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Rate of Change of Frequency (ROCOF)

Review of TSO and Generator Submissions

Final Report

Submitted to: Commission for Energy Regulation

In association with: TNEI Services Ltd

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CONTENTS

1 Introduction

This report presents the findings of a review carried out by PPA Energy and TNEI for the Commission for Energy Regulation (CER) of the submissions received from electricity industry stakeholders regarding proposed changes to the Ireland Grid Code relating to Rate of Change of Frequency (ROCOF). This review was requested in response to a consultation process that has been ongoing following the submission of proposed changes to the Grid Code by EirGrid and SONI as the TSOs.

The report addresses a range of questions raised by the CER in the e-mail sent to the consultants by Robert O'Rourke on Monday 4th February 2013, focusing on the issues raised in a range of documents submitted to the CER[1] and in particular:

- the appropriateness of the proposed standard, taking account of the proposed 40% penetration of RES by 2020 in the Island – this assessment will be based on a critical review of the evidence presented from studies submitted by the TSO;
- the relevant international experience of setting ROCOF standards and the range of issues that have been taken into consideration in other jurisdictions, to the extent that this can be assessed from a review of public domain information;
- the evidence presented regarding the ability or otherwise for conventional generators to tolerate the proposed ROCOF of 1 Hz/s; and
- the extent to which there is a connection between the fault ride through capability of the generators in the Irish and Northern Irish networks and the ability to withstand ROCOF.

There are then a number of aspects of the ROCOF problem on which we have been asked to express views based on our reading of the above documents and our understanding of the technical issues, but extrapolating from the information provided to draw general conclusions about the advisability or otherwise of accepting the proposed change to a maximum ROCOF of 1 Hz/s.

These include:

- assessing the likely approach, timescale and budget that would be required for studying the effect of ROCOF on a conventional steam turbine or gas turbine power plant. This would require reference to manufacturers' of such plants, combined with our own knowledge of power system simulation studies, and

[1] See Appendix 1

will be dependent to some degree on the willingness of manufacturers to engage in appropriate dialogue;

- commenting, to the extent possible, on the risk of a loss of commercial life to generating plants as a result of ROCOF events occurring. This would be based on a review of the factors highlighted by the TSO and the respondents to the proposed Grid Code change in their submissions, together with dialogue with plant manufacturers where possible. We would note, however, that it is highly unlikely that a definitive conclusion can be reached on this issue, in the absence of detailed studies and tests of specific plants;

- commenting, to the extent possible, on the risks of catastrophic failure of a generator and the associated safety issues that would result from a ROCOF event. This requires dialogue with manufacturers, although we have applied our own engineering judgement and research into any cases in the public domain of generating plant that has failed as result of mechanical stresses;

- reviewing the potential gains or otherwise of carrying out a system wide study of the entire generation fleet rather than requiring individual generators to carry out their own studies – we note that this would be dependent on it being considered that there are sufficient similarities between types of generators for generic findings to be representative and acceptable to the TSO and the generator community;

- commenting on the impact of increasing System Non Synchronous Penetration of generation to the predicted 75% level, and the effect that this could have on the frequency of ROCOF events occurring – this would be based on a conceptual consideration of the issue and a review of the studies carried out by KEMA for the TSO, and would not involve independent studies being carried out by PPA Energy or TNEI;

- assessing the implications of a change in the ROCOF standard on the distribution system, including giving an opinion on the issue of islanding and how this can be avoided with other types of protection. This would include reference to our knowledge of other distribution companies' practices in this area, coupled with TNEI's understanding of the locational variation of the rate of change of frequency in the transmission networks in Ireland and Northern Ireland, gained from their earlier studies of this phenomenon;

- commenting on the practicality of testing plants' responses to ROCOF and the extent to which this should be undertaken as part of a process of ensuring that the TSO is able to safely increase the system non-synchronous generation penetration (SNSP) and the resulting higher ROCOF in the event of system faults.

Comments on the above range of issues, with reference to the consultants' engineering judgement, experience of other studies and public domain information about international experience, together with other points that have emerged from our review of the information submitted by parties affected by the final decision, are documented in the later sections of this report. We also draw conclusions and recommendations as to the appropriate course of action for the CER to pursue on this complex issue.

2 TSOs' Submissions

2.1 Proposed Grid Code Modification MPID229

The TSOs have submitted a Grid Code Modification Proposal Form which presents changes to three sections of the Grid Code: CC7.3.1.1(d), WFPS.1.5.1 and CC7.5.

Clauses CC7.3.1.1(d) and WFPS1.5.1 contain text that refers to a requirement for Generation Units and Controllable WFPSs to remain connected to the Transmission System during frequency excursions involving a maximum rate of change of frequency of 0.5 Hz per second. It is proposed that this is replaced by a requirement that plant remains connected for rates of change of frequency of up to 1 Hz per second, as measured over a rolling 500ms period. It is further noted that during transient conditions involving voltage dips on the network, a localised rate of change of frequency in excess of 1 Hz per second may be encountered; the ability of generators to ride through such events is specified in the Fault Ride-Through clauses (CC7.3.1.1(h) and WFPS1.4.1) which are deemed to supersede the requirements of the ROCOF clauses.

In the case of interconnectors, the requirements of CC7.5 already specifies a maximum ROCOF of 1 Hz per second; this clause is proposed to be modified by including reference to the rolling 500ms measurement period and similar provisions made for the possibility of localised ROCOF exceeding 1 Hz per second in situations involving voltage dips, at which point Fault Ride-Through provisions contained in clause CC7.5.1.1(g) are deemed to prevail over CC7.5.1.1.(d).

The need for these changes is argued by the TSOs as arising from a lack of clarity as to the capabilities of generators and windfarms, which is leading to restrictions on the level of non-synchronous generation that can be allowed to connect to the power system, whilst enabling the system to be operated in a safe and prudent manner. The TSOs have submitted a number of documents in support of this claim, which we summarise below. We then explore further the justification for this claim, together with the rationale and the implications of extending the ROCOF requirements from 0.5 Hz/s to 1 Hz/s, in the remainder of this report.

2.2 Summary of Studies on ROCOF events on the All-Island System – August 2012

This report summarises the findings from studies carried out into ROCOF that were carried out by EirGrid and SONI, to investigate the effects of losing the East-West Interconnector (EWIC) whilst exporting power from Ireland and the loss of the Louth-Tandragee lines, resulting in the separation of the Ireland and Northern Ireland systems. These studies were performed as part of the over-arching "Delivering a Secure, Sustainable Electricity System" (DS3) programme. The studies investigated the impact of major system disturbances arising in situations with high levels of non-synchronous generation on the network. They build on the studies that were included in the Facilitation of Renewables (FOR) report, which first gave rise to the concerns

that the current Grid Code ROCOF specification of 0.5Hz/s maximum could be in adequate. The FOR focused on the effects of losing "the largest credible infeed" into the system, however the August 2012 report describes additional scenarios in which interconnectors are tripped. These studies are based around a minimum demand condition that is roughly comparable with the 2015 All-Island Summer Valley load from the Transmission Forecast Statement 2012-18, with a high SNSP of 63%. The report highlights two important considerations:

1. that localised ROCOF figures can vary significantly, due to the characteristics of the power system interconnecting the different sources of generation; and

2. it is important to identify the timescale over which ROCOF is measured.

ROCOF measurements over a sliding 500ms window are proposed in the Grid Code modification; on this basis an average system ROCOF of 0.43 Hz/s is observed for a loss of the EWIC, but with a localised maximum that is understood from the report to reach 0.63 Hz/s. The average ROCOF rises to 1.59 Hz/s over a 100ms period. In the case of split system operation, a ROCOF in excess of 2 Hz/s is observed in the SONI system.

The findings of these studies therefore support the conclusion drawn that Grid Code ROCOF standards of 1 Hz/s in Ireland and 2 Hz/s in Northern Ireland should be adopted as an interim measure, with an all-island standard of 1 Hz/s being adopted after the introduction of a second North-South tie-line.

2.3 Analysis of the Frequency Response of the Power System Following Large Disturbances

This report presents an analysis of the ROCOF figures associated with historical events in Ireland, Northern Ireland and other international examples of small synchronous systems.

These present a number of scenarios in which the 500ms ROCOF following major system events ranges from 0.37 Hz/s to 3.7 Hz/s. The report states that in none of these situations were cascade trips of generation or mechanical failures observed, although in several cases generator trips resulting from control issues were noted due to incorrect settings on governors.

The report states that in none of the cases examined in Ireland or Northern Ireland did any generation trip purely due to a ROCOF event or did any conventional generating unit experience damage as a result of a ROCOF occurrence; it draws a similar conclusion in respect of the examples from New Zealand, Cyprus and Hawaii, whilst noting that over-temperature protection acted on two gas turbine generators in Hawaii as a result of a ROCOF event. This was overcome by adjusting the controller parameters.

The TSOs acknowledge that whilst there is no evidence from these cases to indicate that conventional generation would experience significant damage as a result of high ROCOF events, there is relatively limited information available from actual system events from which to draw firm conclusions.

2.4 DS3 Joint Grid Code Working Group Position Paper on ROCOF, September 2012

This paper summarises the position reached by the DS3 Joint Grid Code Working Group on the ROCOF issue. It states that in the light of the studies referred to above, "either all units should materially ride through ROCOF in the range of 1-2 Hz/s or other means must be found to ensure ROCOF does not exceed 0.5 Hz/s with increasing levels of non synchronous generation."

The report summarises the views of stakeholders on the issue as follows.

2.4.1 Conventional Generators

The key points identified by conventional generators are stated as being:

- two areas of risk to conventional generators that may result from higher levels of ROCOF:
  - **operational consequences** of a unit failing to deliver adequate response during a ROCOF event, or tripping as a consequence of high ROCOF, leading to further cascade tripping, followed by load shedding, islanding or system blackouts; and
  - **mechanical integrity issues** resulting from a single ROCOF event or a series of events, arising from machinery damage leading to forced outages or risk of injury to plant personnel;
- the need for a detailed review, followed by validation and testing, on a plant by plant basis, to assess the impact of these risks on specific plants;
- the possible need for further investment in the light of these studies.

Generator owners note the possible need for a 24 month period to complete the ROCOF investigation, following the agreement of an appropriate cost recovery mechanism.

2.4.2 Wind Farm Power Stations

It is noted that all wind farms are capable of riding through ROCOF values of at least 1 Hz/s and in some cases as high as 4 Hz/s. WFPS owners do not therefore consider

that there is a fundamental issue with riding through ROCOF values in the range 1-2 Hz/s.

2.4.3 Distribution System Operators

From the DSOs' perspective the main implication of a change in the ROCOF withstand specifications in the Grid Code would be a need to adjust the settings on ROCOF relays applied to prevent the islanding of distributed generation. The DSOs are reviewing the status of loss of mains protection on their systems and implications of any change to the Grid Code standard.

2.4.4 Transmission System Operators

The TSOs' position is summarised as:

- EirGrid proceeding with a Grid Code Modification Request to increase the ROCOF standard in Ireland from 0.5 Hz/s to 1.0 Hz/s based on a rolling measurement over 500ms.

- The TSOs seeking a standard of 2 Hz/s for Northern Ireland as an interim measure until further North-South tie-lines are constructed.

In parallel with these steps, the TSOs are investigating a range of approaches through modified system services such as the levels of minimum generation that can be supported by conventional generators, to assist with the retention of high inertia plant on the network at times of light load. Improved identification of periods when the system is at risk, periods of high wind generation and understanding of the performance of the system in periods of high SNSP may also be possible through improved control centre tools.

The TSOs state that until the above measures are in place, it will not be possible to increase the SNSP beyond 50%.

2.5 Northern Ireland System Separation Studies, November 2012

This report provides further background details of the studies reported on in the Summary of Studies (as discussed in Section 2.2) on ROCOF events on the All-Island System, and supports the requirement for a 2 Hz/s ROCOF standard in the Northern Ireland system.

2.6 ROCOF Modification Proposal – TSOs' Recommendations, November 2012

This report presents a consolidated collection of the results of the earlier studies, with a commentary providing the context for the ROCOF problem. It states that ROCOF is the binding limitation on operating the power system beyond SNSP of 50%.

It notes that in Northern Ireland historical events have occurred that have given rise to a ROCOF in excess of 1 Hz/s, which have not resulted in sympathetic tripping of generators. It also notes that whilst there is no Grid Code specification of ROCOF requirements in Northern Ireland, a Minimum Functional Specification (MFS) has been provided for generators seeking connection since 2000, which includes a ROCOF specification of 1.5 Hz/s.

The report emphasises the requirement from system studies for generators to be capable of riding through ROCOF events in excess of 0.5 Hz/s, but not exceeding 1 Hz/s on the all-island system, or not exceeding 2 Hz/s in Northern Ireland, in the situation where a system separation has occurred.

The report clarifies the situation in terms of ROCOF at the transmission level and in the distribution networks. The Grid Code modifications that are proposed for dealing with ROCOF are required to ensure that generators and windfarms connected to the transmission or distribution networks have the capability to ride through high ROCOF events resulting from generator or interconnector trips. The DSOs also need to specify limits on ROCOF that will enable them to protect against generation islanding, but that will not result in cascade tripping of distribution connected generation that could lead to a blackout situation.

The report presents details of the process that led up to the proposal of Grid Code modification MPD 219, which has focused around the work of the Grid Code Review Panel and a Joint Grid Code Working Group that was set up specifically to take the views of a range of stakeholders into account. The report notes that an initial ROCOF proposal of 4 Hz/s was proposed in October 2011, which met signification opposition from generators. The results of studies supporting the need for a ROCOF value in the range 1-2 Hz/s are presented, leading to the conclusion that a Grid Code figure of 1 Hz/s should be adopted, measured over 500ms, with a temporary standard of 2 Hz/s being applied in Northern Ireland.

The TSOs summarise the position as they see it in relation to conventional generators' concerns regarding high ROCOF values associated with operating the network with low system inertia.

The key points noted are:

- that the TSOs have not in their studies or operating experience seen evidence to suggest that higher ROCOF values would have a material impact on generating plant;

- that some generators have concerns about the impact of higher ROCOF values on plant life, though they may not be concerned about the risk of catastrophic failure of plants;

- that the TSOs have not seen evidence of catastrophic failure or cascade tripping from ROCOF in Ireland, Northern Ireland or elsewhere, although they note that they have looked at a relatively small number of events, and that the proposed penetration levels of non-synchronous generation in Ireland and Northern Ireland is substantially greater than that seen elsewhere;

- that during significant voltage dips, such as those occurring during fault conditions, generators see substantially greater short term ROCOF values than 1 Hz/s, and that the forces experience by the generators in these conditions are correspondingly greater. Catastrophic plant failures and/or cascade tripping are not seen after faults, however, although again the TSOs note the potentially cumulative effect of any damage done to plants.

Notwithstanding the lack of evidence of plant failures and/or cascade tripping resulting from ROCOF events, however, the TSOs have confirmed that higher SNSP values will not be pursued until the generators concerns have been addressed "to the TSOs' satisfaction".

Comments relating to DSOs relate to the need for altering the settings loss of mains protection, or exploring alternative protection philosophies, to enable DSOs to protect their systems adequately in the presence of higher levels of ROCOF and to provide suitable protection from system islanding occurrences.

As far as the ROCOF standard is concerned, therefore, the TSOs conclusion is that "the proposed ROCOF standard of 1 Hz/s measured over 500ms at the generator's connection point is a pragmatic standard that can be achieved by all plant." They also state that "The TSOs are unaware of any theoretical reason why there should be an issue moving to 1 Hz/s as a ROCOF capability of generators and windfarms."

This report also presents information about the likely frequency of occurrence of high ROCOF events on the all-island system, which is estimated to amount to up to five events per annum presenting a ROCOF value in excess of 0.5 Hz/s. The report indicates that 15 frequency events occurred in 2011, which resulted in frequency dips below 49.5 Hz, with one similar event in 2012. This compares with a figure of approximately 30 short-circuit faults on the Irish transmission system per annum, and a smaller number in Northern Ireland. The figure of five high ROCOF events per year is understood to be based on the 30% capacity factor that is typically applicable for wind generation being applied to the number of generator trips occurring each year; this is not an unreasonable estimate therefore. (It should be noted that the proposed 1.0 Hz/s over 500ms standard is primarily defined on the basis of the impact of losing the largest infeed to or export from the network and is not based on the effects of voltage dip induced frequency dips, which it is understood will be addressed through a combination of technical interventions and windfarm standards).

2.7 DS3 Rate of Change of Frequency Modification Recommendation to the CER

This document summarises the current standard and need for change, the process adopted to date, and also lists the issues raised by generators, as discussed in more detail in the report "ROCOF Modification Proposal – TSOs' Recommendations".

The document raises the additional concern noted by parties in the Grid Code Review Panel meeting of 4th December 2012, concerning the long term costs to generating plants, or of operating the system, that could result from the increased ROCOF standard. In particular the impacts of such costs on customers were raised.

The report quotes costs of up to USD 1.5 million per conventional generating plant and 12 months elapsed time for each plant for the necessary studies to be completed to demonstrated the capability of plants to ride through the proposed new level of ROCOF. It points out that the generators are seeking clarification of the cost recovery process for these studies before being prepared to commission them, and that until such time as the studies are completed, the generators with conventional plants will be unable to accept the proposed Grid Code modification.

Representatives of the renewable energy producers are reported to have confirmed that their plants have no problems in coping with the proposed higher ROCOF values, and are supportive of the Grid Code amendment as this would enable higher levels of non-synchronous renewable generation in the system.

The document also refers to a study commissioned by the TSOs from the consultants DNV KEMA into the ROCOF capabilities of generating plant, and to give an international perspective on the problem. We comment on this report in the following section.

2.8 ROCOF: An independent analysis on the ability of Generators to ride through Rate of Change of Frequency values up to 2Hz/s (DNV KEMA Report, February 2013)

2.8.1 Summary of the findings from the DNV KEMA Report

This report was commissioned by EirGrid from DNV KEMA, and examines the limitations on existing generators to tolerate ROCOF values of up to 2 Hz/s. The study examines the impact on the transient stability of a range of generator sets of high rates of change of frequency, and looks at scenarios involving the operation of units over a range of power factors. The modelling undertaken also examines the torque experienced by the machines during high ROCOF events, and compares these with the torques experienced in other operating scenarios.

The report recognises that a simplified mathematical model of synchronous machine performance is used in the analysis. There is a limit therefore to the range of mechanical and electrical phenomena which are addressed in the study, and the study cannot be considered comparable with the detailed analysis that is proposed by

turbine manufacturers to consider the full range of mechanical and control system issues that arise in exposing generators to high rates of change of frequency. DNV KEMA note that the study could be considered pessimistic as a result of not considering the effects of governor action on the generators or the effects of the network in damping transient effects.

The results of the studies undertaken by DNV KEMA indicate that transient stability of all the generators studied can be maintained for a ROCOF of up to 1 Hz/s, except in situations of generators operating at a leading power factor (i.e. absorbing reactive power, for example as could occur at times of light load on the system). This is based on an assessment that looks at a 1 Hz/s ROCOF over a sliding 500ms time period, i.e. comparable with the TSOs' proposed specification of ROCOF in the revised Grid Code.

The following table reproduces the results of the KEMA study, showing in summary the types of units studied and the results of the stability analysis in response to a 1 Hz/s ROCOF event, as measured over a 500ms sliding window.

Generator Type	**Unit Size (MW)**	**Stable during ROCOF event?**		
		0.5 Hz/s	**1.0 Hz/s**	**2.0 Hz/s**
CCGT Single-shaft	400	Y	Y*	N
CCGT Dual-shaft	260	Y	Y*	N
CCGT Dual-shaft	140	Y	Y*	N
Steam Thermal (Reheat)	300	Y	Y*	N**
Steam Thermal (Once Through)	150	Y	Y*	N
Steam Thermal (Fluidised Bed peat)	150	Y	Y*	N
OCGT	50	Y	Y*	Y*
Salient-pole Hydro	30	Y	Y	Y

Key: Y is used to indicate stable operation
Y* is used where a pole slip is only observed for a 0.93 leading power factor operating mode
N is used when a pole slip is also observed for power factors of unity and/or 0.85 lag
N** is used when no pole slip is observe for power factors of unity and/or 0.85 lag, but negative power generation is detected.

Source: DNV KEMA

The results of the study investigating mechanical stress on the machines experiencing high ROCOF indicate that in the 1 Hz/s situation the maximum torque experienced by the generator is around 160% of the steady state value. The report notes that in short

circuit conditions, which generators are designed to withstand, torques of 400 – 600% of the steady state value could be encountered. The report therefore concludes that torques associated with ROCOF events in the 1 Hz/s category would not be incompatible with the levels that machines are already designed to comply with in fault ride-through situations. It is, however, noted that wear and tear on the machine(s) might be affected, and further investigation of the mechanical stability of the machine in response to such events would be needed.

2.8.2 Consultants' comments

From the above analysis it can be seen that instability leading to pole slipping (a condition in which the generating unit loses synchronism with the power system, which can lead to large power flows occurring and significant damage to generating plant) is avoided for a 1 Hz/s ROCOF in all but those situations where leading power factor operation is required.

The implications of this conclusion on the acceptability of a 1 Hz/s standard for ROCOF in the Grid Code are that restrictions on generator operation may need to be considered in light load conditions or situations where voltage control is required to avoid overvoltages in areas of the network where there is significant generation infeed. These restrictions would reduce the TSOs' options for achieving some aspects of system voltage control, therefore, and would need to be taken into consideration in determining the overall operating regime of the network.

A key issue therefore concerns the likely frequency of the ROCOF events that would be experienced on the network in comparison with fault occurrences, and the cumulative effect of ROCOF events as compared with short circuits on the wear and tear on generators. The TSOs have stated that five ROCOF events per annum could be anticipated in 2020, compared with approximately 30 short-circuit type faults in a year. More investigation would be needed, however, to validate the estimate of five ROCOF events per annum in the situation where a higher proportion of SNSP exists in the future, since the reduction of overall system inertia could lead to more high ROCOFs associated with fault occurrences than is currently the case.

Although it must be noted that the report deals only with a very specific issue, the consultants concur, in general, with its key findings. In particular, it is relatively straightforward to establish that the transient forces experienced by a synchronous generator during a transmission network fault event are potentially much more severe than that same machine would experience for a ROCOF event. The implication being that since all machines are designed (and required by the Grid Code) to tolerate network faults, then they must by necessity also be able to tolerate less onerous ROCOF events. However, we consider that this approach could over-simplify the issue as it only considers one aspect (synchronous stability) of the ROCOF scenario. It must be recognised that a ROCOF event comprises a different sequence of events than, say, a network fault event. OEMs consider the impact of network faults when designing their machines (and the associated auxiliary equipment), but they have probably not considered high ROCOF events as part of that design process. The real

possibility exists that some of the existing plant might be unable to ride through a ROCOF event, although the likelihood of significant damage to the plant items (generators, shafts, turbines) appears low, based on the limited information available.

It is important to note that the KEMA report focuses primarily on the issue of plant synchronous stability, yet the submissions from plant owners do not appear to raise this issue as a particular concern. For the generators, it appears to be mainly the effects of high ROCOF events on flame management, torsional effects on the turbine/generator shaft and the generator control systems that are of primary importance. These effects are not readily studied through the type of analysis undertaken in the KEMA study.

2.9 Meeting with TSO

A meeting was held between the consultants, CER and EirGrid in May 2013 to afford EirGrid the opportunity to discuss the ROCOF issue. At this meeting, EirGrid re-iterated a number of the issues raised in its written submissions, and also raised concerns that the generation fleet might be unable to demonstrate its ability to handle the existing Grid Code 0.5Hz/s ROCOF requirement.

3 Generators' Responses

3.1 ESPBG Comments on the DS3 ROCOF Modification – TSO Recommendations Paper

This short document primarily addresses aspects of the following TSO papers:-

- TSO Recommendations Paper;
- TSO paper "Analysis of Frequency Response of the Power system following large disturbances".

The ESBPG submission specifically disagrees with a number of the conclusions of those TSO papers. Specifically ESPG makes the following points:

- the TSO does not appear to believe that plant owners' concerns are valid;
- a detailed review by plant must be carried out in conjunction with the OEM's before any change can be made to the existing ROCOF levels;
- the information on historical system events presented by the TSO does not support the argument that the conventional generation fleet can move to a higher ROCOF level;
- the proposed ROCOF requirement of 1 Hz/s measured over a 500ms period is materially more severe than an instantaneous value experienced during a voltage dip event;
- the validity and consistency of some of the textbook quotes referenced by the TSO;
- ESBPG has consulted with OEMs and with EPRI, who have indicated that they would have reservations with moving to a ROCOF value of 1 Hz/s without carrying out appropriate reviews;
- ESBPG raises the requirement for OEM sign-off on any move to a higher ROCOF, for insurance purposes;
- ESBPG believes that it would not be prudent to change the ROCOF requirements prior to the necessary studies being carried out by the conventional generators;

The above comments are broadly consistent with those received from other plant owners. The point about the need for OEM sign-off to meet with insurers' requirements is an important one from the commercial perspective of the plant owners.

3.2 Response to the TSO Recommendation on the ROCOF Modification Proposal, SSE Generation Ireland Ltd

This document presents an exposition of the causes of frequency oscillations on a power system (in general), and makes the pertinent point that the increasing proportion of CCGT generation on the Irish transmission system renders the characteristics of such plant, particularly with regard to frequency control, very important.

The document then considers the historical events presented by the TSO in their document "Analysis of the Frequency Response of the Power System following Large Disturbances", and suggests that the conclusions drawn by the TSO are difficult to justify given the limited amount of available data. SSE states that an increase in ROCOF levels could impact on customer load shedding and security of supply.

The document states that "Conventional generators are currently engaging with OEMs to determine the impact of an increase to the current ROCOF value. Generators understand from manufacturers, that this type of study has not been undertaken by any of the OEMs involved, for any other country or network." It then goes on to state that "Until such time as a review is completed and shows with certainty that the change does not pose risk to generation plant and can be operated safely, generator owners cannot support any proposed changes to the Grid Code ."

The document also calls on the TSO to undertake more detailed studies to determine if 1Hz/s can be accommodated.

The views presented in this submission are consistent with those from other plant owners.

3.3 Letters to Generators regarding Enquiries re. ROCOF Capability of GE Equipment

Four submissions have been received from generators originating from GE, regarding the performance of their generating plant in high ROCOF situations.

These four submissions all appear to be based on the same document from GE, so they are reviewed together here.

The key points of this document are:-

- GE confirms its support for the DS3 process

- GE states that the consideration of an increase in ROCOF raises a number of complex issues, specifically:-
  - GT Combustion & Controls – ability to handle without LBO (lean blow-out)
  - Torsional impacts on GT/ST+GEN rotor shaft train
  - Transmission & Generation system stability
  - Protection Settings
  - Other Equipment impacts – GT, ST, generator, excitation, Power System Stabiliser application & Balance of Plant (BOP) (e.g.Low Voltage Ride Through) and possible BOP motor load instability

The document includes a detailed description of each of these issues, and also states that "It should be noted that the ability of a given unit to withstand a single event does not imply that the same or similar units will survive frequent instances of such events, or that other units of the same type will regularly survive the same or similar events … and therefore each plant would have to be separately assessed".

3.4 Letter to CER re. Suggested Cost Recovery Mechanisms for ROCOF Required Studies, ESB Generation and Wholesale Markets

This document echoes some of the points raised in the separate ESBPG document "Assessment of Possible Technical Risks to ESB Generation Plant due to increase for Rate of Change of Frequency", in which an approximate cost of €11M is estimated for the OEMs to undertake technical assessments of the ability of all of ESB's plant to accommodate the proposed ROCOF increase. It also makes clear that there may be additional as yet unknown costs to modify plant as a result of the assessments.

ESB argues that it is inherently unfair for these costs, not of the generators' making, to be borne by the generators. ESB strongly recommends that generators be permitted to recoup the costs.

ESB proposes three alternatives for the recovery of the assessment costs:-

- a modification to the Use of System charging mechanism
- through the Demand System Service charge
- Since ROCOF studies are required to establish Grid Code compliance, then the Grid Code Testing Procedure provides a mechanism for cost retrieval through the SEM Imperfections Charge.

ESB's stated position that the costs of generator assessments and modifications should not be borne by the generators is to be expected. However, this is the only submission to include any proposed cost recovery mechanisms.

3.5 Assessment of Possible Technical Risks to ESB Generation Plant due to increase for Rate of Change of Frequency (ESB Generation)

The key points from this submission are:

- In the absence of evidence to the contrary, ESB is greatly concerned that increased ROCOF has significant potential for both operational and mechanical integrity implications.
- A series of studies are required to be performed to check the operation of installed plant in a more volatile grid environment, i.e. with ROCOF events higher than the current limit of values up to and including 0.5 Hz/s.
- It is considered necessary that the series of studies are carried out by the plant Original Equipment Manufacturers (OEM).
- The studies will extend to all major components within the respective plants, including but not limited to:
  - Generator
  - Turbine(s) (incl. couplings, casings, blades and valves)
  - Compressor
  - Rotor (shaft, couplings, retaining rings, stator and rotor end windings)
  - Combustion system
  - Electrical equipment (AVR, Protection)
  - Control & Instrumentation equipment
  - O.E.M. Auxiliary plant
- The estimated cost of the studies is in the region of €900k per plant, or €11M in total for all of ESBPG's plants.
- It is estimated that the time required to complete a full study will be circa 28 months.

The document then includes a breakdown of ESBPGs generation fleet, including details for each plant.

ESBPG proposes an individual assessment for each of its plants, and this is consistent with the opinion expressed by GE.

3.6 Letter re. ROCOF Capability of GE Equipment at Tynagh Power Station, Tynagh Energy Ltd

This is essentially a cover letter to the GE document 16, but includes the following key points:-

- TEL states that if the cost of a technical assessment were to borne by itself then this would in effect be a support paid to its renewable non-synchronous competitors.

- Under such circumstances it is difficult to see how TEL would receive shareholder or bank support for the investment.

The letter ends with the clear statement:-

"Without confirmation from GE that the unit can safely operate at the proposed higher ROCOF standard TEL will be unable to comply with this higher ROCOF standard."

This submission is therefore broadly consistent with those from other plant owners.

3.7 E-mail headed "ROCOF – some feedback", relating to the cost of studies of generator ROCOF performance, GE

This brief email simply states that the cost to undertake a technical assessment of a 9FB or 9FA CCGT plant could be in excess of $1.5M and the timescale would be approximately 1 year.

The email states that the resources and systems needed for such analysis are of a very specialist nature and therefore not readily available.

The cost estimate provided by GE is approximately consistent with that stated by ESBPG in their document "Assessment of Possible Technical Risks to ESB Generation Plant due to increase for Rate of Change of Frequency".

3.8 DS3 – Rate of Change of Frequency Working Group Paper, AES Ballylumford

This document provides a brief assessment of technical considerations for the AES plants at Kilroot and Ballylumford, although it is noted that the Ballylumford B-station (3x180MW) with be closed by early 2015, and the Kilroot sets are envisaged to run infrequently post March 2015.

For the Ballylumford CCGT (C station) the following conclusions are drawn:

- Initial investigation on the C Station has concluded that at present AES Ballylumford believe there are no existing electrical or C& I protection devices that would cause the gas turbines to trip as a result of a rate of frequency change of 2 Hz/s.

- If there were a situation of an initial high frequency followed by a rapid increase in speed due to the loss of a large feeder there is the potential for a trip of ST 20 on acceleration protection. Further investigation in conjunction with the OEM is required on this

- Acceptance testing carried out in May 2004 has determined that the Block 2 unit operated as expected following an instantaneous 1 Hz injection of both increasing and decreasing frequency.

- Should the system experience events with a ROCOF of 2 Hz/s on a more frequent basis additional studies involving the OEM will be required to further consider the long term effects on the machines and the potential impact on any service agreements and insurance arrangements.

For Kilroot, similar conclusions are stated:

- Although It is unlikely that the Kilroot units will have a significant load factor when the SNSP levels reach those required to cause the ROCOF values of 2 Hz/s predicted in the study initial studies have identified that there is no existing electrical or C & I protection which would cause the units to trip as a result of a ROCOF of 2 Hz/s.

- Should the system experience events with a ROCOF of 2 Hz/s on a more frequent basis additional studies involving the OEM will be required to further consider the long term effects on the machines and the potential impact on any service agreements and insurance arrangements.

This submission from AES appears to be less pessimistic in tone that those from the other plant owners. However, AES does mention the possible need for OEM assessments and also insurance implications.

The comment regarding acceptance testing of the CCGT, including 1 Hz injection of frequency, requires careful interpretation. It is TNEI's opinion that a 1 Hz injection test is a significantly less onerous event that a genuine system frequency excursion, and the successful performance of the injection test should not be taken as evidence that the plant can accommodate a real-world frequency excursion of this magnitude or ROCOF.

3.9 Assessment of Possible Technical Risks to ESB Generation Plant due to an increase in limits for Rate of Change of Frequency (ESBPG)

This document outlines the technical issues that require consideration if moving to a higher ROCOF, and describes the phenomena that would be of concern. The issues listed include:-

- Flame stability or over-temperature in GTs
- Hydraulic transients in hydro plant
- Additional demands on plant control systems
- Impact on auxiliary plant such as motors (e.g. boiler feed pumps, gas compressors)
- Impact on plant protection systems
- Mechanical integrity – transient torques on machine shafts and turbine blades

The document concludes:-

- The Transmission System Operator is proposing to increase the limit for Rate of Change of Frequency. As detailed above, there are potential risks to the operation and integrity of generating units within the ESB fleet associated with ROCOF events at this higher limit value.
- In order to determine if these risks will apply to the specific plant within the ESB fleet, detailed analysis and validation by testing will need to be carried out to determine the impact of the higher ROCOF limit on the operation and integrity of each individual generating unit.

This submission is therefore consistent with those from a number of other plant owners.

3.10 Meetings with Generators

A number of meetings were held between the consultants, CER, and a number of individual generators in May 2013. The following paragraphs present the key issues that arose from those meetings, and that were not already adequately covered in the written submissions previously received.

- It is apparent that most, if not all, of the generation plant owners in Ireland have no option but to rely on their OEMs for guidance on this ROCOF issue.

- For a number of the generating plants in Ireland, the owners have experienced considerable difficulty in engaging their OEM, which in many cases has itself undergone significant organisational changes since the plant was commissioned.

- It is apparent that the issue of ROCOF might not been studied in detail by OEMs in the past, and that their "comfort" with the existing ROCOF requirement of 0.5Hz/s is based mainly on historic worldwide operating experience. It is apparent that there is limited design or analysis documentation available regarding this issue. Real-world events involving high ROCOFs have been historically rare, so there appears to be little relevant operating experience.

- Initial indications are that it would take a significant period of time for the OEMs to study each generating plant on the Irish system. For example, one OEM has indicated a duration of 18 months to study a single plant, with little opportunity to run multiple studies in parallel. This would suggest timescales of 8-10 years to study all of the plants on the system.

- Wind generation is generally able to accommodate ROCOFs of 1Hz/s without difficulty, although it should be noted that loss-of-mains protection may need adjustment or reconfiguration.

  It was noted that a high-ROCOF event would impact on all users of the power system, and not just on generators. The impact of high ROCOFs on system demand customers is an important issue that may require further consideration and consultation.

4 International Review

4.1 Introduction

In order to gain some perspective on the significance of the proposed Grid Code change to a 1 Hz/s standard for ROCOF in Ireland, this standard has been compared with other international references with which PPA Energy is familiar, to see if these give any additional insights.

4.2 Europe

ENTSOE are in the process of drafting a Network Code Requirements for Grid Connection (NC RfG) applicable to all generators. The original draft stated the following in respect of ROCOF:

Article 7 GENERAL REQUIREMENTS FOR TYPE A UNITS (also applicable to Type B, C & D)

3b) With regard to the rate of change of frequency withstand capability, the Generating Unit shall not disconnect from the network due to rates of change of frequency up to 2 Hz/s other than triggered by loss of mains protection. The frequency shall be measured using 100 ms average.

The consultation on the Requirement for Grid Connection (RfG) received a number of objections/comments including:

- The rate of change of frequency is very high and unrealistic.
- The limit may be outside the limits of existing generation units and may be even outside the safe operational limits of national codes, e.g. GB code.
- The existing generation units do not have the capability to meet the requirement and it may have a significant commercial impact on new plants.
- The requirement has been proposed without a quantitative assessment. A full cost benefit analysis should be conducted to justify this new requirement.
- In the category of micro CHP, there are diverse technologies which cannot be regulated in the same way. For example a micro CHP stirling engine cannot comply.

An evaluation of the above consultation comments was carried out by ENTSOE in June 2012, followed by meetings with RfG user group and DSO technical expert group. An amended network code was submitted to the Agency for the Cooperation of Energy Regulators (ACER) in June 2012.

The latest ENTSOE "Network Code for Requirements for Grid Connection' (NC RfG) issued in March 2013 (Article 8) states that "With regard to the rate of change of Frequency withstand capability, a Power Generating Module shall be capable of staying connected to the Network and operating at rates of change of Frequency up to a value defined by the Relevant TSO while respecting the provisions of Article 4(3) other than triggered by rate-of-change-of-Frequency-type of loss of mains protection. This rate-of-change-of-Frequency-type of loss of mains protection will be defined by the Relevant Network Operator in coordination with the Relevant TSO and subject to notification to the National Regulatory Authority. The modalities of that notification shall be determined in accordance with the applicable national regulatory framework."

Synchronous Area	Frequency Range	Time period for operation
Continental Europe	47.5 Hz – 48.5 Hz	To be defined by each TSO while respecting the provisions of Article 4(3), but not less than 30 minutes
	48.5 Hz – 49.0 Hz	To be defined by each TSO while respecting the provisions of Article 4(3), but not less than the period for 47.5 Hz – 48.5 Hz
	49.0 Hz – 51.0 Hz	Unlimited
	51.0 Hz – 51.5 Hz	30 minutes
Nordic	47.5 Hz – 48.5 Hz	30 minutes
	48.5 Hz – 49.0 Hz	To be defined by each TSO while respecting the provisions of Article 4(3), but not less than 30 minutes
	49.0 Hz – 51.0 Hz	Unlimited
	51.0 Hz – 51.5 Hz	30 minutes
Great Britain	47.0 Hz – 47.5 Hz	20 seconds
	47.5 Hz – 48.5 Hz	90 minutes
	48.5 Hz – 49.0 Hz	To be defined by each TSO while respecting the provisions of Article 4(3), but not less than 90 minutes
	49.0 Hz – 51.0 Hz	Unlimited
	51.0 Hz – 51.5 Hz	90 minutes
	51.5 Hz – 52.0 Hz	15 minutes
Ireland	47.5 Hz – 48.5 Hz	90 minutes
	48.5 Hz – 49.0 Hz	To be defined by each TSO while respecting the provisions of Article 4(3), but not less than 90 minutes
	49.0 Hz – 51.0 Hz	Unlimited
	51.0 Hz – 51.5 Hz	90 minutes
Baltic	47.5 Hz – 48.5 Hz	To be defined by each TSO while respecting the provisions of Article 4(3), but not less than 30 minutes
	48.5 Hz – 49.0 Hz	To be defined by each TSO while respecting the provisions of Article 4(3), but not less than the period for 47.5 Hz – 48.5 Hz
	49.0 Hz – 51.0 Hz	Unlimited
	51.0 Hz – 51.5 Hz	To be defined by each TSO while respecting the provisions of Article 4(3), but not less than 30 minutes

Table 2: Minimum time periods for which a Power Generating Module shall be capable of operating for different frequencies deviating from a nominal value without disconnecting from the Network.

4.3 Denmark

The Energinet Technical Regulation for Thermal Power Station Units of 1.5 MW and higher, regulation for grid connection TF 3.2.3, Version 5.1, 1 October 2008 states:

> "5.3.4 Transient frequencies
>
> The general purpose of the following requirements is to ensure that the power station unit is designed in such a way that it can continue to operate at transient frequency deviations. These deviations normally occur in connection with grid faults. A power station unit must be able to withstand transient frequency gradients (df/dt) of up to **±2.5 Hz/s** in the connecting point without disconnecting."

4.4 Spain

The Grid code in Spain specifies a ROCOF of 2 Hz/s. (Wind Integration: International Experience WP2: Review of Grid Codes 2nd October 2011, Ecar Energy)

4.5 NGC

There is no ROCOF requirement in the existing Grid Code. This is being considered at present. Connection Codes CC 6.1.3 and CC 6.3.12 state that Generators must operate within 52 – 47.5 Hz at all times and 47 – 47.5 Hz for at least 20 sec; unless NGC has agreed to any frequency or ROCOF relays under the Supplemental Agreement.

An open letter was sent to industry 24/1/2013. The proposals being considered by a Workgroup are for a ROCOF expected to be in the range 1 Hz/s to 2 Hz/s.

4.6 South Africa, NERSA

The South African Grid Code, The Network Code version 7, does not refer to ROCOF, however the Grid Code Requirements For Wind Turbines Connected to Distribution or Transmission Systems In South Africa, Draft rev 4.4 specifies for Wind Energy Facilities (WEF):

> "The WEF shall remain connected to the DS or TS during rate (for falling frequencies, but not rising) of change of frequency of values up to and including 0,5 Hz per second, provided the network frequency is still within the continuous frequency characteristic"

4.7 Comments on international experience

From the above range of countries, it is clear that a ROCOF standard of 1 Hz/s is within the range of expectation, or currently under discussion, in most of the examples examined. The most notable exception is the Grid Code of South Africa, which relates to a large predominantly coal, nuclear and hydro based system experiencing relatively high demand growth. The inertia of the system is therefore unlikely to be reduced significantly by the development of renewable generation in the short term. Whilst Europe were proposing a standard of 2 Hz/s over a 100 ms period there has been a recent revision to these proposals due to concerns in respect of existing generation capability, commercial impacts on new plant and the inability of some plant to comply. This has led to a devolvement of ROCOF responsibility from the ENTSOE Network Code to the individual national frameworks where the ROCOF has yet to be defined by each TSO.

5 Comments on Key Issues raised by CER

5.1 Appropriateness of the proposed ROCOF standard in Proposed Grid Code Modification MPID229

The proposed Grid Code modification refers to a standard for ROCOF ride-through of 1 Hz/s, as measured over a rolling 500ms period. This represents a raising of the required standard, which is currently specified as 0.5 Hz/s. It is noted however that in Northern Ireland, new generators are already connected under a Minimum Functional Specification that specifies 1.5 Hz/s as the required standard.

It is pointed out by the TSOs that in reality generators on the network are already seeing ROCOF events in excess of these levels during fault conditions, although over significantly shorter periods. The key issues therefore relate to the cumulative effect of these events taking place with increased regularity, as more wind generation is connected to the All-Island network and the inertia of the system falls. This will lead to more rapid rates of change of frequency following faults on the system or the tripping of generation.

The standard proposed by the TSOs is based on studies that look at the likely penetration of RES in 2020, performed as part of the All Island TSO Facilitation of Renewables Studies. These demonstrate that ROCOF in the range 1-2 Hz/s could be encountered on the All Island system in the event of decreased wind generation output following network faults, and that for ratios of wind-plus-imports to load-plus-exports of 60-70%[2].

In the light of this, and looking at the range of standards under discussion in Europe, a proposed ROCOF standard of 1 Hz/s appears reasonable. The justification for the measurement being made over 500ms is less clear. In discussions recorded in the minutes of the Grid Code Working Group this is cited as aligning with the required recovery time for wind generation post-fault; it's also referred to in the ROCOF Modification Proposal – TSOs' Recommendations as the time taken for generators to return to "a coherent state".

The TSOs claim that measurements of ROCOF viewed over shorter time periods than 500 ms are typically higher than 1 Hz/s in the All-Island system, and that a higher standard would therefore have to be specified were a shorter interval to be proposed. This suggests that effectively a ROCOF standard of greater than 1 Hz/s measured over 100ms is being sought; there is insufficient evidence available in the studies presented, however, to assess the ROCOF magnitude over 100ms that would occur. Also the requirement for generating plant to tolerate a ROCOF of 1 Hz/s over a

[2] All Island TSO Facilitation of Renewables Studies Fig 4-13

duration of 500ms is clearly more stringent than the more usual 100ms timeframe such as that which was being considered by the new European standard.

In view of the potential significance of the longer duration of ROCOF withstand for generators in terms of potential cumulative effects of wear and tear, further justification should be sought from the TSO for the 500ms duration.

5.2 Relevant international experience

As noted above, the most relevant international reference for the setting of the ROCOF standard is the work being carried out by ENTSOE in the development of the Network Code Requirements for Generation, which following industry consultation in respect of a proposed standard of 2 Hz/s measured over 100ms has resulted in a devolvement of ROCOF responsibility from the ENTSOE Network Code to the individual national frameworks where the ROCOF has yet to be defined by each TSO. National Grid in Great Britain is considering a ROCOF standard between 1 Hz/s and 2 Hz/s but it is not clear at this stage over what time period the ROCOF would be measured.

The Great Britain system is a useful reference in that it has a lower inertia than the large, interconnected European network and is therefore likely to experience more frequent transients and potentially more rapid changes of frequency than are seen in larger systems.

That both ENTSOE and National Grid have been considering a ROCOF between 1 Hz/s and 2 Hz/s indicates that the standard being sought in Ireland is not out of line with international practice; a key consideration, however, is the timescale over which this rate of change of frequency is measured. Further discussion with the TSO and with OEMs will be required to establish the possible implications of evaluating ROCOF over the longer 500ms timeframe.

5.3 Evidence of conventional generators' capability in relation to ROCOF of 1 Hz/s

There is little direct evidence available in the information provided by the TSOs and the generators regarding the likely performance of conventional generating plant in response to ROCOF events of up to 1 Hz/s in severity. The generators refer to the need for detailed studies by OEMs, and the consultants concur with this view, as it is not possible to tell from the studies carried out by the TSOs to date what the impact of the mechanical effects associated with exposure to high ROCOF occurrences would be on generation equipment. Whilst the studies carried out by DNV KEMA are helpful in demonstrating the ability of plants to ride through 1 Hz/s ROCOF occurrences in terms of maintaining transient stability, this is only one factor in the complex set of mechanical phenomena that can affect plant performance and possible degradation in terms of wear and tear as a result of repeated ROCOF occurrences.

None of the evidence presented in the submissions to the CER thus far enables therefore enables a firm conclusion to be drawn as to the impact of ROCOF events of up to 1Hz/s on conventional generators.

5.4 Connection between fault ride-through and ROCOF withstand

The KEMA report's conclusion that the effects of a ROCOF event on a plant are less onerous that that of a system fault event is entirely correct. TNEI has previously undertaken fault simulations using models of the all-island network that clearly demonstrate that a large CCGT can experience accelerating ROCOFs of 8%/s (4 Hz/s) for a duration of 100ms (during a fault-induced voltage depression) followed immediately by a decelerating ROCOF of 2%/s (1 Hz/s) for longer than 500ms. All synchronous machines on the network are designed to tolerate this kind of event, although not on a frequent basis.

However, caution is required in assuming that just because a plant is capable of tolerating a grid fault event, it is also therefore naturally capable of handling an apparently less onerous ROCOF event. The rationale for this opinion is simply that ROCOF events might not have been included in the list of design considerations for any of the plants. Furthermore, the ability to tolerate faults and ROCOF says nothing about the cumulative effect of such events on generating equipment, which requires the OEMs' intervention to address.

5.5 Approach, timescale and budget for studying ROCOF effects on steam or gas turbine power plants

Cost estimates received from two OEMs (GE and Siemens) via plant owners suggest that the budget for studying the ROCOF effects on a *single* plant might be in the region of €0.9M - €1.15M. The timeframe suggested by OEMs is in the region of 12 months. Such a study would comprise a desk-top exercise undertaken by the OEM (i.e. it would not involve tests on the plant) and would consider the following aspects:-

- Generator
- Turbine(s) (incl. couplings, casings, blades and valves)
- Compressor
- Rotor (shaft, couplings, retaining rings, stator and rotor end windings)
- Combustion system (where appropriate)
- Electrical equipment (AVR, Protection)
- Control & Instrumentation equipment

- O.E.M. Auxiliary plant

The consultants consider that this proposed approach would be appropriate. The suggested costs do appear high, although it must be recognised that the specialist resources required to undertake such studies are not widely available. Were such studies to proceed, fully costed quotations including a detailed statement of the methodology to be adopted and the resource requirements and day rates of the personnel involved should be sought and reviewed carefully.

5.6 Risk of a loss of commercial life to generating plants as a result of ROCOF events occurring

The consultants are not in a position to comment authoritatively on this impact of ROCOF events on plant life or on maintenance and inspection regimes. However, it is the consultants' opinion that high ROCOF events are unlikely to occur in practice except during the unplanned trip of a large generator station, and this is (and is likely to remain) an infrequent event. We would therefore anticipate that the impact on plant commercial life would be no worse than the impact of severe system fault events, which are also infrequent.

5.7 Risk of catastrophic failure of a generator and other safety issues resulting from a ROCOF event

The consultants consider that the transient impact of a high ROCOF event is likely to be less onerous on the major plant items (turbines, shafts, generators) than severe network fault events. The major plant items are designed to ride-through network fault events, and would not be expected to sustain catastrophic damage in such circumstances. We therefore consider it highly unlikely that plants would suffer catastrophic damage, or give rise to other safety issues, during a high ROCOF event.

5.8 Potential advantages/disadvantages of a system-wide study of the effects of ROCOF on the generation fleet

In view of the high costs and along timescales associated with analysis of the effects of 1 Hz/s ROCOF on individual generating plants, the consultants have considered the possibility of a generic study being undertaken that could identify the degree of impact of ROCOF on typical conventional plant. This would be valid if it were considered that there were sufficient similarities between plants of different manufacture and combustion technology to make possible comparisons between the results for one plant and the likely impacts for others.

A range of technical and commercial considerations need to be borne in mind in considering this option. As noted by ESBPG, the specific impacts on generators associated with ROCOF are anticipated to include:

- Flame stability or over-temperature in GTs

- Hydraulic transients in hydro plant
- Additional demands on plant control systems
- Impact on auxiliary plant such as motors (e.g. boiler feed pumps, gas compressors)
- Impact on plant protection systems
- Mechanical integrity – transient torques on machine shafts and turbine blades

A study of an individual CCGT plant, for example, would enable a subset of these issues to be considered and would provide valuable insight into the options for achieving the necessary flame stability and the impact of ROCOF on the torques experienced by machine shafts and turbine blades. If such a study were to conclude that for a typical unit there were major issues with flame stability or mechanical integrity that were likely to apply to other units, this would simplify the process going forwards, as a conclusion could potentially be drawn that other similar plants were unlikely to be able to tolerate the proposed ROCOF situation. This would provide valuable insight to the TSOs, in that it would raise the priority of seeking alternative methods of maintaining higher inertia on the All Island system, e.g. through the revision of plant stable minimum generation requirements.

If the results of a single study concluded that for a specific type of GT no problems were anticipated in tolerating a 1 Hz/s ROCOF, this would require careful discussion and review with other OEMs. At this point a number of commercial factors come into play, in that if insurers, shareholders, banks and others are to be satisfied that future plant performance is not going to be jeopardised, then they are highly likely to seek assurances from the OEMs of the specific plants in question. It is very unlikely that one OEM would give an assurance about its own plant based on the results of studies carried out by another OEM, and this practical reality therefore has to be borne in mind in considering the validity of a generic study.

A further consideration is the impact of the timescale to carry out a single study on the programme for the wider uptake of low carbon generation in Ireland and Northern Ireland. Based on the information from GE suggesting that the sort of study required would take more than a year to complete, this would clearly slow down the process of achieving Ireland's 2020 renewables target if it were then found that other studies were required due to inclusive results being obtained from the single plant study.

GE further states that each plant would need to be separately assessed from a technical perspective, and the consultants concur with this view. Our experience is that apparently similar plants from the same OEM are often based on different derivations of equipment, and each plant could be essentially be considered bespoke in one or more key technical aspects, including the characteristics of the transmission system at the plant connection point.

On balance, therefore, the consultants are of the view that there would be insufficient benefit gained from a study of a single plant to warrant the delay required to complete this before considering the implications for other plants.

The commercial consideration of the assurances needed by the owners and backers of each individual plant would also suggest that carrying out an industry-wide independent study by other than the OEMs of individual plants is unlikely to provide the level of certainty needed. It therefore seems unlikely that any real cost advantage would be derived by commissioning OEM assessments centrally.

5.9 Impact of increasing System Non Synchronous Penetration of Generation

The All Island TSO Facilitation of Renewables (FOR) Study, 2010, analysed the impact on ROCOF of the loss of the largest infeed and the effects of voltage induced frequency dips on the 2020 network, for a range of percentages of System Non-Synchronous Penetration.

The results of this work are quoted in the report "ROCOF Modification Proposal – TSOs' Recommendations", and clearly demonstrate the effects of increasing SNSP on particularly the levels of ROCOF experienced at higher levels of SNSP as a result of voltage dip events on the network. These voltage dips occur generally as a result of faults occurring at the distribution and transmission levels, with short circuits causing the collapse of the voltage on the system which is most severe in the immediate proximity of the fault. The ability of wind generation to ride through faults and the effects of low voltages on the power output of the machines has been the subject of separate studies in Ireland and discussion on the relevant Grid Code standard. What is important from the viewpoint of ROCOF however is that when wind generators reduce their power output during a fault and then take time to recover their output during post-fault recover, the loss of real power generation coupled with the "lightness" of the system (as inertia decrease with increasing SNSP) leads to higher ROCOF levels with increasing SNSP.

The frequency of high ROCOF events occurring on the system is directly related to the number of faults that occur on the networks and the number of generator trips that take place, either as a result of network faults or plant failures, coupled with the number of interconnector trips leading to reduced system imports or exports. There is no reason to suggest that the frequency of these network occurrences will increase with increasing SNSP; what will change, however, is the level of ROCOF seen following these faults, as SNSP increases. This is clearly shown for example in Figure 2 of the report "ROCOF Modification Proposal – TSOs' Recommendations", reproduced below.

This diagram shows the very rapid increase in the level of (negative) ROCOF that occurs following voltage dips as SNSP increases above 40%.

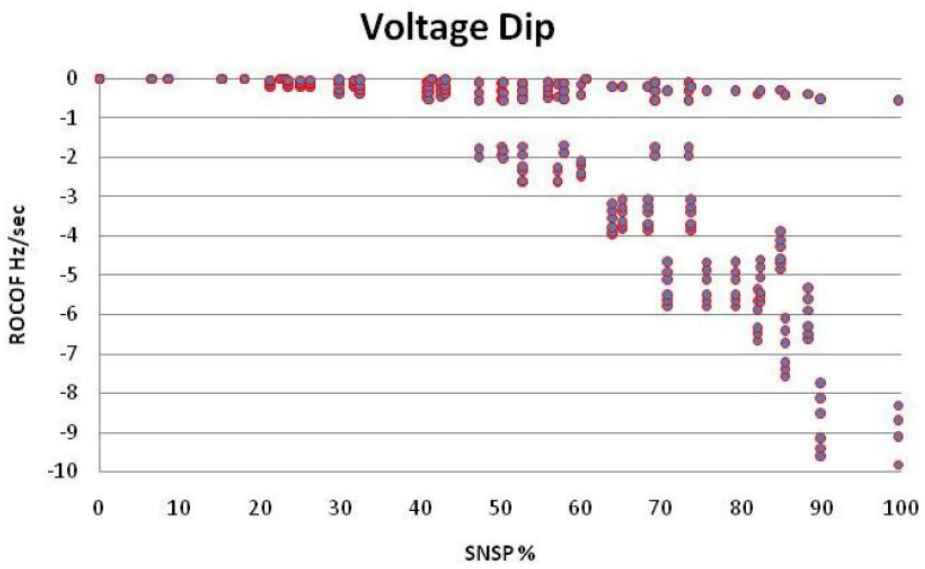

Figure 2 FoR Study Results on Voltage-Induced Frequency Dips in 2020: The initial proposal of 4Hz/s would have allowed SNSP levels up to 65-70%. The current proposal of 1Hz/s in Ireland means that this issue must be dealt with through better windfarm standards.

Source: Eirgrid/SONI report: "ROCOF Modification Proposal – TSOs' Recommendations"

It is clear therefore that at levels approaching 75% of SNSP, levels of ROCOF of up to 6 Hz/s will become more frequent occurrences on the network. Further analysis would be required to investigate the relative numbers of fault events on the system that would lead to the higher levels of ROCOF.

5.10 Implications of a change in the ROCOF standard on the Distribution System

ROCOF relays are presently used by embedded generation to provide protection against operating in islanded mode. Generators connected at 110 kV will probably have intertrip communications to disconnect them if an islanding situation arises. For generators connected at lower voltage there is a balance between ensuring generators do not trip for a frequency deviation, but do trip when there is loss of mains or an island situation. As well as ROCOF relays there are other passive and active techniques available to detect islanding mode such as reverse power flow, reverse reactive power flow, voltage vector phase shift, reactive export error detection, system impedance monitoring and frequency shifting.

The FOR study observed that Distribution connected generators currently have ROCOF relays, the actual settings of which are not known, but which disconnect the generator at around ±0.5 Hz/ sec. Operation of these relays following a system disturbance would lead to cascading effects and a dramatic drop in system frequency.

ESB Networks recommend ROCOF settings in their report Embedded Generation Interface Protection, Rate of Change of Frequency Settings for Embedded Generators 30/11/12. The studies undertaken in the report show these settings will avoid nuisance tripping for the contingency scenarios considered; with the exception of the response of heavy synchronous generators or directly connected induction generators to loss of the largest infeed (396 MW import at Dublin Bay Power) followed by tripping of 310 MW at Coolkeeragh power station 1 second later.

The recommended settings for ROCOF are:

- Doubly fed induction generators (DFIG) and full convertor generators
  - 2 Hz/s with a time delay of 0.3s
- synchronous or directly connected induction generators with an inertia greater than 3 MWs/MVA (heavy)
  - ROCOF settings of 0.6 Hz/s with a time delay of 0.6s
- synchronous or directly connected induction generators with an inertia less than or equal to 3 MWs/MVA
  - 1 Hz/s with a time delay of 0.6s.

UK Engineering Recommendation G59 states that it is the responsibility of the generator to incorporate the most appropriate techniques or combination of techniques to detect loss of mains. It states that ROCOF protection is suitable for small power stations (NGT <50 MW, SP <30 MW, SHETL <10 MW). It suggests a value of 0.125 Hz/s to reduce nuisance tripping.

UK Engineering Recommendation G83 (small embedded generators), issue 2, August 2012 has a ROCOF of 0.2 Hz/s. However it is noted in the ER that it is likely a larger ROCOF will be needed to be withstood in the future without tripping as the system inertia decreases and new designs should allow for 2 Hz/s as proposed in the new European Network Codes. It is noted that ROCOF will cease to be an effective loss of mains protection.

The use of ROCOF for distribution networks is to ensure generation is disconnected in the event of an islanded situation arising. Whilst ROCOF protection has traditionally been used to achieve this, with increasing system ROCOF it is unlikely that ROCOF protection will remain suitable and new islanding detection techniques will be deployed. The consultants note therefore that a more fundamental review of the protection that is appropriate for generation connected to the distribution network will need to be undertaken by ESB Networks in response to increasing ROCOF levels on the All Island system, if cascade disconnections of distribution-connected generation are to be avoided in the future following high ROCOF events.

5.11 Practicality of testing plants' responses to ROCOF

The consultants do not consider it feasible to test plants' responses to ROCOF, as to do so would involve deliberately instigating such an event on the transmission system, with the associated risk of loss of system security. We do not believe that the TSO would wish to consider such an approach.

A more appropriate approach would be to install disturbance recorders on all plants (or a selection thereof) and monitor the plants' responses to high ROCOF events that may occur "naturally" over time. Many plants are already fitted with suitable monitoring equipment.

6 Conclusions and Recommendations

The TSOs' and Generators' submissions to the CER on the subject of the Proposed Grid Code Modification MPID 229 have been reviewed by the consultants and assessed in the light of the studies referred to in the submissions and the evidence regarding the issues associated with increasing the ROCOF Standard from 0.5 Hz/s to 1.0 Hz/s measured over a 500ms period. From this review, a number of key conclusions can be drawn.

It is clear that as the System Non-synchronous Penetration (SNSP) increases towards 2020, the number of network events leading to high ROCOF levels will increase. In recognition of this, the TSOs are seeking an increase in the required ROCOF withstand to 1 Hz/s. This level is compatible with standards being considered in Great Britain (where a standard set between 1 Hz/s and 2 Hz/s is under consideration), however agreement across Europe to a proposed ROCOF of 2 Hz/s over 100 ms has not been achieved due to concerns in respect of existing generation capability and commercial impact on new plant. There is valid concern expressed by generators connected to the Irish transmission system, and a recognition by the TSOs, that the ROCOF levels seen over a 100ms period could be significantly higher than the average of 1 Hz/s seen over 500ms.

The effect of high ROCOF levels on the torque experienced by generators in terms of increased wear and tear on generating equipment lies at the heart of the concern that generators have about their equipment being exposed more frequently to events involving ROCOF in excess of 0.5 Hz/s. There is insufficient evidence available from the studies carried out by the TSOs (including the study undertaken by DNV KEMA) to be able to comment on the effects of frequent high ROCOF on the physical condition of generating plant. Similarly, the generators themselves, whilst raising concerns about the potential effects of cumulative ROCOF events on turbine/generator shafts and other mechanical equipment, are unable to present clear evidence in the form of studies of the problem carried out by OEMs, as these studies have yet to be undertaken at the required level of detail.

It is noted, from the DNV KEMA report, that in short circuit conditions generating equipment is already exposed to significantly higher mechanical torques than are predicted to occur during ROCOF events; the issue therefore concerns the effect of any possible increase in the frequency of high ROCOFs over potentially longer periods than the duration of a three-phase fault clearance.

The consultants concur with the views expressed by the generators and OEMs that the only way to ascertain the effects of ROCOF in excess of 0.5 Hz/s on generating equipment is to carry out plant-specific studies to investigate the mechanical behaviour of the equipment. The nature of the mechanical effects involved is such that insufficient certainty is likely to be achieved from a generic or "typical" study. Furthermore, from a commercial perspective, it is highly unlikely that the owners, financial backers and insurers of generating plant of one type of manufacture would

accept the results pertaining to a different OEM's plant as adequate reassurance in this complex area.

A key issue concerns the course of action that would be pursued if the ROCOF standard in the Grid Code is changed and plants declare themselves unable to comply. It would be very important to ensure that plants were not permitted to install ROCOF protection that would trip them from the system in the event of ROCOF greater than 0.5 Hz/s were encountered, as this would severely affect the ability of the system to recover from faults. Short circuits on the network could already result in higher levels of ROCOF than this for short durations, and levels of ROCOF are already likely to be seen by these plants in fault conditions. In the event of a generator seeking a derogation from the requirement to meet a ROCOF of 1 Hz/s over 500ms, if this were the Grid Code standard, the TSOs may well be faced with a situation of having to constrain off such a plant for increasing periods of time as SNSP increases.

Alternative approaches to solving this problem, via maintaining additional conventional generation on the system at lower levels of generation in order to maximise system inertia, are understood to have been considered by the TSOs. There is insufficient detail presented as to what may be possible in this area for the consultants to draw a conclusion as to the viability of this approach, however.

In the light of the above conclusions, the consultants recommend:

- that conventional generators be asked to obtain detailed quotations and timescales for the studies required to demonstrate the ability of their plants to comply with the proposed 1.0 Hz/s over 500ms, including a full justification of the proposed costs from the relevant OEMs and a full technical specification of the proposed studies, against which the adequacy of the OEMs' analysis can be checked by the CER;

- that the TSOs be asked to prepare a report exploring the level of ROCOF that arises over a 100ms period in a range of scenarios that show an average ROCOF of 1.0 Hz/s over 500ms, to enable further consideration of the short term impact of potentially higher rates of ROCOF over this shorter period by generator manufacturers;

- that the TSOs provide further information about the alternatives to changing the ROCOF standard that exist, describing the potential impact of these on system operation and the electricity market, and detail the likely limitations of any alternatives on the level of SNSP that can be achieved in 2020. This is likely to include reference to methods of maximising the amount of conventional generation connected to the system at times of maximum wind penetration, including a qualitative assessment of the implications for system dispatch and the cost of electricity in the market;

- that the TSOs give further consideration to the potential impact of higher ROCOF on system demand customers (at all connection voltages) and, along with the DSOs, consult with demand customer groups on this issue,

- that the TSOs explain the process by which derogations from the proposed new ROCOF standard would be applied, and the generators be required to provide sufficient information to enable derogation requests to be fully assessed, and the implications for the power system of plants not being able to comply with the new standard; and

- a review should be undertaken by the DSOs, to be co-ordinated with the TSOs, of the protection systems and settings that are appropriate at the distribution level to handle high ROCOF situations and to optimise the performance in the presence of high renewable generation penetration.

Pending the results of these processes, the consultants recommend that CER does not approve MPID 229.

Appendix 1: List of Documents Reviewed

No.	Originator	Organisation	Title
1	EirGrid/SONI	TSOs	DS3 Rate of Change of Frequency Modification Recommendation to the CER
2	EirGrid/SONI	TSOs	RoCoF Modification Proposal – TSOs' Recommendations
3	EirGrid/SONI	TSOs	DS3 Joint Grid Code Working Group Position Paper on RoCoF
4	EirGrid/SONI	TSOs	DS3 Grid Code Working Group Minutes
5	EirGrid/SONI	TSOs	Analysis of the Frequency Response of the Power System Following Large Disturbances
6	EirGrid/SONI	TSOs	Northern Ireland System Separation Studies
7	EirGrid/SONI	TSOs	Summary of Studies on Rate of Change of Frequency events on the All-Island System
8	EirGrid	TSO	Achieving the Highest Levels of Wind Integration – A System Operator Perspective
9	ESBPG	Generator	ESPBG Comments on the DS3 RoCoF Modification – TSO Recommendations Paper
10	EirGrid	TSO	Grid Code Modification Proposal Form
11	SSE Generation Ireland Ltd	Generator	Response to the TSO Recommendation on the ROCOF Modification Proposal
12	GE	Generator manufacturer	Letter to Bord Gais Éireann re. Enquiry re ROCOF capability of GE equipment at Whitegate Power Station
13	ESB Generation and Wholesale Markets	Generator	Letter to CER re. Suggested Cost Recovery Mechanisms for RoCoF Required Studies
14	ESB Generation	Generator	Assessment of Possible Technical Risks to ESB Generation Plant due to increase for Rate of Change of Frequency
15	Tynagh Energy Ltd	Generator	Letter re. ROCOF Capability of GE Equipment at Tynagh Power Station
16	GE	Generator manufacturer	Letter re. Enquiry re ROCOF capability of GE equipment at Tynagh Power Station
17	GE	Generator manufacturer	E-mail headed "ROCOF – some feedback", relating to the cost of studies of generator ROCOF performance
18	GE	Generator manufacturer	Letter re. Enquiry re ROCOF capability of GE equipment at Whitegate Power Station
19	AES Ballylumford	Generator	DS3 – Rate of Change of Frequency Working Group paper
20	ESBPG	Generator	Assessment of Possible Technical Risks to ESB Generation Plant due to an increase in limits for Rate of Change of Frequency
21	GE	Generator manufacturer	Letter re. Enquiry re ROCOF capability of GE equipment at Coolkeeragh Power Station
22	ESB Networks	DNO	Embedded Generation Interface Protection: Rate of Change of Frequency Settings for Embedded Generators
23	KEMA	Consultants to EirGrid	An independent analysis on the ability of Generators to ride through Rate of Change of Frequency values up to 2Hz/s

24	ACER	ENTSOE	ENTSO-E amendments to the Network Code for Requirements for Grid Connection Applicable to all Generators
25	ENTSOE	ENTSOE	Requirements for Grid Connection - Consultation- list of comments