding, than are VS relays. The two exceptions of that are events when islanding is triggered by a three-phase fault or, for VS relays set to operate at 6 degrees, following single phase to earth faults. However, irrespective of any other conditions, an island cannot be maintained with a three phase short circuit in place.

4.20 The comparison between the risk levels of failing to detect islanding for various settings for VS relays compared to having no LoM protection at all and depending on over/under voltage or over/under frequency to de-energise the island are shown in Figure 5. In this figure, a ratio of 1 indicates that VS relays would not offer any benefit over and above that which could be achieved by other protective relays that embedded generation has to be fitted with in accordance with ER G59 and ER G83.

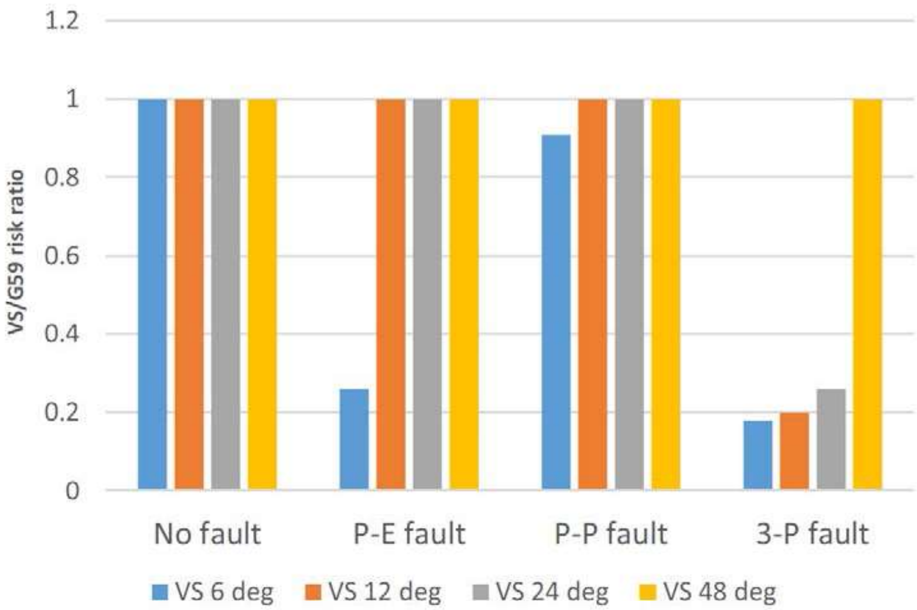

Figure 5

4.21 The comparison in Figure 5 suggests that VS relays are not very effective in detecting islanding resulting from switching operations (No fault). VS relays with settings higher than 6° would not reduce the risk of islanding following any event other than a three phase short circuit. VS relays with a setting of 6° would only marginally reduce the risk of islanding following a line to line fault. Three phase faults are less common in the system and would be detected by other form of protection and an island cannot be maintained with a three phase short circuit in place.

4.22 The Workgroup concluded that VS relays are not effective in detecting islanding and are likely to trip for transmission faults and therefore should not be used as a means of LoM protection

4.23 Further, the Workgroup concluded that the increase in the risk of out-of-phase auto-reclosure due to proposed changes to RoCoF settings does not present an unacceptable risk, and that the use of RoCoF relays with setting of $1Hzs^{-1}$ with a time delay of 500ms instead VS, as LoM protection, will reduce the overall risk. The Workgroup also notes there is no known documented evidence of hazards of any nature associated with possible islanding incidents. This is important given that VS relays are ineffective for island detection as documented from section 4.16 of this report under the title 'Effectiveness of Vector Shift Relays'. It shows that the theoretical modelling and risk assessment probably significantly overstates the risks. However, it should be noted that no known attempt has been made to systematically record such events.

Risks of Islanding – Empirical Evidence and Absolute Risk

4.24 There is no known documented evidence of any embedded generation being damaged due to out of phase auto-reclosure resulting from sustained islanding following disconnection from the distribution network. With an ineffective form of LoM protection, VS relays, being in use as the LoM protection on some embedded generators, for the last 25 years or more, the number of known and/or documented islands and/or damaged generators should be a better reflection of the actual risk of islanding.

4.25 Some industry experts believe that anecdotally there might have been a very small number of incidents over this period, but the lack of documentation of any sort means that it is not possible to factor this into the analysis. In any event if any such incidents did occur, there is nothing to say that the equipment in question was compliant with the Distribution Code or G59. It is reasonable to assume that the number of any such incidents is small (and materially less than the 100 per year indicated by the University of Strathclyde analysis) otherwise the issues would have been raised for attention and resolution within the industry.

4.26 Comparing this apparent zero incident rate, to the 100 incidents/annum estimated in the University of Strathclyde reports imply that the assumptions made in these reports are very pessimistic and that the results should be accepted for only as far as the relative benefit that could be achieved from one form of protection compared to another. Hence using RoCoF relays with $1Hzs^{-1}$ with a 500ms time delay settings, rather than a VS relay, would reduce what is already a demonstrably very low risk even further and that the expected number of out-of-phase auto-reclosure incidents is a fraction of what is almost a zero sustained islanding incidents/annum. The Workgroup noted that, if the current $0.125Hzs^{-1}$ is to be used, the risks of islanding and out-of-phase auto-reclose would be reduced by two orders of magnitude. However, the costs of managing the inadvertent tripping of these relays outweigh the reduction of what has been demonstrated to be an immaterial risk.

4.27 Therefore, it is the view of the Workgroup that provided that the proposals dictates the use of a form of LoM protection that is more effective than VS relays, the implementation of the proposal should not be made subject to the definite requirement for site specific risk assessment (as was recommended by GC0035) – although the responsibility of managing these considerations still rests with the generator.

The Two-Stage Approach

4.28 The Workgroup noted that the GC0035 Workgroup has recommended that the revised RoCoF relay settings for embedded generators with a registered capacity >5MW should apply retrospectively. The estimated cost of this retrospective application was £11M. This value is proportional to the number of generating units which protection settings were altered.

4.29 This GC0079 Workgroup is still assessing the benefits of the retrospective application of the changes proposed in this report. Similar to the GC0035 Workgroup estimates, the estimated cost of retrospective application will be a function of the number of embedded generation plants which protection settings are to be revised.

4.30 Considering the FES 2016 projections, and looking only on the expected growth of embedded generation with capacity below 1MW, a conservative projection of the total number of embedded generating units is shown in Fig 6. This is based on an assumption that all units will have an equal capacity of 0.999MW.

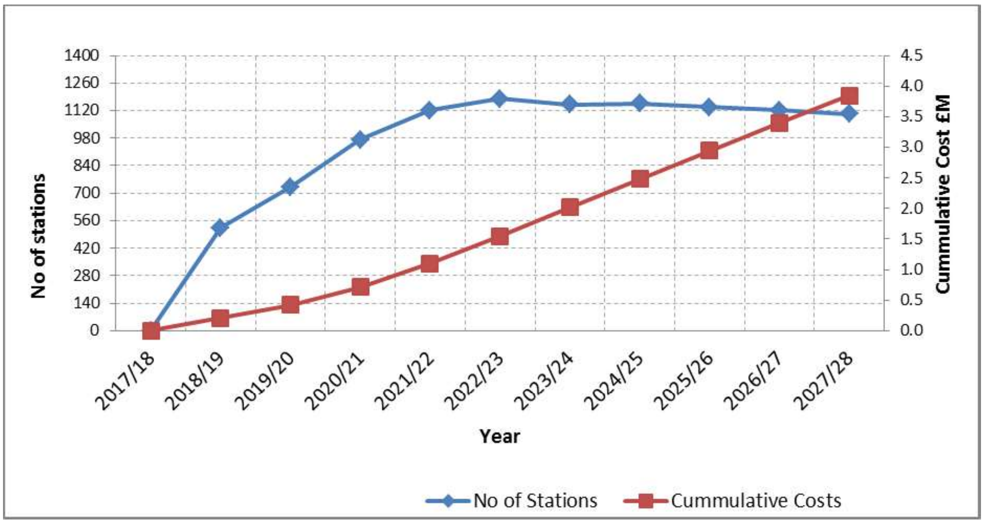

Fig 6

4.31 As the number of embedded generation units and their MW contribution to the system increase, the cost of securing the system against inadvertent tripping will continue to rise if nothing is done. The same is with the costs of retrospective application of any change to the relay settings.

4.32 If the status quo is maintained and a decision is made to retrofit the plant at a later date eg 27/2028 at least £4M will be added to the existing retrofitting cost. This is based on an estimated cost of £0.4k /generating unit. Fig 6 shows the accumulative costs resulting from connecting additional plant to the network.

4.33 The Workgroup notes that these costs are the most conservative estimate as they:

4.33.1 Ignore generation of capacity higher than 1MW but less than the capacity of a **Large Power Station**;

4.33.2 Assume that all other generating units will be of the highest possible capacity; and

4.34 Therefore, it is the view of the Workgroup that

4.34.1 **The Distribution Code, ER G59 and ER G83 should be revised as soon as reasonably practicable and ahead of concluding on whether the change should apply retrospectively or not in order to minimise the future potential expenditure; and**

4.34.2 **The Workgroup should continue its work to determine whether there is a benefit from retrospective application of these requirements or not.**

Implementation Options

4.35 Connection requirements applicable for embedded generation can be categorised into two sections. The first category concerns plant whose LoM protection is covered by ER G59 (relay operated) and the second is Type Tested Embedded Generators covered by both ER G59 and G83. The purpose of the type tests is to demonstrate compliance with the generic requirements of this Engineering Recommendation (although the exact LoM technique to be used it not specified). By satisfying the test conditions in the relevant annex of G59 and G83 the generating plant can be considered an approved generating plant for connection to a public low-voltage Distribution System.

4.36 To mitigate the risk of inadvertent tripping associated of embedded generation the workgroup explored two options:

4.36.1 Option 1: This option is limited to relay protection only. Its application will be limited to a section of embedded generators where LoM protection is implemented through RoCoF or VS relays. Hence the type tested generation plant of G83 would not be affected, nor would any type tested smaller generation under G59.

4.36.2 G59 would be modified to require the new relay settings and to impose appropriate revised stability tests on the protection consistent with the new settings.

4.36.3 For Option 1 there would be no need to undertake any repeat type testing.

4.36.4 Option 2: This option involves applying new protection and stability test recommendations to all embedded generators including type tested generating plant.

4.36.5 These requirements are specified in both G59 and G83.

4.36.6 Under this option all protection performance for these plants would be required to comply with the workgroup's recommendations.

4.36.8 It will be necessary for all generating units type tested under G83 and G59, to be retested to prove compliance with the revised requirements. The working group welcomes feedback from manufacturers on the practicality of achieving this within the suggested timescales.

4.37 In considering these options it is relevant to note that the EU Network Code Requirements for all Generators (RfG) will specify new performance requirements and new type tests for all generating plant. The specification for these will be available before May 2018 for compliance by May 2019

Implementation Costs

4.38 Under Option 1 no implementation costs are envisaged for this forward looking recommendations as these will be part of the Planning and Connection process.

4.39 Under Option 2 Manufacturers of all type tested generation units under G83 and G59 could incur re-test costs. As part of the industry consultation, the working group sought manufacturers of type tested generating units' opinion and inputs on the cost implications associated with this option.

5 Consultation Responses

5.1 The Consultation opened to industry from 7 August to 1 September 2017.

Consultation objective

5.2 The workgroup consulted on two implementation options as defined in section 4.36 of this report. Option 1 limited the scope to protection relay changes only.

5.3 Option 2 was the workgroup preferred option, and involves applying new protection and stability test requirements to all embedded generators including type tested generating plant.

5.4 As part of the consultation, the Workgroup sought opinions from manufactures of type tested generation plant on additional costs they were likely to incur in complying with recommended requirements.

Consultation Responses

5.5 All the consultation responses received by the formal deadline were in favour of workgroup's proposals and recommendations.

5.6 Annex 7 shows a summary of all the responses to the consultation. Six responses were received comprising four responses from DNOs and two from Generators.

5.7 Further to agreeing with the recommendation, one consultee expressed concern that the current proposals did not include retrospective changes. While this was noted, as mentioned in this report, it was decided to split workgroup mandate into two categories, one which is forward looking and the other for retrospective changes. In parallel to this recommendation, the workgroup is working on the retrospective application aspect in line with its terms of reference.

5.8 No responses were received from manufacturers of type tested generation units by the response deadline.

Post Consultation Enquiries

5.9 The workgroup was concerned that no inverter manufacturer had responded to the consultation. It was noted that over two hundred direct emails had been sent to stakeholders, and that notice of the consultation had been promulgated by National Grid to their stakeholder list and it has also been flagged up in some of the trade press.

5.10 The workgroup then sent 57 emails to 39 inverter manufacturers whose details are held on the ENA data base of type tested inverters. It is believed that only 35 of these addresses are still current and working, and specific responses were received from 6 of these 35.

5.11 Two out of the six manufacturers indicated that they needed more time to understand the implications of the proposed requirements under option 2 as defined in section 4.36.4 of this report (the workgroup's preferred option).

5.12 On further discussion with these manufacturers, it became clear that the need to undertake repeat type testing, particularly the proposed level of vector shift immunity of 50°, may require further investigation and specification before it is prescribed as a requirement. This will need to be applied and tested on the whole population of invertor types in the market and may require time and resources. This feedback was what the workgroup sought from manufacturers and received no feedback on during the consultation period.

5.13 The Workgroup is also not sure whether most of those who responded positively had clearly understood the requirements under option 2. With this in mind it is the workgroup's recommendation that, in the meantime while further engagement with manufacturers is going on, option 1 as specified in section 4.36.1 of this report should be implemented.

6 Impact & Assessment

Impact on the Grid Code and Distribution Code

6.1 The workgroup recommends amendments to the Distribution Planning and Connection Code and Engineering Recommendations G59

6.1.1 The Distribution Code text required to give effect to the proposal is contained in Annex 2 of this document.

6.1.2 The appropriate text for G59 is contained in Annex 3

Impact on National Electricity Transmission System (NETS)

6.2 This will result in limiting the total capacity of embedded generation that is at risk of being unnecessarily disconnected from the system by their LoM protection following an event on the transmission system.

Impact on Embedded power stations

6.2.1 The recommended modification will require that embedded generation connected to the system after 1 February 2018, using the RoCoF techniques for LoM to use a setting of $1Hzs^{-1}$ and time delay of 500ms.

Impact on Grid Code Users

6.3 The proposed modification will reduce the risk of embedded generators from tripping as a result of transmission related secure events.

Impact on Greenhouse Gas emissions

6.4 The proposed change will reduce emissions by reducing the number and duration of the occasions where additional fossil-fuelled plant has to run to provide additional inertia to the total system.

Assessment against Grid Code Objectives

6.5 The proposed amendments would better facilitate the Grid Code objective:

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

The proposal takes another step required to remove a constraint on system RoCoF and VS which means a minimum amount of synchronous generation has to remain connected to the system. In the absence of this change, Balancing Services cost will be incurred at an increasing rate as new users connect asynchronous generation and interconnection to the GB electricity networks.

(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);

The proposal has a neutral impact on this objective.

(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

The proposal takes another step towards reducing a risk of unnecessary demand disconnection following the inadvertent operation of LoM protection on a large number of embedded power stations.

(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 has a neutral impact on this objective.

Assessment against Distribution Code Objectives

6.6 The proposed amendments would better facilitate the Distribution Code objective:

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

LoM will also be more co-ordinated as there are less forms of LoM protection that do not co-ordinate – the protection is more simple and reliable. The proposal will progressively reduce the risk of undetected islanding and inadvertent generation shutdown as new generation sites connect.

(ii) To facilitate competition in the generation and supply of electricity

The proposal has a neutral impact on this objective.

(iii) Efficiently discharge the obligations imposed upon DNOs by the Distribution Licence and comply with the Regulation (where Regulation has the meaning defined in the Distribution Licence) and any relevant legally binding decision of the European Commission and/or Agency for the Co-operation of Energy Regulators.

The proposal has a neutral impact on this objective.

(iv) Promote efficiency in the implementation and administration of the Distribution Code.

The proposal has a neutral impact on this objective.

Impact on core industry documents

6.7 The proposed modification does not affect any other core industry documents.

Impact on other industry documents

6.8 The proposed modification does not affect any other industry documents.

Implementation

6.9 The workgroup recommends that, the proposed changes be implemented from 1 February 2018, or other such date as the Authority might agree to.

7 Workgroup Recommendations

7.1 Recognizing the scale of the risk of inadvertent tripping and the urgency in both reducing this risk and operational costs (balancing cost) and taking into account the need to further consult the non-type-tested plant manufacturers, the workgroup now recommends that the scope be limited to non-type-tested generators.

7.2 To facilitate the above, the workgroup proposes changes to ER G59 and the Distribution Code to include the following:

7.2.1 VS protection technique should not be used as LoM protection. This is not only because it is not effective in detecting the majority of islanding situations, but also because it constitutes a significant risk to the transmission system. This change should apply for all non-type-tested embedded Small Power Stations commissioned on or after 1 February 2018, or such other date as the Authority decrees.

7.2.2 For plants employing RoCoF relays, all relays should be subject to a setting of $1Hzs^{-1}$ with 500ms time delay as recommended in the proposed Distribution Code and ER G59 amendments. This change should apply for all non-type-tested embedded small power stations commissioned on or after 1 February 2018, or such other date as the Authority decrees.

7.3 While the workgroup recognises that more changes to G59 and or G83 may be required under RfG, the workgroup concluded that these will be better handled within the RfG timeframes under that specific workgroup.

7.4 The workgroup recommends that this proposal is implemented ahead of concluding on whether there is any value of it being applied retrospectively. This ensures that the operational costs of, and risks to, the transmission system and that the costs of retrospective application do not increase.

7.5 The Workgroup will continue its work to determine whether there is a benefit from retrospective application of these requirements or not as well as extending these requirements to type tested plant.

7.6 As the performance of a RoCoF relay with the settings proposed is far better than that of a VS relay, which is currently the least effective form of LoM protection, this proposal contributes towards an overall decrease of islanding. Hence, no further risk assessment is required to be done.

8 Distribution Code Review Panel Recommendation

8.1 At the meeting of the Distribution Code Review Panel (the Panel) held on 26 October 2017, the Panel unanimously agreed to the submission of the Report to Authority as the Panel agreed that the Modification proposal better facilitated the objectives of the Distribution Code.

Annex 1 – Terms of Reference

i) The workgroup will investigate extending the first stage of work (Phase 1 underGC0035) to cover all distributed generation as Phase 2.

ii) The workgroup will undertake Phase 2 of the work. The context for Phase 2 includes the following considerations:

a) There is a convergence of technical considerations when transmission system faults give rise to both voltage and frequency phenomena. GC0079 is concerned primarily with the frequency effects on the Total System, or on DNO power islands.

b) It is recognized that National Grid will have to develop a formal operating standard in line with the European Codes defining the maximum RoCoF that the total system is secured against. This is an expected consequential requirement of implementing the EU Network Code currently titled "Network Code on Operational Security" in the GB frameworks.

c) There are a number of factors that will prevent generating plant riding through frequency changes. These include both the physical capabilities of electrical and mechanical components, the capability of control systems, and the effects of protection.

d) Generating equipment connected to distribution networks will generally have protection that fulfils two discrete functions. The first is to protect the generating equipment and ancillaries. The second is to provide the required network interface protection, i.e. as currently required by G59 or G83.

e) The focus of Phase 2 is to address the risks of unwanted tripping initiated by the network interface protection, but includes considering mitigation of any additional frequency resilience risks arising from generating equipment protection and control.

f) Phase 2 will investigate the suitability of VS shift protection as an alternative to RoCoF, taking into account its possible unsuitability for transmission fault ride through requirements.

iii) Phase 2 will therefore include the following activities:

a) Monitoring the implementation of the protection changes recommended under phase 1.

b) Researching the characteristics (numbers/types etc.) of existing embedded generation of less than 5MW rated capacity including their likely RoCoF withstand capabilities;

c) Researching the characteristics of existing embedded generation of all sizes where the embedded generation is fitted with VS anti-islanding protection.

d) Investigate the likely effect of transmission faults on VS protection techniques, and determine the risk of wide spread DG tripping from VS protection being inappropriately sensitive to transmission faults.

e) Investigating the characteristics of popular/likely inverter technology deployed, particularly in relation to RoCoF withstand capability and island stability;

f) Investigating the characteristics of popular/likely inverter technology deployed in relation to its behaviour in the presence of the voltage phenomena associated with transmission faults;

g) Assessing or modelling the interaction of multiple generators in a DNO power island;

h) Investigating and quantifying the risks to DNO networks and Users of desensitising RoCoF based protection on embedded generators of rated capacity of less than 5MW;

i) Analysing the merit of retrospective application of RoCoF criteria to existing embedded generation of less than 5MW (including comparison with similar programmes in Europe);

j) Considering any other relevant issues in relation to the resilience of the total system in respect of the operating characteristics of small generation;

k) Consider, if appropriate, revised VS protection settings, including any supporting risk assessment analysis;

l) To the extent that revised settings are proposed, create detailed specifications for the application of those revised settings;

m) Consider any other adverse effect on total system operability that existing G59 and G83 requirements may present, given the changed context since G59 and G83 were originally introduced, and include any such issues and their mitigation in the drafting and consultation (for example the current and future implications of Black Start on the existing over and under frequency settings);

n) Developing proposals for consultation on any proposed changes to RoCoF and VS protection drawing out the costs, benefits and risk of such a change to present to the GCRP and DCRP. Proposals should include a recommendation of where implementation costs should fall and the most appropriate workgroup for this issue to sit with;

o) Initiating consideration by DNOs of the future management of out-of-phase reclose risk; and

p) Engaging with the Health and Safety Executive (HSE) and all affected parties considering the different stakeholders that will be affected by any proposed changes.

iv) Phase 2 will deliver proposals concerning RoCoF based protection on embedded generators of rated capacity of less than 5MW and concerning VS protection for all embedded generation.

Annex 2 – Legal Text Distribution Code

Proposed changes to the Distribution Code are documented in a file called **GC0079 Annex 2 D Code proposals** circulated together with this report.

Annex 3 –Legal Text for G59/3-3

Proposed changes to G59 are documented in a file called **Annex 3 –Legal Text for G59/3-3** circulated together with this report.

Annex 4 Strathclyde Report 1

Please see report called **Annex 5 4 Strathclyde Report 1**circulated together with this report. This can also be accessed through the following link:

http://www2.nationalgrid.com/WorkArea/DownloadAsset.aspx?id=45729

Annex 5 Strathclyde Report 2

Please see report called **Annex 5 Strathclyde Report 2**circulated together with this report. This can also be accessed through the following link:

http://www2.nationalgrid.com/WorkArea/DownloadAsset.aspx?id=8589941679

Annex 6 Detailed Consultation Responses

Please see report called Annex 6 Detailed Consultation Responses circulated together with this report. This can also be accessed through the following link: