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BATTERIES: BEYOND THE SPIN

The dawning era of **digital inertia** on the Island of Ireland.

An Everoze report, commissioned by AES, drawing on research by Queen's University Belfast

October 2017

Queen's University Belfast

AES we are the energy

EXECUTIVE SUMMARY

BATTERIES CAN PROVIDE FAST AND EFFECTIVE SYNTHETIC INERTIAL RESPONSE WITHOUT DISPLACING RENEWABLES. THIS IS DIGITAL INERTIA.

Keeping the grid stable means matching supply of and demand for energy, at all times. When a power plant drops off the system, there is an immediate shortfall in energy, which causes the frequency on the system to start dropping. This drop must be arrested and reversed to avoid a system failure.

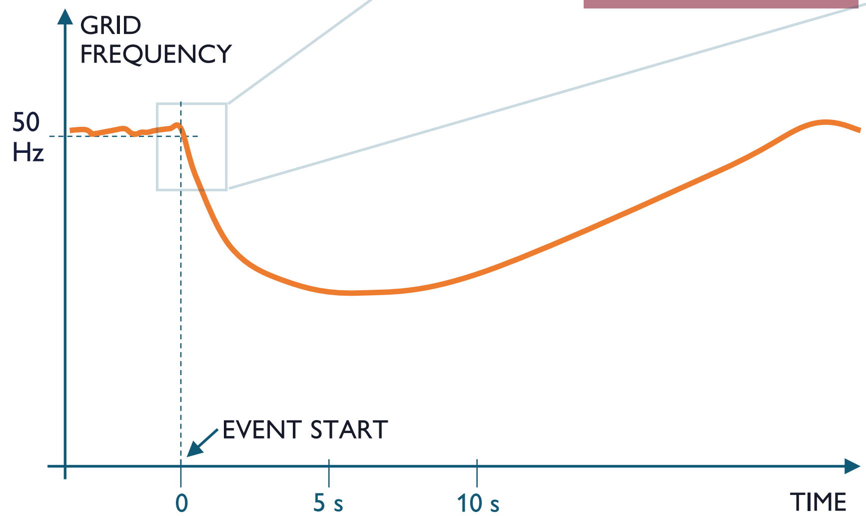
Synchronous generators such as Combined Cycle Gas Turbines (CCGTs) provide instant frequency stabilisation called inertial response, but the number of such plants connected to the grid is dropping.

The Island of Ireland is a world leader in clean power, achieving high levels of renewables deployment thanks to progressive grid policy by Eirgrid and SONI. To take electricity system decarbonisation to the next level, we must now address the challenge of providing clean inertial response.

Queen's University Belfast (QUB) have research and measurements that demonstrate the ability of battery technology to provide an effective synthetic inertial response. This demonstrates the role for batteries as a provider of "digital inertia" - working alongside synchronous generators to enable further deployment of wind and solar without compromising on system stability, consumer bills or CO_2 emissions.

CHALLENGE
Following a fault, the system must limit the speed of frequency fluctuations (RoCoF).

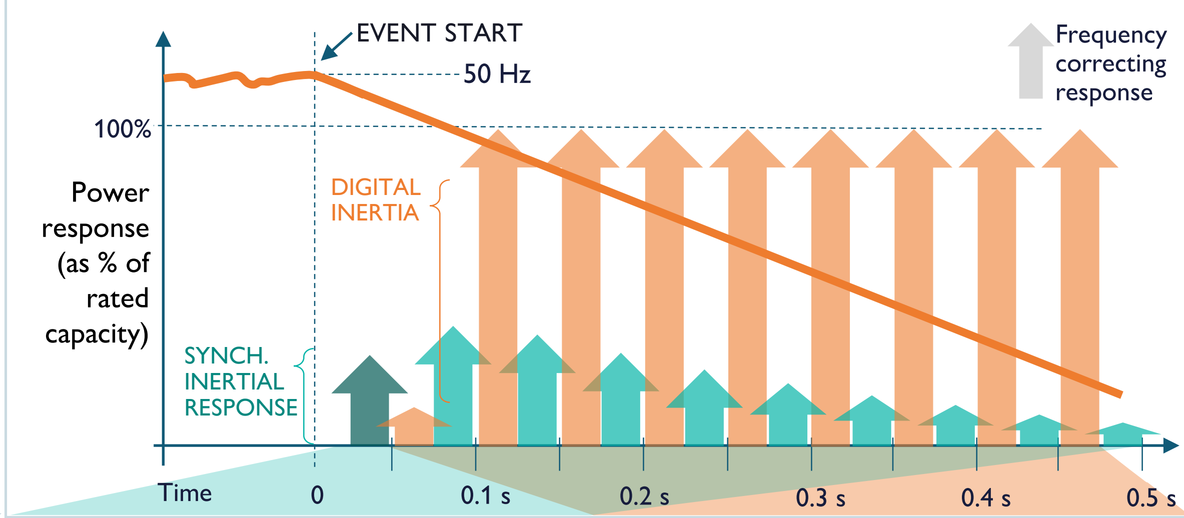
SOLUTION
Energy must be injected quickly and effectively. Both high response speed and power ramp-up help to limit maximum RoCoF.



JARGON BUSTER

***RoCoF:** The Rate of Change of Frequency is a measure of how quickly frequency is changing. If RoCoF exceeds 1Hz/s, additional power stations could be tripped offline and / or damaged in the first few fractions of a second following the fault event.*

POLES APART: DIFFERING RESPONSE CHARACTERISTICS IN THE FIRST HALF-SECOND



SYNCH. GENERATORS
"ANALOGUE INERTIA"

When frequency drops suddenly, synchronous generators respond **automatically and immediately** by slowing down, releasing energy stored by the large rotating masses contained in these plants. This is **inertial response,** with each unit providing a **power increase of 7-14%** of their rated total capacity within 0.05 seconds for a typical large event. The inertial response tails off after a few seconds and then might be replaced by a governor response that tries to push the frequency back up.

To respond, synchronous generators must be running. Each unit can only increase output by a small proportion. This means a large number of units have to be running on the system, in case there is a fault, displacing variable renewables.

BATTERIES
"DIGITAL INERTIA"

Batteries have no moving parts. They begin to **respond as quickly as the fault can be measured**, with reaction times approaching 0.1 seconds being seen. This provides a slightly slower initial response than that of synch. generators. But once the fault is detected, batteries can **respond dynamically with high ramp rates**. This means that with the right control procedures, batteries can deliver **full output in less than 0.2 seconds**. This output can be sustained for minutes to hours depending on the size of the battery.

Batteries are 'turned up' when needed. By responding more aggressively to faults, and at full power output, batteries reduce curtailment – allowing renewable generation to replace more conventional generation.

EXECUTIVE SUMMARY

360MW OF BATTERIES CAN PROVIDE AN EQUIVALENT INERTIAL RESPONSE TO 3,000MW OF CCGT: A POTENTIAL SAVING OF UP TO €19M AND 1.4Mt CO2 EVERY YEAR

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RoCoF management – the options

As the maximum amount of non-synchronous generation allowed on the grid increases, inertial response is eroded – increasing the threat to system security which RoCoF poses.

There are three main options for managing RoCoF at higher System Non Synchronous Penetration (SNSP) levels:

1. **Increase generator tolerance to high RoCoF.** Work is ongoing to incorporate an increased RoCoF withstand level from 0.5 to 1.0 Hz/s into the grid code, increasing system resilience to frequency events.

   This initiative to demonstrate compliance is already approaching completion: additional solutions are needed to achieve 75% SNSP and beyond.

2. **Reduce minimum generation level of thermal plant or add new types of synchronous inertia.** If CCGTs can run at lower part-loading, then there will be less displacement of wind generation, enabling operation at higher SNSP. Alternative technologies include synchronous compensators, rotational stabilisers, compressed air energy storage or pumped hydro storage.

   The SIR (Synchronous Inertial Response) service is designed in part to incentivise both of these options for managing RoCoF, compensating synchronous generators directly for the provision of inertial response.

3. **Increase levels of synthetic / emulated inertia on the system.**

   The system operators on the island of Ireland (Eirgrid and SONI) have undertaken a major study reviewing the ability of synthetic inertia to help keep RoCoF within manageable levels at 75% SNSP level. They concluded positively, provided that assets could provide partial response within 0.1 secs and full power delivery within 0.2 secs.

   QUB research has demonstrated that on a recent system event (July 2017) the AES Kilroot battery array responded in 0.04 to 0.06 seconds – well within the limits proposed by Eirgrid and SONI. With the right control system in place, the battery at Kilroot could ramp to full power in 0.05 secs. Including the response time, this means that batteries can provide full power to the system within 0.1 secs, providing effective synthetic inertia. This is DIGITAL INERTIA.

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SNSP: *The System Non Synchronous Penetration represents the instantaneous proportion of power being delivered by non-synchronous generation sources, such as wind. SNSP is currently limited to 60% but system operators are planning to increase this limit to 75% by 2020 in support of EU renewables targets, through the DS3 programme.*

3,000MW SYNCH. GENERATORS = 360MW BATTERIES

In the faults studied by QUB, 360MW of batteries could have provided the same amount of power after 0.1 secs as the inertial response of 3000MW of synchronous generators. This exceeds the stability requirements set by EirGrid and SONI for system operation at an SNSP of 75% or higher.

€ 19M
Maximum annual savings to the consumer in 2019/20

Whilst the system operators are right to explore a combination of options for managing RoCoF, the QUB study demonstrates how batteries can **fully replace the power and energy delivered by existing inertial response**. On this basis, there is an opportunity to radically reduce the cost of SIR, a product costing consumers up to €19M/yr in 2019/20. Batteries will require some remuneration for this service, but additional costs should be low when stacked with services such as Fast Frequency Response (FFR).

1.4 Mt
Additional CO2 avoided each year

By unlocking the potential of digital inertia, it is possible to refine operational constraints on the system. This will help reverse the current trend towards CO2 intensity of synchronous generators increasing, as CCGTs operate less efficiently to accommodate wind variation. Retirement or mothballing of less efficient thermal assets will enable remaining plants to operate more efficiently, with less cycling and no compromise on system stability.

AN END TO OSCILLATIONS

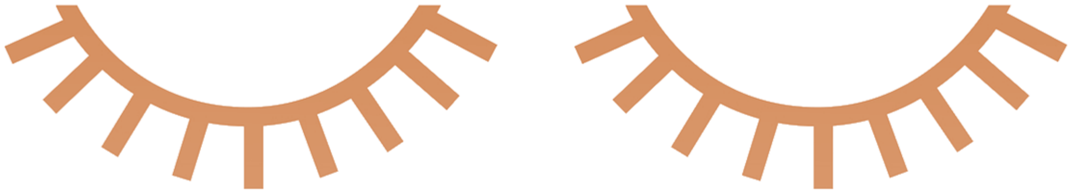
Batteries also offer system operators ultimate flexibility as a grid stability tool, operating predictably and consistently without inducing the power system oscillations which are currently experienced following system events.

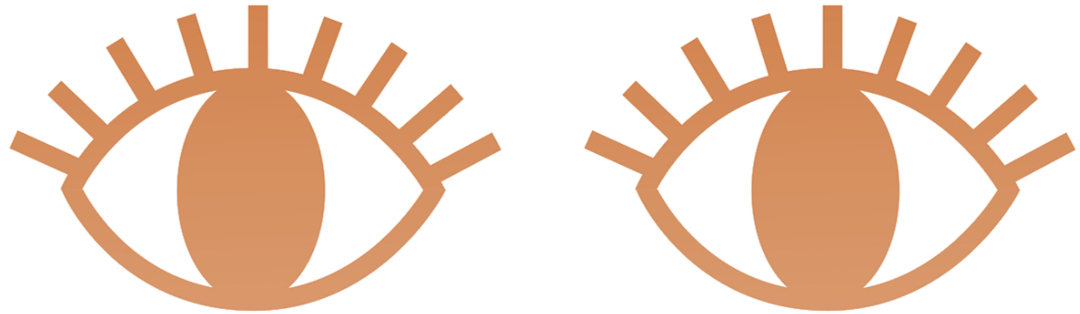
SO WHAT? FOUR POLICY RECOMMENDATIONS TO TAKE INERTIA 'BEYOND THE SPIN'

1. **DEFINE RESPONSE CHARACTERISTICS:** Initiate a system-operator led study to define optimal response characteristics for digital inertia. Conduct further field trials to prove capability.
2. **IMPROVE DETECTION AND COMPLIANCE:** Conduct research to better detect RoCoF, test compliance at finer time resolutions and consider introduction of emergency signals.
3. **ENABLE SIR-FFR SUBSTITUTION:** Open FFR to speed of response faster than 0.15 seconds, to encompass inertial response. Calculate the technical exchange rate of FFR and SIR, conducting technoeconomic research into the intersubstitutability of the products.
4. **SET NEXT SNSP TARGET:** Study the potential for digital inertia to raise the bar further after 2020, ensuring the Island of Ireland remains a world leader in grid decarbonisation.

THIS REPORT EXAMINES THE POTENTIAL OF BATTERIES TO PROVIDE DIGITAL INERTIA, REDUCING THE COSTS AND EMISSIONS ASSOCIATED WITH A STABLE, HIGH RENEWABLES POWER SYSTEM

BLINK AND YOU'VE MISSED IT.





This is a story about what happens to the electricity system on the Island of Ireland in the blink of an eye. When a power station drops offline suddenly, there is an immediate short-fall of energy on the system. This could cause other stations to follow suit if grid frequency drops too fast and too far. Fortunately, help is at hand from other spinning (synchronous) generators – which use some of the kinetic energy stored in their spinning rotors to help stabilise the grid. All this occurs well within the first half a second – literally, the time it takes the human eye to blink.

The Island of Ireland is a world leader in clean power, achieving high levels of renewables deployment thanks to progressive grid policy by Eirgrid and SONI. But this achievement poses a challenge to system stability – the amount of spinning generation on the system is reducing, fast. With ever diminishing levels of "inertial response", it is time to start looking at new ways of maintaining system stability in the first half second following a system fault.

In January 2016 AES completed the installation of a landmark 10MW battery energy storage system at Kilroot Power Station, Northern Ireland. This is the first fully commercial project in the UK and Ireland, and one of the largest in operation across Europe.

Since then Queen's University Belfast (QUB) have undertaken research into the role of li-ion batteries in supporting power system operation, using data from the Kilroot array. This report communicates the implications of this research for policymakers, regulators and system operators. The primary focus is on the All-Island electricity market in Northern Ireland and the Republic of Ireland, with implications additionally drawn out for the GB market.

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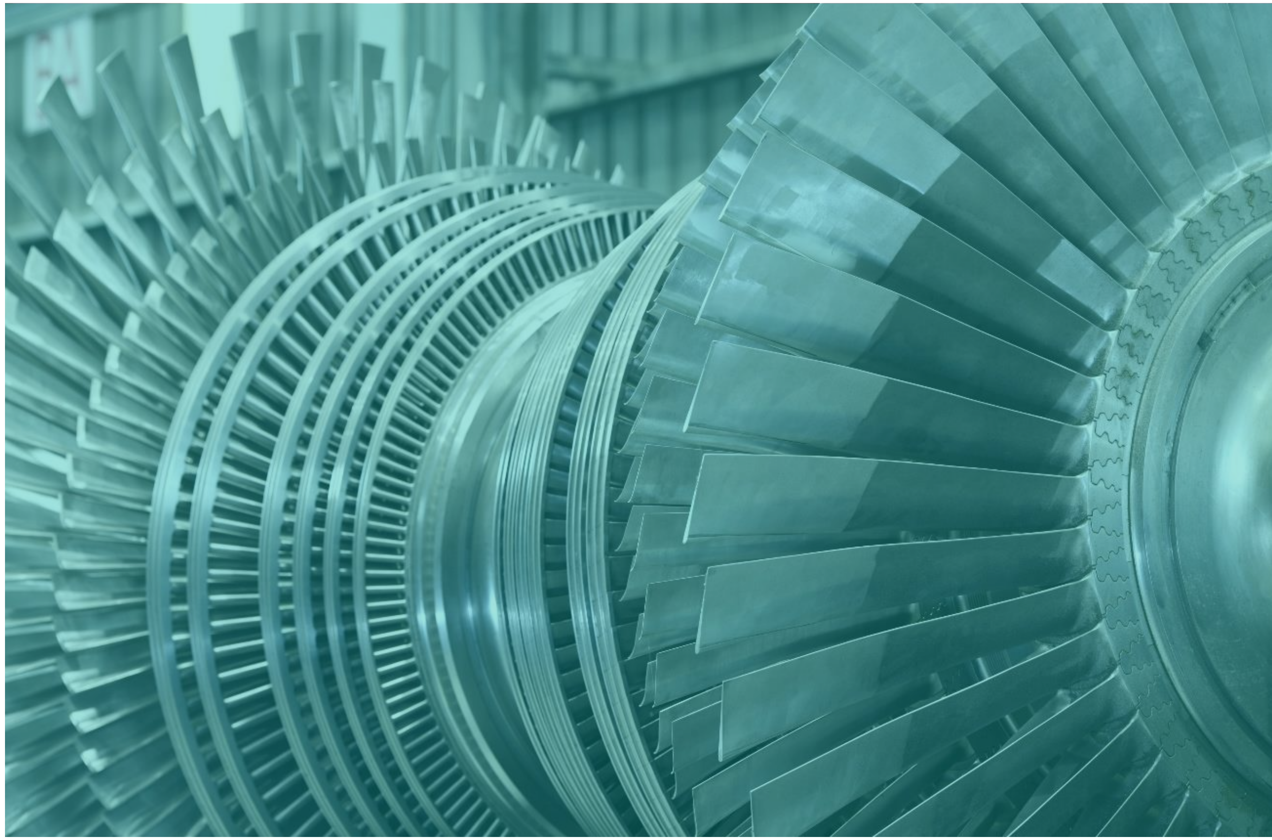
Welcome to the era of digital inertia…

CHAPTER 1

INERTIAL RESPONSE

What it is, why we need it and how it can be provided differently with batteries



THE RATE OF CHANGE OF FREQUENCY (ROCOF) MUST BE ADDRESSED TO KEEP OUR POWER SYSTEM STABLE – VARIOUS STRATEGIES CAN BE DEPLOYED.

THE CHALLENGE
MATCHING SUPPLY AND DEMAND, IN THE BLINK OF AN EYE

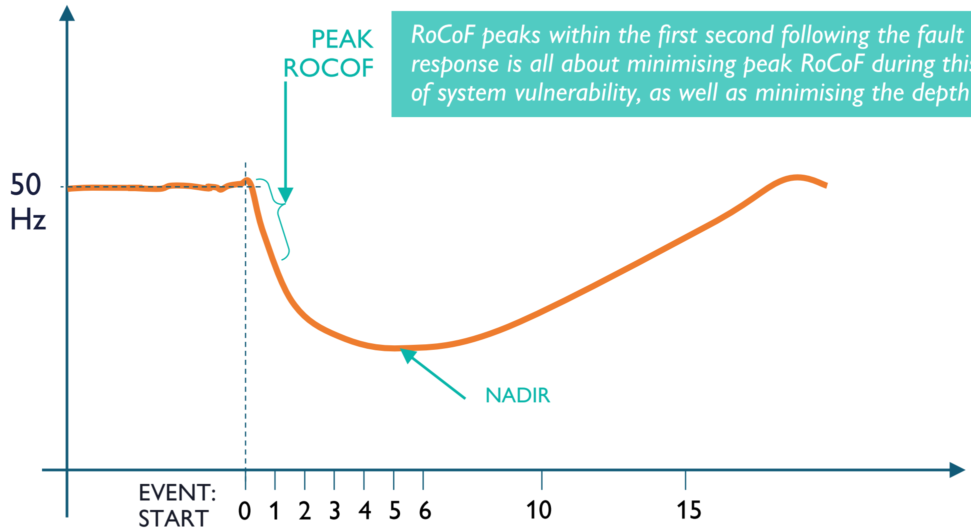
Keeping the grid stable means matching supply of and demand for energy, at all times. When the system is balanced the frequency is stable at around 50Hz. However when a power plant drops off the system, due to a sudden and unexpected fault, there is an immediate short-fall in energy. This causes the frequency of the system to start dropping. This drop must be arrested and reversed to avoid a system failure.

There are two metrics of concern after a fault:

1. **RoCoF**, the Rate of Change of Frequency, is how fast the frequency changes. If RoCoF exceeds 1Hz/s, additional power stations could be tripped offline and / or damaged.
2. **The nadir**, the minimum level the grid frequency reaches during an event. Below 50Hz, the potential for power stations to be tripped offline increases.

This report focuses on the former: RoCoF.

Managing RoCoF is a growing challenge. As the maximum amount of non-synchronous generation – notably wind – allowed on the grid increases, inertial response is eroded – increasing the threat to system security which RoCoF poses.



RoCoF peaks within the first second following the fault event. Inertial response is all about minimising peak RoCoF during this short period of system vulnerability, as well as minimising the depth of the nadir.

THE SOLUTION
LEARNING HOW TO ROCK THE ROCOF

In the face of increasing RoCoF, System Operators have two strategies for RoCoF management. These strategies can be deployed separately or together.

STRATEGY 1: ADAPT

Increase generator tolerance to high RoCoF. The grid code has already been amended to incorporate an increased RoCoF withstand level from 0.5 to 1.0 Hz/s, increasing system resilience to frequency events. However, additional solutions are needed to achieve 75% SNSP and beyond.

STRATEGY 2: MANAGE

Proactively manage RoCoF.

This can be provided through analogue or digital inertia.

ANALOGUE INERTIA

Passively provide instantaneous kinetic energy from rotating synchronous plant

Sample technologies: coal plant, CCGT, biomass plant, synchronous compensators, rotational stabilisers, compressed air energy storage, pumped hydro storage…

This is how RoCoF is currently managed, representing the status quo option; however, as coal and gas plants come offline, it can no longer be taken for granted. The nature of the response is not controllable, and instead is managed by physics.

DIGITAL INERTIA

Actively inject/remove power from asynchronous plant on inertia timeframes

Sample technologies: batteries, demand-side response, interconnectors, wind energy…

Digital inertia can take different forms:

1. Frequency response: providing an enhanced governor response (slow)
2. RoCoF response: emulating the real inertial response (fast but unstable)
3. Step response: effectively a combination of frequency and RoCoF response (fast but needs an engineering consensus).

Batteries can provide all forms.

Note: Although batteries do not provide spinning mass, what we are calling digital inertia response provides a service which provides the same benefits - or greater - as inertia.

UNDER THE STATUS QUO, 'ANALOGUE INERTIA' FROM SYNCHRONOUS GENERATORS HELPS MANAGE ROCOF, BUT BATTERIES PROVIDE AN EXCITING ALTERNATIVE

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SYNCHRONOUS GENERATORS

ANALOGUE INERTIA

HOW DOES IT WORK?

Generators which are connected and spinning at the same frequency as the grid network are termed 'synchronous'. When frequency drops suddenly, synchronous generators on the network respond **automatically and immediately** by slowing down, releasing energy stored by the large rotating masses contained in these plant. This is called an 'inertial response' and is incredibly fast – QUB measured the peak of the power ramp after 0.01 s (a hundredth of a second).

HOW BIG IS THE EFFECT?

The size of the inertial response varies according to the design of the generating station. In the QUB research the inertial response to typical large events was measured to be **7-14% of an individual unit's rated total capacity**. This means a large number of units are required to provide a given response.

WHAT ARE THE PRECONDITIONS?

Synchronous plants have minimum loading levels which means that if they are on the system to provide a response then they also need to provide **a minimum level of power**. Historically this was roughly 50% of capacity but generators are considering operating at ~25-35. This capacity displaces other forms of generation.

BATTERIES

DIGITAL INERTIA

HOW DOES IT WORK?

Batteries are not grid-synchronised and have no moving parts. The connection of batteries to the grid provides no inertia to the system. Instead, batteries **provide inertia digitally** – also described as 'synthetic' or 'emulated' inertia.
Batteries can respond as fast as the fault can be measured (response time) and the system ramped up to full power (ramp time). The primary constraint on speed of response is detecting the RoCoF.

HOW BIG IS THE EFFECT?

Once they have ramped up, batteries can provide **100% of their output** as digital inertia, as demonstrated by QUB's research at Kilroot.

WHAT ARE THE PRECONDITIONS?

A full response is only possible assuming that the battery's **state of charge is managed** so that it is ready to either import or export power, thus ready to respond to either a high or low frequency event. For inertia this is not an onerous requirement, as a response is only required for a matter of seconds, thus entailing minimal energy requirements.

JARGON BUSTER

Let's be honest, "Digital Inertia" is actually a misnomer. Batteries have no physical inertia – they do not move. Instead, they can provide inertial-like response via super fast active power injection and import.

Throughout this report we use the Digital Inertia misnomer deliberately, as it helps to place battery capabilities within the regulatory language of the Island of Ireland.

More on this in Chapter 3.

INERTIAL RESPONSE

QUB RESEARCH AND BATTERY OPERATIONAL EXPERIENCE SHOWS THE ABILITY OF BATTERIES TO SATISFY SYSTEM OPERATOR INERTIA REQUIREMENTS

In 2016, the System Operators (SOs) in the Island of Ireland (Eirgrid and SONI) undertook a major study reviewing the ability of synthetic inertia to help keep RoCoF within manageable levels at 75% SNSP level.

Their report outlined key requirements for synthetic (or digital) inertia providers. QUB's research and international operational battery experience demonstrates that batteries can meet all requirements.

ON THE CUSP
THE ABILITY OF BATTERIES TO MEET SYSTEM OPERATOR REQUIREMENTS

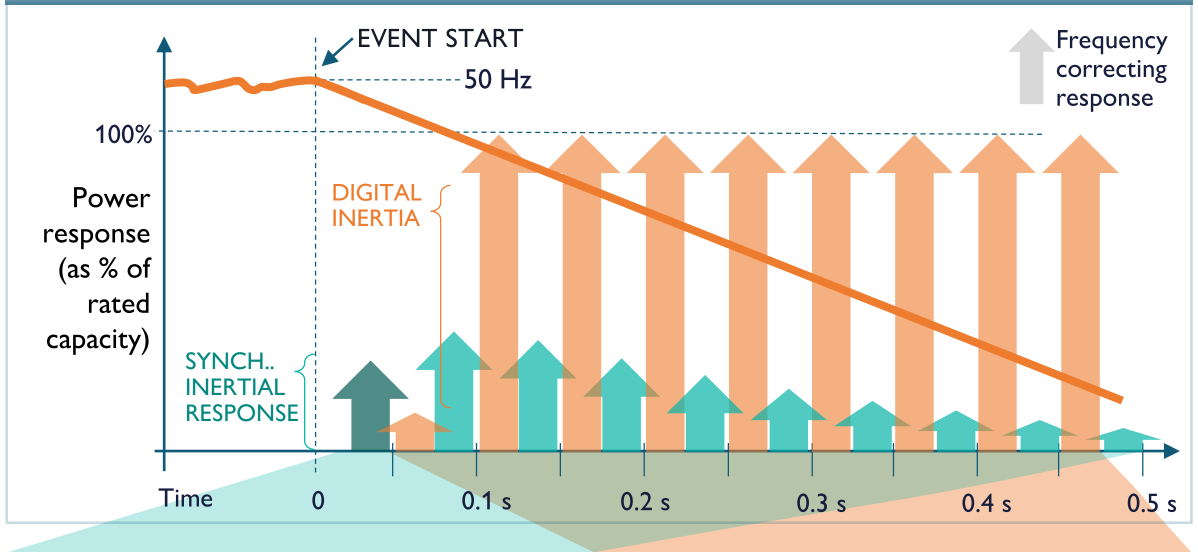
CHECKLIST	PERFORMANCE
1. Fast response *"to begin responding from 100 milliseconds from the start of the event"*	QUB research shows that on recent frequency transients (July-Sept '17) the Kilroot array responded in timescales **approaching 0.1 secs**. This could be reduced through implementing an 'emergency signal' triggered from transient detection, either through voltage or synchronous machine power measurements; this could be generated locally or as part of a wide-area control network.
2. Fast ramp-up *"the active power injection must be fully achieved 200 milliseconds [0.2 s] after the device begins to respond"*	At present the Kilroot array is set up to provide the slower ramp rate required for current services, with a ramp time of ~0.5 seconds. With the right control system in place, the battery at Kilroot could ramp to full power **in 0.05 secs**.
3. Smooth recovery *"to present unintended adverse system issues during the frequency recovery"*	Battery can respond dynamically. The output can be sustained for a period determined by the MWh capacity of the battery; at Kilroot a full response can be provided for up to **30 minutes**.

Eirgrid/SONI (March 2016), RoCoF alternative & complementary solutions project: Phase 2 Study Report

Moreover, in the faults studied by QUB, 360MW of batteries could have provided the same amount of power after 0.1 secs as the inertial response of 3000MW of synchronous generators. This exceeds the stability requirements set by EirGrid and SONI for system operation at an SNSP of 75% or higher.

3,000MW SYNCH. GENERATORS = **360MW** BATTERIES

POLES APART: DIFFERING RESPONSE CHARACTERISTICS IN THE FIRST HALF SECOND



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BATTERIES

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Batteries are 'turned up' when needed. By responding more aggressively to faults, and at full power output, batteries reduce curtailment – allowing renewable generation to replace more conventional generation.

CHAPTER 2

THE DIGITAL INERTIA OPPORTUNITY

How Digital Inertia can reduce cost and cut emissions in a high renewables, stable grid system

DIGITAL INERTIA CAN REDUCE RELIANCE ON AGEING, "CONSTRAINED ON" THERMAL ASSETS, HELPING TO DELIVER A CO2 SAVING OF 1.4 MILLION TONNES PER YEAR IN 2020

As well as saving money for consumers, digital inertia also unlocks additional CO2 reductions and air quality improvements.

On the face of it, wind and gas are the perfect match for generating electricity. Wind output is clean, but variable. So to ensure supply always meets demand, dispatchable, flexible power sources are needed to balance wind generation. Simple.

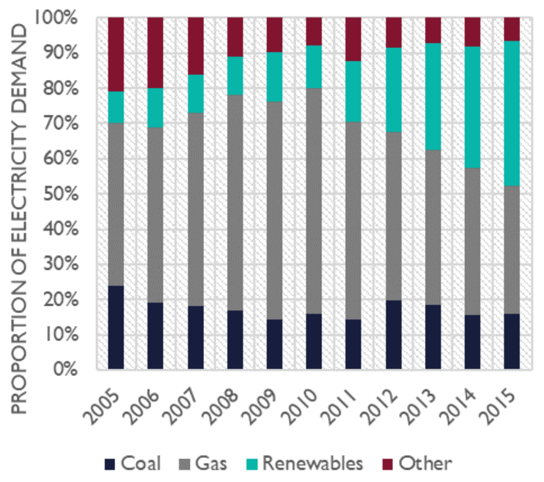
The reality is more complex…

Whilst Combined Cycle Gas Turbines (CCGTs) can operate flexibly and "on demand", they are most efficient when operating at their Maximum Economic Rating, at which thermal efficiencies of up to 60% can be reached, corresponding to a minimum CO2 intensity of around 350kg/MWh. When operating in different modes, such as step change or modulation, efficiency and emissions performance drops off rapidly, particularly for older generation technology.

Since 2010 the electricity fuel mix on the Island of Ireland has been a story of the rapid displacement of gas by wind (see chart right) – a trend which is set to continue through to 2020. Whilst the net effect of this has been to reduce CO2 emissions for the system as a whole, it has also caused CCGT plant to operate in an increasingly variable way, reducing efficiency.

Analysis of Eirgrid data by Tsagkaraki & Carollo of Incoteco shows that in the period 2014-15, CCGT fleet average CO2 intensity was at an average of 575 kg/MWh and by 2020 this is expected to increase to around 720 kg/MWh. For reference, such emissions levels are comparable to new build coal-fired generation.

PUSHING AT THE MARGINS:
WIND HAS SQUEEZED OUT GAS SINCE 2010



Data: CER 2016 Fuel Mix Disclosure

Without reform, there is a risk that further wind and solar deployment makes gas as polluting as coal generation – a barrier to the Island of Ireland decarbonising its electricity system, even if EU renewables targets are met.

Similar findings are relevant for other emissions affecting air quality – notably NOx and SOx. As urban air quality rises up the policy agenda, the imperative to deploy smart technologies such as battery storage to reduce air pollutants will only intensify.

The rapid deployment of Digital Inertia will not only curb consumer costs, but will also help boost the efficiency of the existing thermal fleet, allowing policy objectives to be met and emissions to be cut even further.

THE RATIONALE:
HOW DIGITAL INERTIA CAN MAKE THE CCGT FLEET LEANER AND CLEANER BY 2020

The CO2 intensity of energy generated by synchronous generators, and in particular ageing thermal plants will continue to increase as wind deployment ramps-up.

720 kg/MWh

Projected CO2 intensity of CCGT fleet in 2020, **comparable to new build coal-fired generation**

Tsagkaraki & Carollo (Incoteco), 2016 analysis of Eirgrid data

Adopting DIGITAL INERTIA reduces the need for a minimum number of synchronous generators to be online all of the time. This also increases system resilience.

8

Minimum number of "high inertia machines" **that must be online** at all times.

Eirgrid and SONI Operation Constraints Update, July 2017

DIGITAL INERTIA can reduce Operational Constraints on the system, allowing older, less efficient plant to be retired or mothballed. This has the potential for the CO2 intensity of the CCGT fleet to be arrested at around '14/15 levels.

575 kg/MWh

CO2 intensity of CCGT fleet in 2014/15. Achievable in 2020.

Tsagkaraki & Carollo (Incoteco), 2016 analysis of Eirgrid data

Early retirement or mothballing of less efficient thermal assets will enable the remaining plant to operate more efficiently, with lower cycling and higher capacity factors.

145 kg/MWh

Potential **CO2 intensity saving** in 2020 compared to Eirgrid projections (720-575).

Adopting DIGITAL INERTIA facilitates more renewables onto the system, helping achieve EU 2020 targets (assuming all renewables deployment displaces gas generation in fulfilling such targets).

28%

of electricity demand met by a **leaner, cleaner CCGT fleet** in 2020 (50% in 2016).

Eirgrid, All-Island Generation Capacity Statement 2017-2026

DIGITAL INERTIA can unlock the true system wide potential of renewables by making the synchronous generator fleet cleaner.

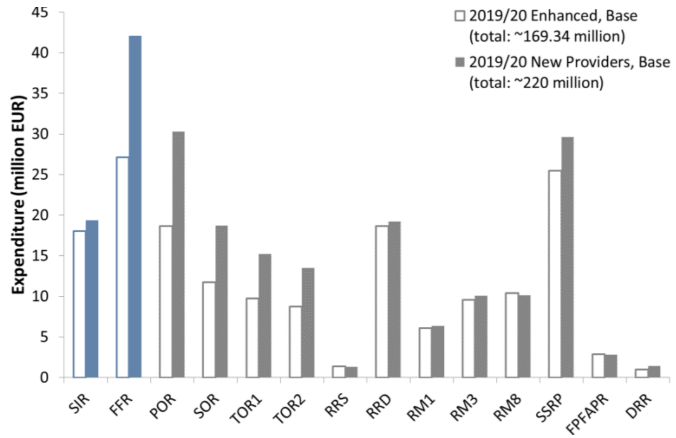
1.4 Mt/year

Annual CO2 savings in 2020, equivalent to annual emissions from the **entire city of Cork.**

World Bank

ADOPTING DIGITAL INERTIA CAN SLASH THE COST OF DELIVERING INERTIAL RESPONSE AS WELL AS IMPROVING THE QUALITY OF POWER RESPONSE FOLLOWING EVENTS

COSTING THE EARTH?
THE CASE FOR SMARTER SPENDING ON MANAGING ROCOF THROUGH SIR AND FFR



Eirgrid/SONI, DS3 enduring tariffs consultation, July '17

Under the DS3 programme, Eirgrid and SONI are bringing forward a suite of new System Services to ensure reliable operation of the grid at 75% SNSP. The estimated annual cost of these services in 2019/20 is €169 - 220M depending on the modelling scenario. Out of the 14 new services, SIR and FFR are key to managing the RoCoF challenge.

Both SIR and FFR are attempts to manage RoCoF, ensuring system stability at higher SNSP levels. Crucially however, SIR is closed to providers of synthetic inertia, which represents a missed opportunity for delivering cost effective RoCoF management using digital inertia.

Yes SIR, No SIR. Synchronous Inertial Response (SIR) was introduced in October 2016 and is designed to compensate synchronous generators on the basis of the stored kinetic energy available to help manage system events within each half hour period. This service is closed to non-synchronous generators at present and is designed in part to incentivise reduced minimum loading of CCGT to ensure there is sufficient conventional inertial response available at all times, in case of a system fault.

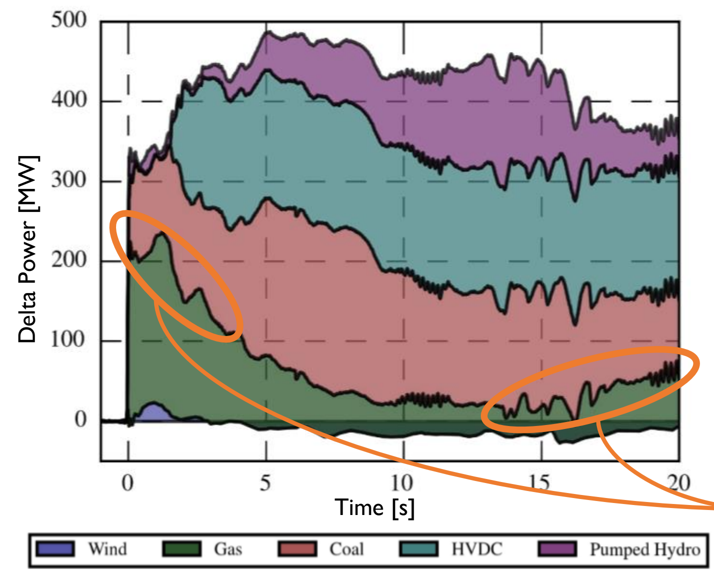
What-the-FFR? Fast Frequency Response (FFR) is a new service designed to compensate providers for providing a response between 2 and 10 seconds after an event, at times when SNSP is above 60%. Incentives are in place to boost revenues to those providers who can respond faster to a minimum of 0.15 seconds, reflecting the value of this service in managing RoCoF during a system event.

€ 19M

Maximum annual savings to the consumer in 2019/20

QUB research at Kilroot clearly demonstrates that batteries **can fully emulate inertial response**, with the potential to deliver full power within 0.1 seconds. On this basis, there is an opportunity to radically reduce the cost of SIR, a product costing the consumer up to €19M / annum in 2019/20. Batteries will require some remuneration for this service, but additional costs should be low when stacked with services such as Fast Frequency Response (FFR). In the longer term, there is an opportunity to combine these services and procure them competitively against a technology-agnostic specification.

QUALITY TIME
ISSUES WITH OSCILLATIONS AND INCONSISTENT RESPONSE CAN BE AVOIDED WITH BATTERIES



QUB. Brogan, Alikhanzadeh, Best, Morrow and Kubik 2017

QUB conducted a study of three occasions in Q2 2016 when a generator tripped while exporting between 432-437MW. This resulted in under frequency transients with a nadir between 49.23 and 49.33Hz. The general power response from generators for one such event is shown to the left. The total inertial power response was around 320MW.

Oscillations witnessed between 0-4 seconds, and 8-22 seconds

Unpredictable power oscillations
Significant oscillations were identified in post-event recovery period for all three events and appear to have originated from some of the conventional thermal plant. In all cases the behaviour instigates inter-area power oscillations before re-stabilisation occurs.

Inconsistent response
Further investigation also revealed that the responses of generators varied significantly between the three events examined. This inconsistent and unexplained power response does not provide confidence in the quality of the inertial and frequency regulating response of ageing synchronous generators at higher SNSP level.

RESPONSE CHARACTERISTICS FOR DIGITAL INERTIA

Batteries offer system operators the ultimate flexibility in terms of dealing with system events. They can step, droop or provide an emulated inertial response. Study is now urgently needed in order to identify up the optimal response characteristics and to then codify these into a re-booted version of SIR and / or FFR.

CHAPTER 3

WHAT NEXT?

What all of this means for the Island of Ireland and GB: 4 recommendations to take inertia “beyond the spin”

WHAT NEXT?

4 TARGETED ACTIONS ACROSS TECHNOLOGY, MARKET AND POLICY DESIGN TO UNLOCK THE FULL POTENTIAL OF BATTERIES ON THE ISLAND OF IRELAND

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	TECHNOLOGY		MARKET	POLICY
	1. DEFINE RESPONSE CHARACTERISTICS	2. IMPROVE DETECTION AND COMPLIANCE	3. ENABLE SIR-FFR SUBSTITUTION	4. SET NEXT SNSP TARGET
WHAT?	• Initiate a system-operator led study to define optimal response characteristics for digital inertia, which take advantage of the full flexibility of batteries to provide a range of dynamic responses. • Conduct further field trials to prove capability, to include consideration of management of power electronics controls interaction across the system.	• Conduct research on reducing timescales to detect RoCoF, and to increase measurement accuracy • Evaluate the introduction of an 'emergency signal' to reduce detection times. This signal would be triggered from transient detection, either through voltage or synchronous machine power measurements.	• Extend FFR scalars to reward speed of response faster than 0.15 seconds, to encompass inertial response • Calculate the "technical exchange rate" of FFR and SIR, conducting techno-economic research into the interchangeability of the products.	• Study the potential for digital inertia to raise the SNSP bar further after 2020. • This will involve power system modelling at SNSPs beyond 75%. *Further details on following page*
WHY?	• Further trials were recommended in the *RoCoF Alternative Phase 2 Study Report* published by Eirgrid/SONI in March 2016. • Further work is needed under ongoing DS3 Qualification Trials to test for inertial response.	• The primary limiting factor on digital inertia is the very high time resolutions involved (millisecond-level). • This causes challenges both for assets to *detect* of RoCoF/frequency deviations, and also for the System Operators to test *compliance* with requirements for delivery.	• To ensure a level-playing field between technologies, overcoming the current technology bias towards the incumbent. • This will stimulate competition and ultimately offer consumers better value for money.	• The DS3 programme has set out an excellent and focused pathway to increase the SNSP limit by 5% each year up to 2020. Now it's time to begin planning beyond 2020 – when SNSP will need to increase beyond 75%. • As the cheapest form of any new power generation, wind and possibly solar will continue to be deployed beyond 2020, even in the absence of specific policy objectives. • This will ensure that the Island of Ireland remains a world leader in grid decarbonisation.
WHO?	System Operator-led, with support of industry and academia	System Operators, industry and academia to partner	System Operators, with guidance from industry and academia	Policymaker-led, with support from System Operators and Regulators

WHAT NEXT?

IT'S TIME TO STOP FRAMING ANCILLARY SERVICES AROUND THE INCUMBENT TECHNOLOGY, AND CREATE A GENUINELY LEVEL PLAYING FIELD.

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CHALLENGE: MOVING ON FROM "INERTIA"


Consultation on
DS3 System Services Enduring
Scalar Design

DS3 System Services Implementation Project

4 July 2017

EIRGRID SONI

MARKET DESIGN LIMITATION	EVIDENCE: DS3 REPORT DATED 4th JULY 2017	HOW THIS ACTS AS A BARRIER TO BATTERY ENERGY STORAGE
1. CONFLATING 'WHAT IS NEEDED' WITH 'HOW IT IS DELIVERED': Rather than framing SIR around system needs (namely RoCoF management), DS3 instead specifies the physical mechanism by which technologies must provide support – namely via kinetic energy. The very language of DS3 is biased by the physics of the incumbent technology, and this linguistic confusion has continued into market design.	UNITS: The name 'Synchronous Inertial Response' by itself specifies certain technologies. In addition, the unit used for SIR compensation is tied to a physical response (kinetic energy), whereas all other products are defined in terms of power output.. The unit is: *MWs2h (Stored kinetic energy)*(SIR Factor – 15).*	BIAS TOWARDS INCUMBENTS: This is not technology-neutral – and in fact prescribes a mode of operation that fails to take advantage of the full flexibility of batteries, which can respond with a power output, rather than being constrained by a predetermined physical profile.
2. ARTIFICIALLY SEPARATING SIR AND FFR: DS3 considers FFR responses faster than 0.15 seconds to be within the bounds of system inertia, and thus incentivises this through SIR only. DS3 analysis does not consider the inter-substitutability of the products.	PRODUCT DESIGN: "the TSOs wish to emphasise that SIR and FFR are distinct System Services designed to incentivise meeting the system requirements for inertia and containment following a frequency event respectively"	BARRIERS TO ENTRY: Batteries do not have a route to market for provision of response faster than 0.15 seconds, and their compensation via FFR is limited by not having the market ability to displace conventional generators in the SIR market.

BOTH THE LANGUAGE AND STRUCTURE OF DS3 ROCOF MANAGEMENT IS FRAMED AROUND INCUMBENT TECHNOLOGY.

Historically this was appropriate – but in the era of new technologies, old assumptions now need to be revisited. The current market boxes the battery industry into framing their capability around 'digital inertia' – though ultimately the flexibility of control offered by batteries is superior to conventional analogue alternatives.

PRAGMATIC SOLUTIONS: EVOLUTION NOT REVOLUTION

We appreciate that at this late stage in the DS3 process, it would be inappropriate to propose a radical structural change to address the inherent technology bias, such as removing SIR altogether. However, to ensure a level playing field, the following refinements are recommended.

WORKING WITHIN DS3: RECOMMENDATIONS

1. **Extend FFR:** Open FFR to 0.00 seconds to encompass inertial response.
2. **Calculate the technical exchange rate of FFR and SIR:** conduct technoeconomic research into the intersubstitutability of the products.

WHAT NEXT?

THE ISLAND OF IRELAND IS A FORERUNNER FOR GB, WHICH HAS AN INERTIA CHALLENGE LOOMING. VALUING INERTIA IN FREQUENCY RESPONSE WILL HELP.

GB's system operator National Grid has been a pioneer in incentivising sub-second response from batteries, notably via awarding 201MW battery projects contracts in August 2016. These projects will provide Enhanced Frequency Response, which includes a requirement to deliver full power within half a second. National Grid has outlined its plans for accommodating reduced inertia in its System Needs and Product Strategy (SNAPS) report.

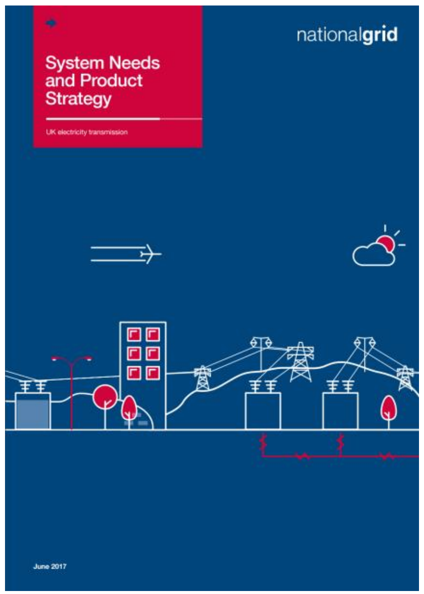
GB PRESENT: INERTIA MANAGEABLE WITH CURRENT TOOLS

- At present, reducing the largest credible loss remains an efficient and cost-effective solution to National Grid to manage inertia in GB.
- In parallel, a programme of desensitising RoCoF relays is allowing the system to operate at lower levels of inertia.

GB FUTURE: ANALOGIES WITH IRELAND

- Reducing the largest loss to manage RoCoF may not always be economic or possible in the future.
- RoCoF emerges as a challenge even within a 5-yr timeframe. By 2021/22, high RoCoF creates a need for multiple curtailments or displacement of wind for over 25% of the time under the 'Consumer Power' scenario.

NATIONAL GRID'S STRATEGY FOR INERTIA



No specific inertia product

Unlike the Island of Ireland, there are no plans for a specific inertia product. This is because, at current levels of non-synchronous penetration, increasing the levels of inertia on the system is less effective than reducing the largest credible loss.

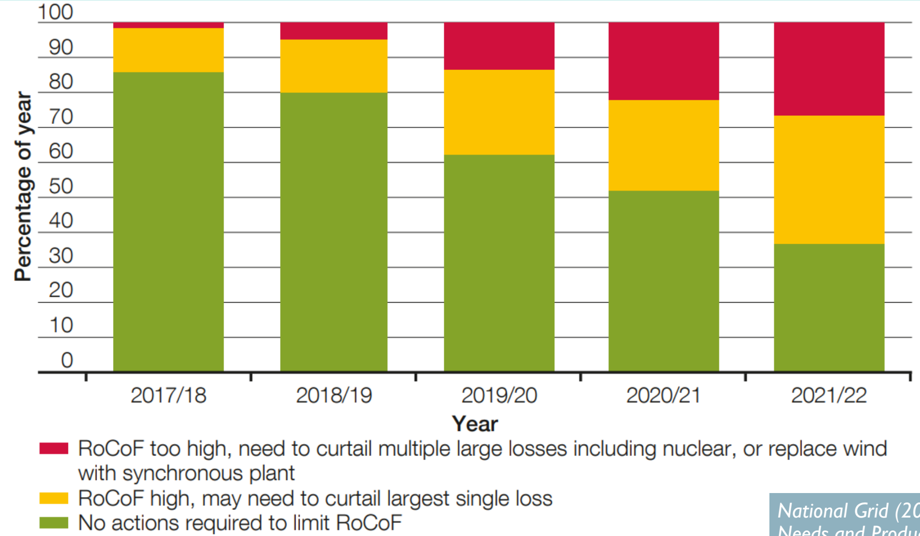
Value inertia in other products

National Grid is considering valuing inertia via frequency response and voltage market design. This will include incorporation into the new frequency response product to be launched by March 2018.

Innovation research into analogue methods

National Grid is conducting research into synchronous compensators and similar devices which can provide inertia without generating active power, via 'Project Phoenix'.

RISING RED
5-YR ROCOF OUTLOOK UNDER 'CONSUMER POWER' SCENARIO



National Grid (2017) System Needs and Products Strategy

SO WHAT? RECOMMENDATIONS TO UNLOCK THE POTENTIAL OF BATTERIES IN GB

1. **Value inertia in other products – without delay:** Valuing inertia within other products is a reasonable approach. It is important to pursue this reform swiftly to ensure that battery projects are designed to offer the full suite of services that the technology is capable of, particularly given the fast pace of project development in GB.
2. **Consider air quality and decarbonisation:** Curtailment of wind and nuclear due to high RoCoF should be seen as a last resort option only, rather than a base case for 25% of the time in 2021/22. Decisions on the hierarchy of RoCoF actions should factor in decarbonisation and air quality impact rather than just the most cost-effective solution.
3. **Invest in digital inertia innovation:** Building on pioneering work such as the Enhanced Frequency Control Capability (EFCC) project, ensure that future programmes consider digital means of providing inertial response. This should be in addition to ongoing research into analogue methods, particularly given that digitisation is one of National Grid's three pillars.

WELCOME TO THE ERA OF DIGITAL INERTIA

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experts | evolving | energy

The Island of Ireland is a world leader in clean electricity, thanks to progressive grid policy by Eirgrid and SONI. To date, analogue inertia has served the power system well – managing the rate of change of frequency in the blink of an eye to keep the system stable at all times.

But QUB's research compels us to re-evaluate our options, prompting a fundamental re-evaluation of how we balance supply and demand on a sub second basis.

We believe it's time to go beyond the spin, and unlock the cost-saving and carbon-cutting power of batteries.

Welcome to the era of digital inertia.

To read the QUB research underpinning this report, see:

Brogan, Alikhanzadeh, Best, Morrow and Kubik (2017), *Fast frequency response requirements for replacement of observed generator response during under frequency transients.*

This report has been prepared and is issued in accordance with contract document AES001-P-01-B dated 25 July 2017, which governs how and by whom this report should be read and used.

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