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 exactly 50Hz. If there is excess generation, the frequency increases; conversely, if there is insufficient generation, the frequency will decrease. The normal operating limits for frequency in Ireland are from 49.9 to 50.1Hz, and it is one of EirGrid and SONI's primary duties to manage the frequency in real time. Frequency excursions outside these limits can occur if there is a sudden change in load or generation, or if generation trips out due to a fault. This is managed by maintaining operating reserves, both spinning and static, on the system that can be used to correct the energy imbalance when it occurs.

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 generation does not trip for large ROCOF values 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 load-shedding for system events such as transmission faults or loss of large infeeds;
c) Voltage-induced frequency dips – transmission faults that lead to reduced power output from windfarms, 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) Generation ramping capability – ensuring that the generation portfolio is able to cope with large 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 a loss-of-load expectation (LOLE) value of 8 hours per year. 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.

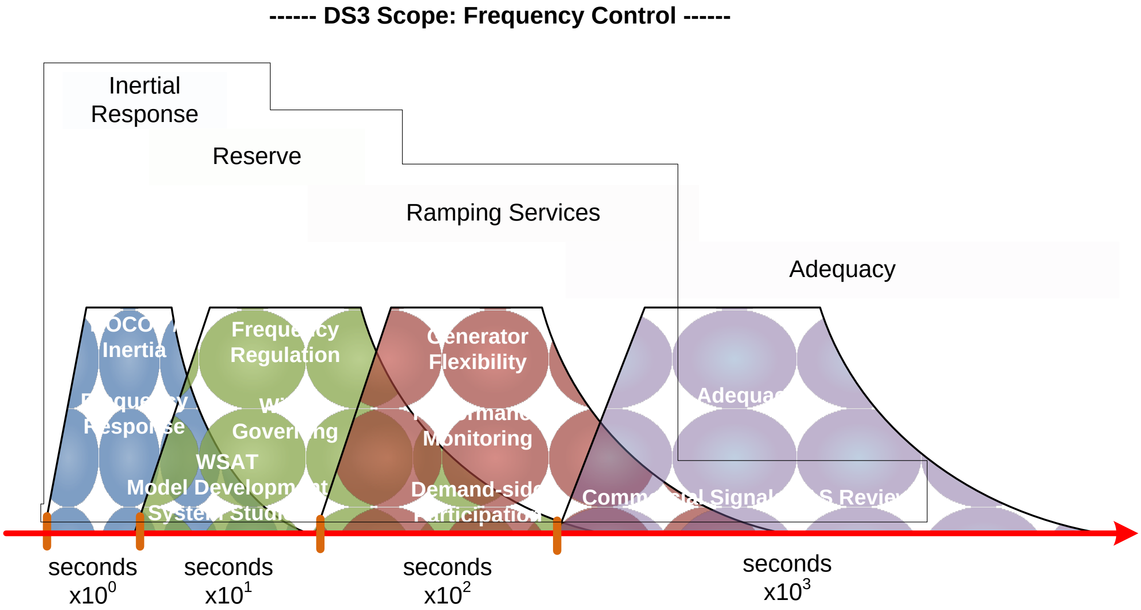


Figure 1: Frequency Control Overview

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.

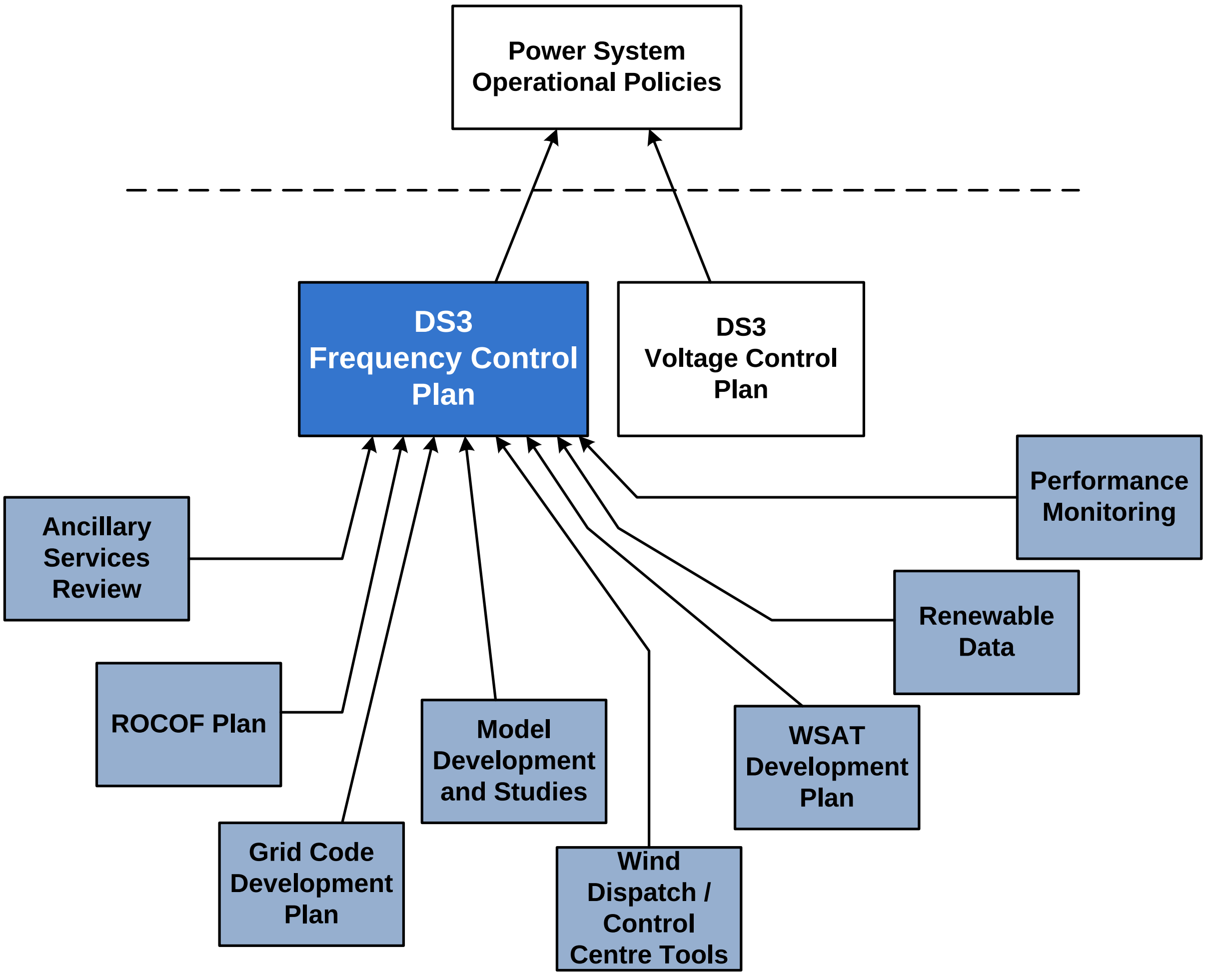
The key dependencies are also outlined below. A number of other workstreams feed into this Frequency Control workstream.

Key Deliverables

1. Operational Policy on Rate of Change of Frequency
2. Operational Policy on necessary operating reserves to meet loss of the largest in-feed in a system with increasing penetration of wind
3. Operational Policy on voltage induced trips on windfarms leading to frequency excursions
4. Operational policy on ramping duties and requirements over timeframes from minutes to hours
5. Operational policy on frequency regulation including negative reserve for high penetrations of wind plant

Key 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 modelling 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.



1.1 Operational Policy on Rate of Change of Frequency

1.1.1 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's 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, in Hz per second. There are two main issues concerning ROCOF. The first issue is that windfarms in Ireland and Northern Ireland have anti-islanding protection based on ROCOF relays. These relays try to detect if the windfarm has become isolated from the rest of the system by monitoring the ROCOF value. Unfortunately, transmission faults can cause temporary frequency spikes that can make the ROCOF relays trips out windfarms 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 electrical inertia to the system. This could lead to a higher ROCOF 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.

1.1.2 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 explictally define a ROCOF standard for generation. Both situations pose challenges to the operation of a power system with high penetrations of wind farms. 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; Performance Monitoring 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

1.2 Operational Policy on Frequency Response to Loss of Large Infeeds

1.2.1 Background

When a conventional machine (or in the future a large windfarm) trips off the system, the resultant energy imbalance causes a large frequency deviation. On the Ireland and Northern Ireland system, frequency deviations in the range 49 – 49.5Hz are quite common. As the frequency falls from 50Hz, several things happen.

i. Conventional machines give an inertial response – this 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
ii. Operation of static reserve – this can be interruptible load, or reserve from HVDC interconnectors which helps correct the energy imbalance
iii. Conventional machine governor response – after a few seconds, conventional machines increase their power output according to their droop characteristic. There is a delay of a few seconds because of governor action, valve actuation, and then for the increased mechanical power to be produced from the prime mover.

iv. If frequency goes under 48.85Hz, under-frequency load shedding relays will disconnect loads around the country 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 reaction to under-frequency events is limited. Fixed-speed wind turbines will give an inertial response. 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 of longer duration in high wind scenarios.

Potential Solutions

This operational policy will review the need and capability of windfarms 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 automatically for under-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: 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 windfarms to mitigate the problem?
Risks: All-island model not available; Dynamic models not available in timely fashion / budgetary considerations; Emulated inertia (too) costly to implement; Frequency governing by windfarms necessitates extra curtailment- regulatory/ industry response to this.

1.3 Operational Policy on Voltage-Dip Induced Frequency Dips

1.3.1 Background

The Facilitation of Renewables study brought to light a potentially significant issue where a transmission fault might a voltage depression near a cluster of windfarms which could lead them to reduce their active power output. If the voltage dip was of significant depth and duration, for instance up to 500ms 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.

1.3.2 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 windfarm responses to faults, and expected windfarm 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.

1.4 Operational Policy Frequency Regulation

1.4.1 Background

The system frequency in Ireland and Northern Ireland is 50Hz and is normally maintained between 49.9Hz and 50.1Hz. When the frequency goes above 50Hz, it indicates that generation exceeds demand. Conversely, if frequency is less than 50Hz, it indicates that demand exceeds generation. The myriad loads on the system switching on and off means that it is impossible to keep the frequency at 50Hz for any length of time. Nevertheless, aggregate system demand is highly predictable, and so it is possible to anticipate the changing demand, and thus keep the frequency relatively close to 50Hz 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 load 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. Each conventional generator in Ireland and Northern Ireland has a governor droop setting 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. 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's 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.

1.4.2 Potential Solutions

The solution to the frequency regulation issue appears relatively straightforward, but may have far-reaching implications. In the Irish Grid Code, each controllable wind farm must have a frequency response system capable of implementing two power-frequency curves (Curve 1/Curve 2). 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 in Ireland 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
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: Is this a problem now? Do we need to consider mandating frequency regulation services from wind farms or other sources?

1.5 Operational Policy Ramping Services

1.5.1 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 requires. 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.

Historical data shows that wind generation can increase or decrease at very high rates as depressions or storm centres across the country. At current wind penetration levels, ramp rates of +/-300-350MW/hour are common. In the future, with up to 6000MW of wind generation installed, the corresponding ramp rate could be +/- 1200MW / hour. If this occurs in tandem with a load rise or fall, then clearly there will significant ramping requirements placed upon conventional generation. While this can be mitigated against 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.

1.5.2 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
Key Deliverables: Analysis of likely ramping requirements in the short to medium terms; Analysis to be fed to System Services workstream; 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?

FREQUENCY CONTROL FOR DS3 PROJECT - HIGH LEVEL PLAN

Operational Policy: ROCOF	**DS3 Workstream Dependencies**	**Action**	**Timeline**
• DS3 Grid Code Workstream	Grid Code	TSOs/RAs / Industry	Q2 2012
• Assessment of outputs from ROCOF Workstream	ROCOF/Grid Code	TSOs	Q4 2012
• Implementation of outputs from ROCOF workstream	ROCOF/Grid Code	TSOs/DSOs	Q4 2013
• Assessment of Renewable Data Workstream output	Renewable Data	TSOs	Q4 2012
Operational Policy: Frequency Response to Large Disturbances	**DS3 Workstream Dependencies**	**Action**	**Timeline**
• Study the frequency response to large disturbances based on historical data	Model Development and Studies	TSOs	Q2 2012
• Look at long-term System Services implications for inertia provision	System Services	TSOs	Q2 2012
• Derive a working all-island system model	WSAT	TSOs	Q2 2012
• Obtain dynamic models for emulated inertia	WSAT / Model Development and Studies	TSOs	Q4 2012
• Look at mitigation scenarios for frequency response in conjunction with wind industry	WSAT / Model Development and Studies System Services	TSOs/Wind Industry	Q4 2012
• Agree best way forward & Produce a report on proposals	Model Development and Studies	TSOs	Q4 2013
• Discuss proposals with regulators and wind industry		TSOs/Wind Industry/RAs	Q4 2013
Operational Policy: Voltage-dip induced frequency dips	**DS3 Workstream Dependencies**	**Action**	**Timeline**
• Derive a working all-island system model	WSAT	TSOs	Q2 2012
• Obtain dynamic models for wind governing / emulated inertia	WSAT / Model Development and Studies	TSOs	Q4 2012
• Analyse and assess potential for voltage-induced frequency dips in short to medium term	Model Development and Studies	TSOs	Q1 2013

• Make decision on how this issue needs to be progressed		TSOs	Q2 2013
Operational Policy: Frequency Regulation	**DS3 Workstream Dependencies**	**Action**	**Timeline**
• Study the frequency regulation issue / historical data / likely issues	Renewable Data / Model Development and Studies	TSOs	Q2 2012
• Look at long-term System Services implications for frequency regulation provision	System Services	TSOs	Q2 2012
• Look at mitigation scenarios in conjunction with wind industry	System Services	TSOs	Q4 2012
• Kick off governor test on wind farms	Performance Monitoring	TSOs/Wind Industry	Q1 2013
• Collate information on wind farm tests on governors and assess	Performance Monitoring / System Services	TSOs	Q3 2013
• Discuss wind governing proposals with regulators and wind industry		TSOs/Wind Industry /RAs	Q1 2014
• Agree best way forward and new operational policies that include wind governing		All	Q3 2014
Operational Policy: Ramping Services	**DS3 Workstream Dependencies**	**Action**	**Timeline**
• Analysis of historical data and studies on expected ramping duty in the future	Renewable Data / Model Development and Studies	TSOs	Q2 2012
• Look at long-term System Services for ramping services provision	System Services	TSOs	Q2 2012
• Development of System Services policy		TSOs	Q4 2012