DS3:
Frequency Control Workstream

CONTEXT

In a synchronous AC power system, such as Ireland and Northern Ireland, all of the conventional generating units are synchronised together, producing electricity at a nominal frequency of 50Hz. When supply and demand are in balance, the frequency will be static. If there is excess generation, the frequency increases; conversely, if there is insufficient generation, the frequency will decrease. The normal operational frequency range is 49.8 Hz and 50.2 Hz. EirGrid and SONI have a primary duty to manage the frequency in real-time. Frequency excursions outside these limits can occur if there is a sudden change in demand, generation or interconnector flow. This is managed by maintaining operating reserves, both spinning and static, on the system that can be used to correct energy imbalances when they occur.

A power system with a high penetration of variable non-synchronous wind generation poses significant challenges for frequency control over multiple timeframes. These challenges can be categorised as follows:

a) Rate-of-Change-of-Frequency (RoCoF) issues – ensuring that post-event system RoCoF values are managed to avoid excessive rates which come about because of the reduced system inertia in a system with high non-synchronous penetration. This issue is being addressed separately in a dedicated DS3 workstream;
b) Frequency Response to Large Disturbances – ensuring adequate system inertia and fast-acting response to minimize chances of excess frequency deviations from the loss of large in-feeds or large exports;
c) Voltage-Induced Frequency Dips – transmission faults that lead to reduced power output from wind farms, leading to a frequency dip;
d) Frequency Regulation – maintaining system frequency within its normal limits, and coping with fluctuations in demand and generation particularly with increased penetration from windfarms; and
e) Ramping Capability – ensuring that the generation and demand side portfolio response is able to cope with changes in demand and wind generation over periods from minutes to hours. This is often referred to as “flexibility” of plant.

Generation adequacy is not covered explicitly in the DS3 plan. It is assumed that this will be provided by the appropriate market signals to satisfy the required loss-of-load expectation (LOLE). It is noted though that the system services workstream may have an impact on incentivising the provision of certain types of plant in the future. The main facets of frequency control are shown in Figure 1 below.

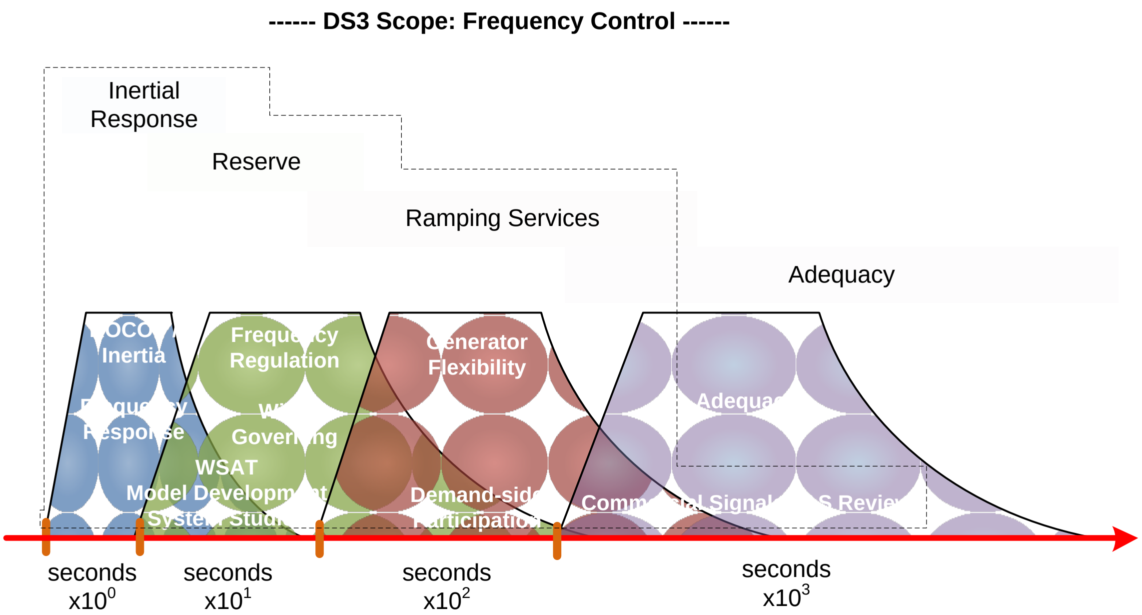


Figure 1: Frequency Control Overview

The purpose of the DS3 programme is to address the various challenges to operating the power system that will occur as wind penetration increases. Frequency control is a central plank of the programme, along with voltage control, as it gets to the very heart of how a power system is operated. The various frequency control issues are discussed in more detail below, and how they will be addressed as part of the DS3 programme.

The key dependencies are also outlined below. A number of other workstreams feed into this Frequency Control workstream.

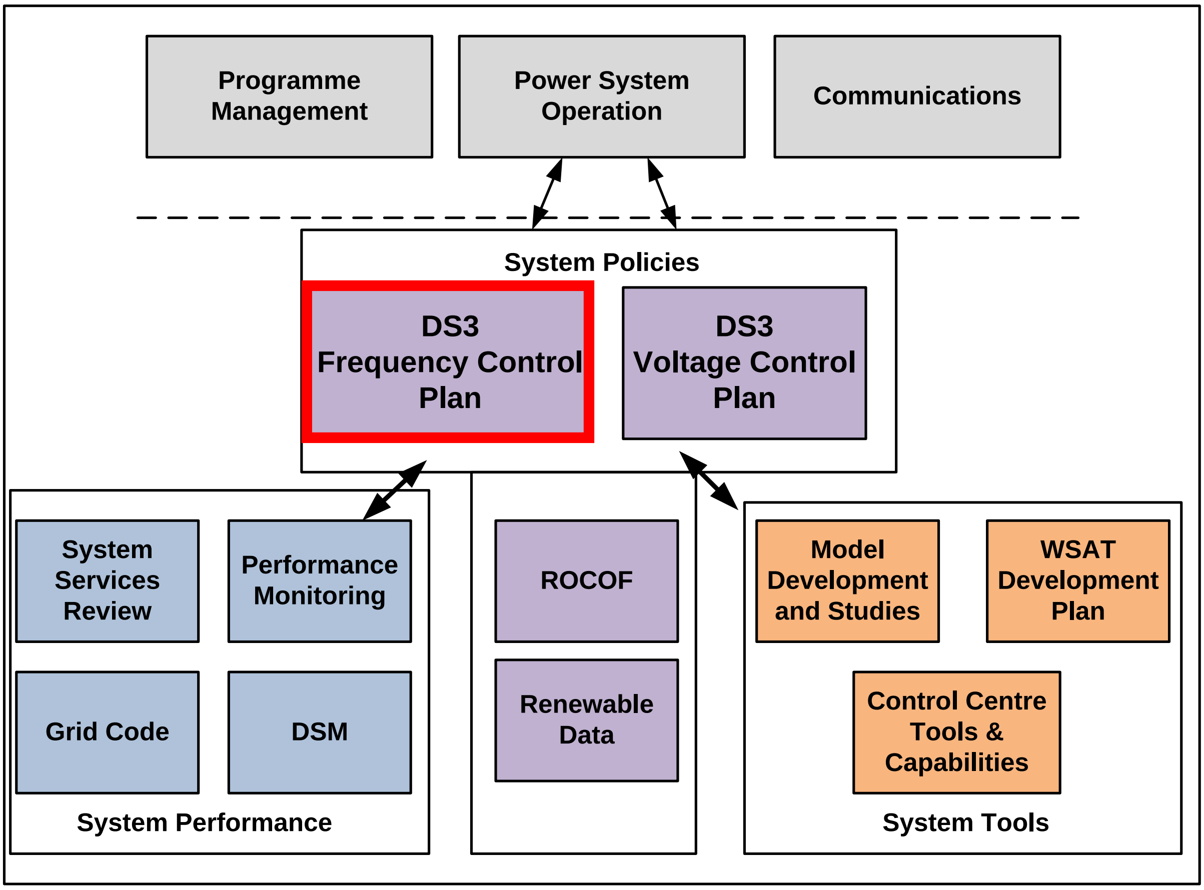
Objectives

The objectives of the Frequency Control workstream are to develop:

1. Operational Policy on the management of Rate of Change of Frequency
2. Operational Policy on necessary operating reserves to meet loss of the largest in-feed and loss of the largest export in a system with increasing penetration of wind
3. Operational Policy on voltage dip-induced frequency dips , i.e. a fault on the system that leads to a frequency excursion due to slow active power recovery of wind-farms causing an energy imbalance after the fault has been cleared
4. Operational Policy on ramping duties and requirements over timeframes from minutes to hours
5. Operational Policy on frequency regulation for high penetrations of variable renewables

Dependencies

The DS3 Frequency Control workstream is dependent on the results of other parts of the DS3 programme, as well as its own internal elements. The starting point for the plan is the Facilitation of Renewables study results, which showed that in high wind penetrations, frequency control could prove to be challenging and was a key factor that could limit the amount of wind allowed on the system. Specifically the model development and studies, System Services, WSAT and RoCoF workstreams will provide key inputs into the Frequency Control workstream. However, other workstreams will also play a role as depicted graphically below.



Work Completed in 2012

During 2012 the System Services workstream defined and consulted upon additional system service products required for frequency control into the future. The additional products are as follows:

1) **Synchronous Inertial Response (SIR)**
The response in terms of active power output and synchronising torque that a unit can provide following disturbances. It is a response that is immediately and intrinsically available from synchronous generators (when synchronised); it has significant implications for rate of change of frequency (RoCoF) management during power imbalances.

2) **Fast Frequency Response**

With appropriate control systems, synchronous and non-synchronous generators can provide fast-acting response to changes in frequency that supplements any inherent inertial response. Fast Frequency Response, a reserve response faster than the existing Primary Operating Reserve times will in the event of a sudden power imbalance, increase the time to reach a frequency nadir and mitigate the RoCoF in the same period, thus lessening the extent of the frequency transient.

3) **Fast Post-fault Active Power Recovery**

Units that can recover their MW output quickly following a voltage disturbance (including transmission faults) can mitigate the impact of such disturbances on the system frequency. If a large number of generators do not recover their MW output following a transmission fault, a significant power imbalance can occur, giving rise to a severe frequency transient. Provision of fast post-fault active power recovery will form part of the frequency control strategy.

4) **Ramping Margin**

To incentivise the generation and demand side portfolio to provide the necessary margins to manage secure system operation within frequency limits a new ramping product is required. The management of variability and uncertainty is critical to a power system with high levels of wind farms to avoid excessive frequency deviations. Capacity adequacy alone is insufficient to meet system ramping requirements over all the necessary timeframes. The ability of plant to consistently ramp output to balance the variable renewable sources and changes in interconnector flows is required to maintain system security.

Work carried out in 2012 involving system high frequency tests in conjunction with the loss of export from interconnectors identified the requirement for further consideration of high frequency issues to be progressed within the frequency control workstream.

The Wind Security Assessment Tool (WSAT) became operational on an all island basis during 2012. The tool will ultimately, following further development and verification, provide predicative post fault analysis of dynamic events that generate frequency transients to enhance frequency control management.

FOCUS IN 2013

The final output of the workstream will be operational policies to address specific system frequency management areas including rate of change of frequency, response to large disturbances, voltage-dip induced disturbances, regulation and ramping. Before the policies can be completed two issues have to be addressed during 2013. The first is the resolution of the RoCoF issue which will set the benchmark or standard for RoCoF management requirements, leading to policies for inertia and fast acting reserve requirements. The second is the determination of the degree of renewable participation in frequency control. This will involve, in participation with the wind industry, wind farm governor and other plant tests, trials for frequency response performance assessment and the development of proposals for how governing of renewable generation would operate in the market and priority dispatch environment. Other activities include system model verification and improvement (including both conventional and renewable generation models), consideration of high frequency events and requirements, studying the frequency regulation requirements, and the development of a draft ramping policy.

The following sections appeared in the original workstream plan as published in December 2011 and give some background and potential solutions to the issues being examined

OPERATIONAL POLICY ON RATE OF CHANGE OF FREQUENCY

Background / Issues

When there is an energy imbalance on the power system, the frequency will change. If there is too much generation, the frequency goes up; conversely if there is too little generation, the frequency will go down. The Rate of Change of Frequency (RoCoF) is the measure of how fast the frequency goes up or down, measured in Hz per second. There are two main issues concerning RoCoF. The first issue is that wind farms and other distribution connected equipment in Ireland and Northern Ireland have anti-islanding protection based on RoCoF or Vector Shift relays. These relays are designed to detect if generation has become isolated from the rest of the system by monitoring the RoCoF or a vector shift value. Transmission faults may cause temporary frequency spikes that can make the relays operate and disconnect trip out wind farms and other distribution connected generation erroneously. This issue is being addressed via the RoCoF workstream through discussions between the TSOs, DSOs, and the wind industry.

The second issue centres on the displacement of synchronous conventional generation with asynchronous generation that does not provide any synchronous inertia to the system. The reduction in system synchronous inertia could lead to a higher RoCoF following a sudden generation/demand imbalance (e.g. following the tripping of a generator), which could in turn lead to the cascade tripping of plant. This issue is of crucial importance for the facilitation of large amounts of wind generation.

Potential Solutions

Current Grid Code requirements in Ireland only specify a RoCoF limit of 0.5Hz/s, and generation can trip off for values above this. The Grid Code in Northern Ireland does not explicitly define a RoCoF standard for generation. Both situations pose challenges to the operation of a power system with high penetrations of wind generation. A Grid Code modification is being proposed that will increase the RoCoF standard for plant in Ireland and Northern Ireland and also be consistent with the capabilities of the protection employed in the distribution network.

In addition, methods for maintaining sufficient inertia on the power system will be investigated to see if high RoCoF can be mitigated.

Key Inputs: DS3 RoCoF workstream; Grid Code workstream; Renewable Data workstream; Model Development and Studies workstream; System Services Review workstream; Performance Monitoring and Testing workstream

Key Deliverables: Operational policy that allows more than 50% non-synchronous penetration on the power system
Outcomes: Less curtailment of wind
Risks: Conventional generation may not have technical ability to withstand the RoCoF levels required

OPERATIONAL POLICY ON FREQUENCY RESPONSE TO LOSS OF LARGE IN-FEEDS AND LOSS OF LARGEST EXPORT

Background

When a conventional machine (or in the future a large wind farm) trips off the system, the resultant energy imbalance causes a large low frequency deviation. With the lifting of export restrictions on Moyle and the commissioning of EWIC there is also now the potential for an interconnector to trip while exporting a large amount of power leading to a high frequency deviation.

On the Ireland and Northern Ireland system, frequency deviations in the range 49.0 – 49.5 Hz are quite common. As the frequency deviates from 50Hz, several things happen:

i. Conventional machines give an inertial response – for a low frequency event there is a temporary surge in electrical output as the stored rotational energy of the machine is converted into electrical energy as the machine slows down. For a high frequency event there is less demand for the electrical energy output of the machine and the machine speeds up converting the excess electrical energy into increased stored rotational energy.
ii. Operation of static reserve as the frequency passes through initiation frequency set points – this can be interruptible load (for low frequency events), or reserve from HVDC interconnectors (for high and low frequency events) which helps correct the energy imbalance.
iii. Conventional machine governor response – conventional machines increase or decrease their power output according to their mechanical and governor characteristics. There is typically a delay of a few seconds because of governor action, governor valve actuation, fuel firing changes and then for the change in mechanical power to be initiated from the prime mover.
iv. If the frequency goes under 48.85Hz (present setting), under-frequency load shedding relays will disconnect loads around the island in co-ordinated groups. The goal of power system operation is to avoid load-shedding if at all possible.

Issues

At present in Ireland and Northern Ireland, the wind farm response to frequency events is limited. Displacement of conventional generation by wind generation will mean reduced governing generation, so there will be a reduced ability to increase power output for the loss of a large infeed. Also, if system inertia is reduced, it will mean the RoCoF will be more rapid (these high rates of change of frequency could cause wind farms and conventional generators to trip off, however this issue is being addressed in a separate DS3 workstream). Frequency dips will tend to be deeper and potentially of longer duration in high wind scenarios.

The performance of conventional generators and wind farms to low frequency events is relatively well understood through many years of experience. However the same level of understanding does not exist for high frequency events as these have been relatively rare to date and mainly driven by demand tripping events which have been much less severe than the potential loss of an interconnector while operating at full export. High interconnector exports are more likely to occur at times of high wind penetration and so understanding the performance of wind farms in the event of an interconnector export trip will be critical to ensuring the security of the power system.

Potential Solutions

This operational policy will review the need and capability of wind farms to contribute to the frequency control as well as ensuring that the ability of conventional plant is better utilised and is reliably provided. This can be done in two ways:

1. Wind farms operate on a power-frequency curve such that their power output increases or decreases automatically for under or over frequency events.
2. Wind farms can have emulated inertia capability. Emulated inertia is a type of fast-acting response whereby if a frequency dip is detected, some of the stored energy in the blades of a wind turbine is converted into electrical energy.

These issues and potential solutions will be addressed within the DS3 programme, through engagement with industry and regulatory authorities, as well as studies on the operational impact by the TSOs.

Key Inputs: Grid Code workstream; WSAT All-island model; Performance Monitoring Data; System Data; Dynamic models with inertia emulation / wind governing capability

Key Deliverables: Study of impact of using wind generation with inertia emulation and governor-type response; Proposals for changes to Curve1/Curve2 power-frequency settings; Scope for pilot project and identification of wind industry partnerships; Feed results to System Services workstream; Results to inform changes to operational policies.

Key Output Decisions: Can we use wind farms to mitigate the problem, thus reducing curtailment?

Risks: All-island model not available; Dynamic models not available in timely fashion / budgetary considerations; Emulated inertia (too) costly to implement; Frequency governing by wind farms necessitates extra curtailment – regulatory / industry response to this, uncertainty about system performance during high frequency events

OPERATIONAL POLICY ON VOLTAGE-DIP INDUCED FREQUENCY DIPS

Background

The Facilitation of Renewables study brought to light a potentially significant issue where a transmission fault might lead to a voltage depression near a cluster of wind farms which could lead them to reduce their active power output. If the voltage dip was of significant depth and duration, for instance up to 500 ms due to a zone 2 clearance, and if there was significant amounts of wind in the area, then this could lead to hundreds of MW of active power being lost for up to 1 second assuming a performance in line with the Grid Code standards.

A significant energy imbalance like this could lead to unsustainable RoCoF values, and could in a worst-case scenario lead to the loss of the system or widespread load shedding.

Potential Solution

This issue will be addressed in the DS3 programme initially through studies to determine if the issue is likely to occur in the short-to-medium term. The issue will also be mitigated against through upcoming Grid Code modifications to RoCoF standards and active power response following voltage dips. This may include a consideration of DC choppers on wind turbines, so that they do not need to pitch their blades during transmission faults.

Key Inputs: Renewable Data; System Data; All-island Dynamic Model (WSAT); Performance Monitoring

Key Deliverables: Carry out an analysis of the problem, based on known wind farm responses to faults, and expected wind farm locations; Results to inform changes to operational policies

Key Outcome Decision: Answer the question as to whether this problem will become significant in the future, and whether Grid Code changes and planning standard changes are required.

OPERATIONAL POLICY FREQUENCY REGULATION

Background

The nominal system frequency in Ireland and Northern Ireland is 50 Hz and it is normally maintained between 49.8 Hz and 50.2 Hz. When the frequency goes above 50 Hz, it indicates that generation exceeds demand. Conversely, if frequency is less than 50 Hz, it indicates that demand exceeds generation. Interconnector flows also effect the generation and demand balance. The myriad of loads on the system switching on and off means that it is impossible to keep the frequency at exactly 50 Hz for any length of time. Nevertheless, aggregate system demand is highly predictable so it is possible to anticipate the changing demand and interconnector flows, and thus keep the frequency relatively close to 50 Hz throughout the day by re-dispatching or committing generation.

One of the results of the increased wind generation on the system is that the frequency fluctuations are more significant on windy days. This is because at present, wind generators maximise their power output, and so appear as a fluctuating power source on the grid. Wind fluctuations and demand fluctuations are independent of each other, so the aggregate frequency fluctuation is not a simple sum of the two components. Conventional generators are equipped with frequency governors to cope with the fluctuations. A governor is a control system which senses either a low or a high frequency, and instructs the generator to alter its output to correct the imbalance. Conventional generators in Ireland and Northern Ireland normally have governor droop settings of 4%. This means that a frequency deviation from 50Hz of 4% (i.e. 48Hz) would lead the generator to increase its power output by 100% of its rated power. By interpolation, one can see that frequency deviation from 50 to 49.8Hz would lead a machine to increase its output by 10% of its rated power. All conventional machines have the same droop to ensure that they all share equally in the requirement to increase or decrease their power as a percentage of their rated output. These governor power adjustments occur continually throughout the day.

As wind penetration increases, this will have several impacts on frequency regulation:

1. The frequency fluctuations that conventional machines have to cope with necessarily increase because of the fluctuations in wind generation adding to the fluctuations in demand.
2. Displacement of conventional generation by wind generation means there are less conventional machines online to carry out frequency regulation. Therefore, those machines will have to adjust their power output by larger amounts, which will have an impact on the lifetime or wear-and-tear on the conventional machines.
3. There will be a general increase in the magnitude of the frequency fluctuations if there is less governing generation online. This is related to the frequency droop characteristics of conventional machines – large power imbalances being corrected by a relatively small number of conventional generators will necessarily lead to larger frequency deviations.

Potential Solutions

The solution to the frequency regulation issue appears relatively straightforward, but may have far-reaching implications. As prescribed in both the EirGrid and SONI Grid Codes each controllable wind farm must have a frequency response system capable of achieving frequency regulation. In order to provide frequency regulation, the wind farms would have to be dispatched down at nominal frequency. As part of the DS3 programme, studies will need to be undertaken on frequency regulation to look at the impact of using wind farms for frequency control. A demonstration project will be set up on one or more of the transmission-connected wind farms on the island to see how best to implement governing capability on wind farms. When the output from this project has been reviewed, an implementation plan will be developed for the roll out of this type of frequency control.

Key Inputs: Performance Monitoring Data; Renewable Data; System Frequency Data; Model Development and Studies workstream

Key Deliverables: Study of frequency regulation – how much regulation is required now? How will that evolve over time and with higher wind penetrations? Feed information into System Services workstream. Results will inform changes to operational policies.

Key Output Decisions: How and when should frequency regulation services from wind farms or other sources be utilised?

OPERATIONAL POLICY RAMPING SERVICES

Background

Demand for electricity varies throughout the day in quite a predictable way. Demand at peak times is approximately twice that during valley periods, and so there is a clear need for generators to be able to increase or decrease their output as demand or interconnector flows require. Traditionally this was done using a mixture of cheap, but slowly ramping plant, mid-merit plant with higher ramp rates, and finally, expensive peaking plant with high ramp rates. Pumped storage plant can also be ramped quickly but has a limited energy store.

Historical data shows that wind generation can increase or decrease at very high rates as depressions or storm centres cross the country. At current wind penetration levels, ramp rates of

+/- 300-350 MW/hour are common. In the future, with up to 6000 MW of wind generation installed, the corresponding ramp rate could be +/- 1200 MW/hour. With the introduction of the EW interconnector and the existing Moyle interconnector, market driven flow changes of 1000 MW import to 1000 MW export would be possible; the combined interconnector rate of change is presently limited to 600 MW/hour. If wind generation output changes and interconnector flow changes occur in tandem with a load rise or fall, then clearly there will significant ramping requirements placed upon conventional generation. While this can be mitigated somewhat by enforcing or reducing the ramp rate limits on wind generation, it is an issue that needs to be seen in a wider context of provision of system services. As such it appears in the DS3 programme under the frequency control workstream and the system services workstream.

Potential Solutions

Work needs to be done to understand what the ramping requirements will be in the future, and how best to meet those requirements.

Key Inputs: Historical Data; Renewable Data; High Wind Reports; Generation Data, Interconnector data

Key Deliverables: Analysis of likely ramping requirements in the short to medium terms; Results will inform changes to operational policies

Key Outcome Decisions: Will ramping services need to be addressed through market mechanisms or are there sufficient ramping services in place already?

HIGH LEVEL PLAN

TASK NO.	TASK / DELIVERABLE	DS3 WORKSTREAM DEPENDENCIES	RESPONSIBLE	ORIGINAL DUE DATE	DUE DATE
Operational Policy: RoCoF					
FC.1.0	DS3 Grid Code Workstream	Grid Code	TSOs / RAs / Industry	Q2 2012	COMPLETE
FC.1.1	Assessment of outputs from RoCoF Workstream	RoCoF / Grid Code	TSOs	Q4 2012	Q2 2013
FC.1.2	Implementation of outputs from RoCoF workstream	RoCoF / Grid Code	TSOs / DSOs	Q4 2013	Q4 2013
FC.1.3	Assessment of Renewable Data Workstream output	Renewable Data	TSOs	Q4 2012	COMPLETE
FC.1.4	6-monthly assessment of Renewable Data Workstream output	Renewable Data	TSOs	New Task	Q2 2013
FC.1.5	6-monthly assessment of Renewable Data Workstream output	Renewable Data	TSOs	New Task	Q4 2013
Operational Policy: Frequency Response to Large Disturbances					
FC.2.1	Study the frequency response to large disturbances based on historical data	Model Development and Studies	TSOs	Q2 2012	COMPLETE
FC.2.2	Look at long-term System Services implications for inertia provision	System Services	TSOs	Q2 2012	COMPLETE
FC.2.3	Derive a working all-island system model	WSAT	TSOs	Q2 2012	COMPLETE
FC.2.4	Obtain dynamic models for emulated inertia	WSAT / Model Development and Studies	TSOs	Q4 2012	Q1 2013
FC.2.4.1	Audit / review system frequency- and voltage-sensitive protection device settings		TSOs	New Task	Q2 2013
FC.2.5	Look at mitigation scenarios for frequency response in conjunction with wind industry	WSAT / Model Development and Studies / System Services	TSOs / Wind Industry	Q4 2012	Q2 2013
FC.2.5.1	Investigate Over-Frequency Response requirement		TSOs	New Task	Q2 2013
FC.2.6	Investigate possible changes to reserve requirements, in particular considering Fast Frequency Response System Service		TSOs	Q4 2013	Q4 2013
FC.2.7	Discuss proposals with regulators and wind industry		TSOs / Wind Industry / RAs	Q4 2013	Q4 2013
Operational Policy: Voltage-dip induced frequency dips					
FC.3.0	Derive a working all-island system model	WSAT	TSOs	Q2 2012	COMPLETE
FC.3.1	Obtain dynamic models for wind governing / emulated inertia	WSAT / Model Development	TSOs	Q4 2012	Q1 2013

		and Studies			
FC.3.2.1	Analyse and assess potential for voltage-induced frequency dips in short -term	Model Development and Studies	TSOs	Q1 2013	Q2 2013
FC.3.2.2	Analyse and assess potential for voltage-induced frequency dips out to 2020	Model Development and Studies	TSOs	Q1 2013	Q3 2013
FC.3.3	Make decision on how this issue needs to be progressed		TSOs	Q2 2013	Q2 2013
Operational Policy: Frequency Regulation					
FC.4.1	Study the frequency regulation issue / historical data / likely issues	Renewable Data / Model Development and Studies	TSOs	Q2 2012	COMPLETE
FC.4.2	Look at long-term System Services implications for frequency regulation provision	System Services	TSOs	Q2 2012	COMPLETE
FC.4.3	Look at mitigation scenarios in conjunction with wind industry	System Services	TSOs	Q4 2012	Q2 2013
FC.4.4	Kick off governor test on wind farms	Performance Monitoring	TSOs / Wind Industry	Q1 2013	Q1 2013
FC.4.5	Collate information on wind farm tests on governors and assess	Performance Monitoring / System Services	TSOs	Q3 2013	Q3 2013
FC.4.6	Discuss wind governing proposals with regulators and wind industry		TSOs / Wind Industry / RAs	Q1 2014	Q1 2014
FC.4.7	Agree best way forward and new operational policies that include wind governing		All	Q3 2014	Q3 2014
Operational Policy: Ramping Services					
FC.5.1	Analysis of historical data and studies on expected ramping duty in the future	Renewable Data / Model Development and Studies	TSOs	Q2 2012	COMPLETE
FC.5.2	Look at long-term System Services for ramping services provision	System Services	TSOs	Q2 2012	COMPLETE
FC.5.3	Development of System Services Ramping policy	System Services	TSOs	Q4 2012	Q3 2013
FC.5.4	Draft Ramping Operational Policy		TSOs	New Task	Q4 2013
FC.5.5	Approved Ramping Operational Policy		TSOs	New Task	Q1 2014

Key External Dependencies					
GC.02.07.1	Decision on Ireland wind farm Grid Code modification proposals	Grid Code	CER	Q4 2012	Q1 2013
GC.02.07.2	Decision on Northern Ireland Wind Farm Power Station Settings Schedule modification proposals	Grid Code	UReg	Q4 2012	Q1 2013
GC.03.7.1	Decision on Ireland RoCoF Grid Code modification proposals	Grid Code / RoCoF	CER	Q4 2012	Q1 2013
GC.03.7.2	Decision on Northern Ireland RoCoF Grid Code modification proposals	Grid Code / RoCoF	UReg	Q4 2012	Q1 2013
RCF.2.03.1	Report on RoCoF capability of Ireland Distribution System	RoCoF	ESBN	Q2 2012	Q1 2013
RCF.2.03.2	Report on RoCoF capability of Northern Ireland Distribution System	RoCoF	NIE	Q2 2012	Q1 2013
	Reports on RoCoF capability of plant	RoCoF	Generators	New Task	Q4 2013