Summary of Studies on Rate of Change of Frequency events on the All-Island System

August 2012

Authored by: Salim Temtem & Karen Creighton

Checked by: David Cashman & Raymond Skillen

Approved by: Jonathan O' Sullivan & Dick Lewis

1 Purpose

This document summarises the studies investigating the rate of change of frequency (RoCoF) that were performed by EirGrid and SONI as part of the DS3 Programme. The studies performed included the loss of the East-West Interconnector (EWIC) while exporting and also the loss of the Louth-Tandragee tie-lines resulting in a system separation between Ireland and Northern Ireland. These studies were conducted with a view to determining if the Grid Code standard for RoCoF that is being proposed by the Transmission System Operators (TSOs) is sufficient to cover these potentially high RoCoF events.

2 Background

EirGrid and SONI, the Transmission System Operators (TSOs) in Ireland and Northern Ireland have a responsibility to operate the power system in a secure, safe and reliable manner. Considerable challenges exist when integrating significant amounts of non-synchronous renewable generation into the power system. In order to achieve Ireland's and Northern Ireland's 2020 targets these technical challenges must be addressed to ensure that the system can operate in a secure manner. The rate of change of frequency (RoCoF) following a large system disturbance is one of the major issues associated with system security when high levels of non-synchronous generation are connected to the system. Detailed technical studies were performed which form part of the Facilitation of Renewables (FOR) report[1] and these studies indicated that RoCoF could pose a threat to the security of the power system. The FOR studies demonstrated that during times of high wind generation that following the loss of the single largest credible contingency, RoCoF values in excess of the current Ireland Grid Code standard of 0.5Hz/s could be experienced on the power system. Values in excess of 0.8 Hz/s for the loss of the largest in-feed on the island were seen in some scenarios.

Two significant events that were not covered in the FOR studies were the loss of an interconnector while on export and the loss of the Louth-Tandragee tie lines resulting in a system separation between the North and the South. These events were highlighted as potential events which could cause significant RoCoF levels on the system. This report describes the studies performed by EirGrid and SONI to investigate these events.

[1] "Facilitation of Renewables", EirGrid-SONI June 2010

3 Investigation of the loss of the East-West Interconnector (EWIC)

This section describes two events involving the East-West Interconnector (EWIC) which would result in significant RoCoF events on the Irish Power System. Both events considered EWIC exporting power from Ireland to the National Grid GB system. The first event considered a trip of EWIC resulting in the loss of the 530 MW export. The second event involved investigating a fault at the Shotton station in Great Britain which would result in a transient power reversal on the HVDC link before the interconnector trips.

3.1 Loss of EWIC at maximum export

The tripping of EWIC was investigated whilst operating at its maximum export of 500 MW. This event results in a rise in frequency on the Irish power system and therefore a positive RoCoF event occurs. This event is therefore a different event in nature to the loss of a large in-feed on the system as the RoCoF is positive as opposed to negative.

The study considered was for a tripping of EWIC while at full export in a summer minimum load scenario case with a high System Non Synchronous Penetration Level (SNSP). This case was selected as it was a potentially onerous scenario from the point of view of a RoCoF event on the system. The system setup for this case was as follows:

- Demand (MW)
  Ireland: 1742
  Northern Ireland: 542
  All-Island: 2284

- Wind (MW)
  Ireland: 1160
  Northern Ireland: 220
  All-Island: 1380

- Interconnector Flows (MW)
  EWIC: -530 (export)
  Moyle: 400 (import)

- SNSP (%)
  All-Island: 63%

The simulations were performed in PSS/E and RoCoF results were determined by taking the derivative of the measured frequency at various points in the network. The RoCoFs at different points on the system were recorded along with the average 'system' RoCoF taken from the average frequency measurement. The RoCoF was calculated using a 500 ms time window as has been proposed for the new modification for the existing Ireland Grid Code clause CC7.3.1.1 (d)[2]. This proposed Grid Code standard specifies a RoCoF of 1 Hz/s over 500 ms as the level which all generators on the transmission system must comply with. Figure 1 demonstrates the RoCoF seen at Ballylumford (BALLY), Poolbeg (PB), Aghada (AD) and Louth (LOU) busbars. In addition to these buses the average (AVG) RoCoF on the system is displayed.

[2] EirGrid Grid Code, Version 4, December 8th 2011.

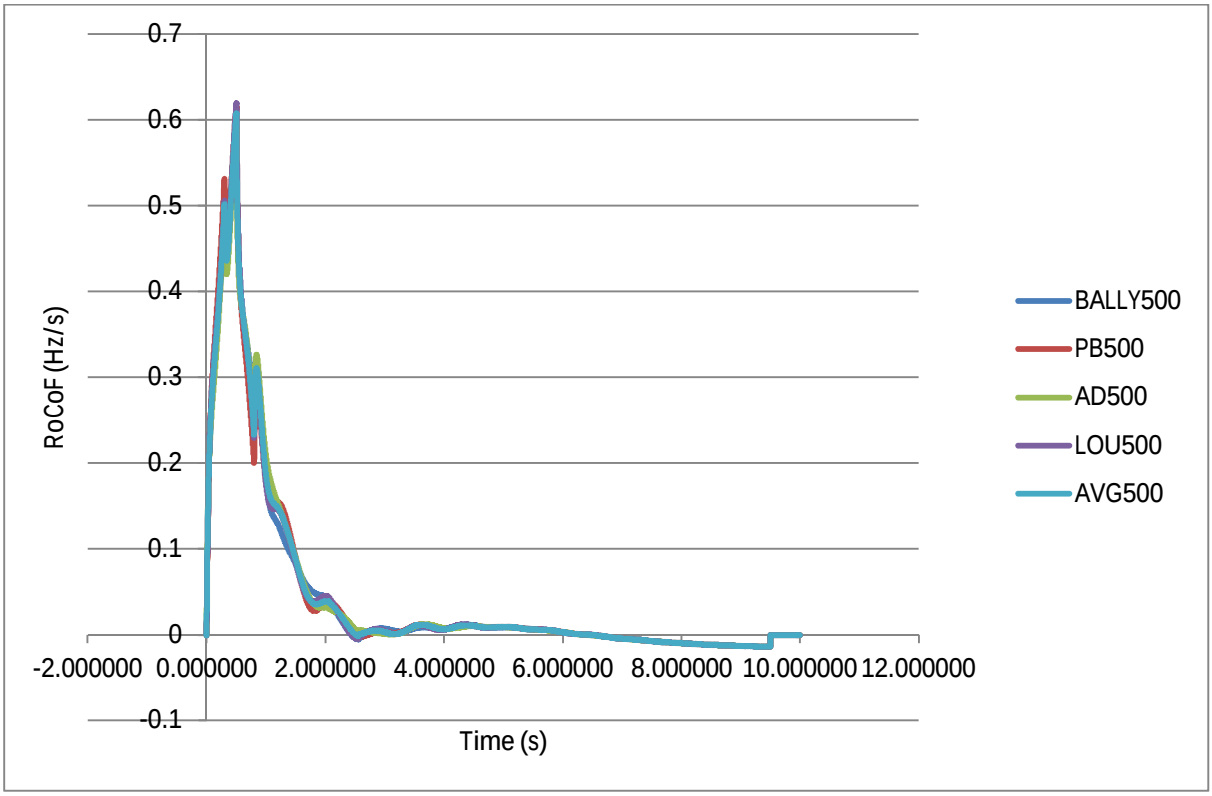

Figure 1: Ballylumford, Poolbeg, Aghada, Louth and Average RoCoFs for the tripping of EWIC at maximum export.

Figure 1 illustrates that the RoCoF calculated due to the tripping of EWIC while at full export was approximately 0.63 Hz/s. This RoCoF was recorded for a summer minimum load scenario with an SNSP of 63%. The RoCoF is seen to remain within the proposed Grid Code standard of 1 Hz/s. This indicates that the tripping of EWIC should not pose a threat to system security if all units on the system meet the proposed RoCoF standard.

The results also illustrate a good correlation between the various measurements across the system which indicate that the RoCoF measured is a global event rather than a localised electro-magnetic transient. This is in line with the definition of RoCoF proposed for the new Grid Code standard.

3.2 Fault at Shotton end of EWIC resulting in transient power reversal

The second event involving EWIC that was analysed by the TSOs involved a fault occurring at the Shotton end of the DC link when EWIC was operating at maximum export to the Great Britain (GB) system. This event would result in a transient reversal of power from 500 MW export to GB to an import of 300 MW to Ireland for 50 ms before the interconnector power flow settles to zero. All of this occurs within the protection operation time.

The results for RoCoF across a range of buses were recorded for the proposed 500 ms time window proposed in the Grid Code and also for a 100 ms time window. Table 1 displays the RoCoF results for the Ardnacrusha (AA), Aghada (AD), Cathaleen's Fall (CF), Louth (LOU), Carrickmines (CKM), Great Island (GI), Ballylumford (BALLY) and Poolbeg (PB) substations.

Bus	T = 100 ms	T = 500 ms
AA	0.23	0.41
AD	1.07	0.41
CF	1.34	0.42
LOU	2.09	0.43
CKM	1.91	0.43
GI	1.56	0.42
BALLY	1.55	0.43
PB	2.71	0.53
AVG	**1.59**	**0.43**

Table 1 Maximum RoCoF measurements at each measurement bus for different time windows

The results in Table 1 highlight a key issue in the measurement of RoCoF across the system which is that the frequency measured at different points in the system can vary significantly under transient conditions. It can be seen that for the lower time window of T = 100 ms that there is a wide range of RoCoF values measured. In particular, the highest RoCoF measured was at Poolbeg which had a 2.71 Hz/s RoCoF. Conversely the lowest frequency measurement was in Ardnacrusha which had a RoCoF of 0.23 Hz/s. The average maximum RoCoF was measured to be 1.59 Hz/s. This indicates a large deviation in measurements across the system with 'local' RoCoF issues arising in different parts of the system. At this time window it is difficult to determine a consistent system wide RoCoF measurement. This is largely due to the fact that electrical transients will play a role in the frequency measurement during the event. During transient events generator rotor speeds may also differ from each other due to local and inter-area interactions. In order to obtain a consistent system wide measurement of RoCoF, the electrical transients need to be removed from the analysis and only the mechanical transients on the system should be considered. By extending the measurement window the electrical transients can be removed from the RoCoF measurement allowing for a more consistent system RoCoF to be determined.

If the time window is extended to 500 ms it can be seen that most buses were consistent in the RoCoF measurement. However, a higher RoCoF was still seen at Poolbeg than the other buses investigated. It should be noted that for the longer time windows the RoCoF measurement is much more consistent across the system. This gives a larger confidence in determining the system wide RoCoF. The average system RoCoF for this event was approximately 0.43 Hz/s which remained within the proposed Grid Code standard of 1 Hz/s.

- *Studies for the loss of EWIC indicate that RoCoF levels will remain within the proposed Grid Code standard.*
- *EirGrid intend to bring a Grid Code modification forward to the Ireland Grid Code to modify the RoCoF standard to a level of 1 Hz/s over a 500 ms period.*

4 System Separation Event in Northern Ireland

This study investigated the separation of the Northern Ireland (NI) system due to the loss of the Louth-Tandragee tie-lines. A three phase fault is simulated in Tandragee resulting in the tripping of the 275 kV lines connecting into Louth and also the inter-tripping of the 110 kV lines between Enniskillen – Corraclassy and Strabane – Letterkenny. The study considers frequency stability under these conditions when the system inertia may be reduced following system separation.

The system fault and resulting system separation can have a significant effect on NI frequency stability depending on network conditions. The generation/load imbalance is affected by a number of factors including:

- Commutation failure or blocking of the Moyle interconnector during low voltage conditions
- Loss of Wind Farm Power Station (WFPS) active power production during and after fault clearance, and failure of WFPS commissioned pre 2005 to ride-through the fault
- Loss of active power import or export on the Louth-Tandragee tie lines during and after fault clearance
- Reduced active power output from conventional generators depending on the retained voltage during faults

Simulations were performed in PSS/E with the RoCoF calculated over a 500 ms period in line with the proposed Grid Code proposals for Ireland and Northern Ireland. A number of dispatch scenarios were considered. The dispatches of interest included combinations of the Coolkeeragh gas and steam unit, Ballylumford unit B10 and Kilroot units K1 and K2.

During the simulation of the fault at Tandragee there was a significant drop in generation due to the blocking of the Moyle Interconnector and a significant drop in wind generation due to the voltage dip. This led to a significant RoCoF event on the separated Northern Ireland system. The system RoCoFs observed from the simulations are shown in Table 2.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
NI Conventional Plant				
GT8	Synchronous Compensation	Synchronous Compensation	Synchronous Compensation	Synchronous Compensation
C30 – ST (MW)	100	0	100	0
C30 – GT (MW)	160	0	160	0
K1 (MW)	110	110	110	110
K2 (MW)	110	110	110	110
B10 (MW)	0	65	0	65
Interconnector Flows				
Moyle (MW)	450 (import)	450 (import)	320 (import)	300 (export)
N – S Tie Line (MW)	260 (import)	260 (import)	260 (import)	280 (export)
Renewables				
NI Wind (MW)	450.9	450.9	800	800
Demand				
NI Load (MW)	1550	1380	1840	520
All Island SNSP (%)	52	54	56	58
RoCoF Results				
100ms (Hz/s)	4.2	8.3	3.1	2.4
500ms (Hz/s)	2.1	3.9	1.8	1.4

Table 2 Maximum RoCoF measurements on SONI system for separation event

It can be seen in the table that RoCoF values in excess of 2 Hz/s are possible on the system in Northern Ireland. The worst case was Scenario 2 where the Coolkeeragh unit had been replaced by Ballylumford B10 which has a significantly lower inertia than Coolkeeragh. It should also be noted that Scenarios 3 and 4 consider wind levels that are expected in 2018. The RoCoF values shown in Table 2 were measured over 100 ms and 500 ms time periods. The results for the 100 ms time period were again seen to be higher than those for the 500 ms period. This is consistent with the analysis presented in Section 3.2 of this report.

The RoCoF values observed were in excess of the proposed Grid Code standard of 1 Hz/s for the all-island system. It is therefore proposed that a higher RoCoF specification be defined for the Northern Ireland system until further re-enforcements on the network have been added through the introduction of the North-South 400 kV tie line.

SONI must therefore operate the system in a manner that ensures potential RoCoFs are limited to circa 2 Hz/s. To achieve this, SONI may have to re-dispatch the generation portfolio; reduce the tie line south - north transfers or the Moyle flow. SONI will also ensure the frequency stability of the system for existing and future levels of wind generation by maintaining adequate inertia on the system. SONI will also continue to analyse the potential impacts of system separation on frequency stability and rate of change of frequency levels.

- *Studies demonstrate that in the event of system separation, following a fault on the Northern Ireland system, RoCoF levels in excess of 2 Hz/s are possible on the Northern Ireland system. SONI will mitigate against credible risks to operate the system in a stable manner. SONI intend bringing a Grid Code modification forward to the Northern Ireland Grid Code to specify a RoCoF standard of 2 Hz/s over a 500 ms period for the Northern Ireland system.*

5 Conclusions

This report presents a selection of system studies which have been performed by EirGrid and SONI to investigate the rate of change of frequency (RoCoF) on the all-island system for specific events. The studies were performed to complement previous analysis carried out as part of the Facilitation of Renewables (FoR) studies. The events of interest included the loss of the East-West Interconnector (EWIC) while exporting power and also the event where system separation between Ireland and Northern Ireland occurred, following a fault on the Northern Ireland system. The aim of the analysis was to determine if the proposed Grid Code standards would be sufficient to cover the RoCoF levels likely to be seen in these events.

The simulations demonstrated that in the case where there was a fault on EWIC while operating at maximum export, a maximum RoCoF of 0.63 Hz/s would result which is within the proposed Grid Code standard of 1 Hz/s. Therefore, once all units on the system are compliant with the new Grid Code Standard this event should not cause a threat to the stability of the power system. The results demonstrate that the proposed 1 Hz/s standard for the Ireland system would be sufficient to cover the loss of 500 MW exported. This indicates that the tripping of EWIC should not pose a threat to system security if all units on the system meet the proposed RoCoF standard.

In the case of a system separation event occurring, following a fault on the Northern Ireland System, the resulting RoCoF levels seen on the isolated SONI system were of a significant level. RoCoF values in excess of 2 Hz/s were observed. The proposed Grid Code standard for the Northern Ireland system is therefore revised to cater for the higher RoCoF levels. The revised standard for Northern Ireland is 2 Hz/s measured over 500 ms. SONI will mitigate against credible risk to operate the power system in a stable manner.

EirGrid and SONI have proposed interim Grid Code standards of 1 Hz/s for the Ireland system and 2 Hz/s for the Northern Ireland system. Studies have demonstrated that these standards are sufficient to cover RoCoF events following large disturbances on the system provided adequate operational policies are adopted by the TSOs. These standards will be kept under review but will remain in place until the 2nd North – South 400 kV tie line is in place. At that stage the intention is to establish an all-island standard of 1Hz/s.