Assessing the impact of CLASS on the GB Electricity Market

CLIENT: Electricity North West Ltd

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Version History

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Contents

List of Acronyms

ABSVD	Adjusted Balancing Service Volume Data	**GW**	Gigawatt
ACER	Agency for the Cooperation of Energy Regulators	**HV**	High Voltage
BM	Balancing Mechanism	**HVDC**	High Voltage Direct Current
BMU	Balancing Mechanism Unit	**Hz**	Hertz
BSC	Balancing and Settlement Code	**ICCP**	Inter-Control Centre Communications Protocol
BSUoS	Balancing Services Use of System (charges)	**kV**	Kilovolt
CBA	Cost Benefit Analysis	**LCNF**	Low Carbon Network Fund
CCGT	Combined Cycle Gas Turbine	**LRMC**	Long Run Marginal Cost
CHP	Combined Heat and Power	**LV**	Low Voltage
CLASS	Customer Load Active System Services	**MVAr**	Mega Volt Amps (reactive)
CM	Capacity Market	**MW**	Megawatt
DNO	Distribution Network Operator	**NCEB**	Network Code on Electricity Balancing
DS3	Delivering a Secure, Sustainable Electricity System	**NGET**	National Grid Electricity Transmission
DSO	Distribution System Operator	**Non-BMU**	Non-Balancing Mechanism Unit
DSR	Demand Side Response	**NPV**	Net Present Value
DUoS	Distribution Use of System (charges)	**OCGT**	Open Cycle Gas Turbine
EDL	Electronic Dispatch Logger	**RIIO**	Revenue = Innovation + Incentives + Outputs (GB price control methodology)
EFR	Enhanced Frequency Response	**RoCoF**	Rate of Change of Frequency
ENTSO-E	European Network for Transmission System Operators for Electricity	**SO**	System Operator
ENWL	Electricity North West Limited	**SQSS**	Security and Quality of Supply Standard
EOD	Event of Default	**SRMC**	Short Run Marginal Cost
ERPS	Enhanced Reactive Power Service	**STOR**	Short Term Operating Reserve
FCDM	Frequency Control by Demand Management	**TNUoS**	Transmission System Use of System (charges)
FFR	Firm Frequency Response	**TSOs**	Transmission System Operators

1 Executive Summary

Electricity North West Limited (ENWL) has commissioned Baringa Partners (Baringa) to assess the impact of Customer Load Active System Services (CLASS) capabilities on the GB Electricity Market, focusing on its ability to provide Balancing Services to National Grid Electricity Transmission (NGET), in its role as GB System Operator (SO). This report summarises our findings, and accompanies a public version of the Cost Benefit Analysis (CBA) tool developed as part of this work.

ENWL successfully trialled CLASS between 2014 and 2015, with support from the Low Carbon Networks Fund (LCNF)[1]. It demonstrated that it is possible to use remote management of transformers on primary substations on distribution networks to deliver a rapid reduction, or increase in the underlying load, and developed control and communications systems that would be required to harness this capability within useful timescales. ENWL concluded that up to 200MW of such flexibility could be delivered using its own network, which could potentially be scaled to 3GW if rolled out market-wide.

CLASS' capabilities are focused on NGET's Balancing Services, which are the flexible and responsive energy and capacity products that it procures from market participants in order to meet its statutory obligations for maintaining the system balance in a steady state (thereby ensuring real-time security of supply). Our review of CLASS capabilities against the Balancing Services specifications concluded that it appears particularly well-suited to provide:

- **Firm Frequency Response (FFR)** – a very fast ramping (either 10 or 30 second) increase or reduction in consumption, which may be used for between 30 seconds and 30 minutes,
- **Fast Reserve** – a fast ramping (2 minute) reduction in consumption, which may be used for up to 15 minutes at a time,
- **Short Term Operating Reserve (STOR)** – a medium-speed ramping product, (20 minutes preferred) which can be used for up to two hours at a time, and
- **Reactive Power (through the Enhanced Reactive Power Service (ERPS))** – absorption of reactive power within 2 minutes of an instruction (though this service is locational).

To assess the impact that CLASS would have in each of these markets, we developed a CBA tool that considers CLASS in the context of the current Balancing Services market, and a view of what the market could look like in the future:

- The current market is based on FY2014/15, being the most recent year for which we have data on active market participants and their bid prices,
- The future market is based in 2027, to allow for a series of expected structural changes to take place (such as an increase in distributed generation, demand side response (DSR),

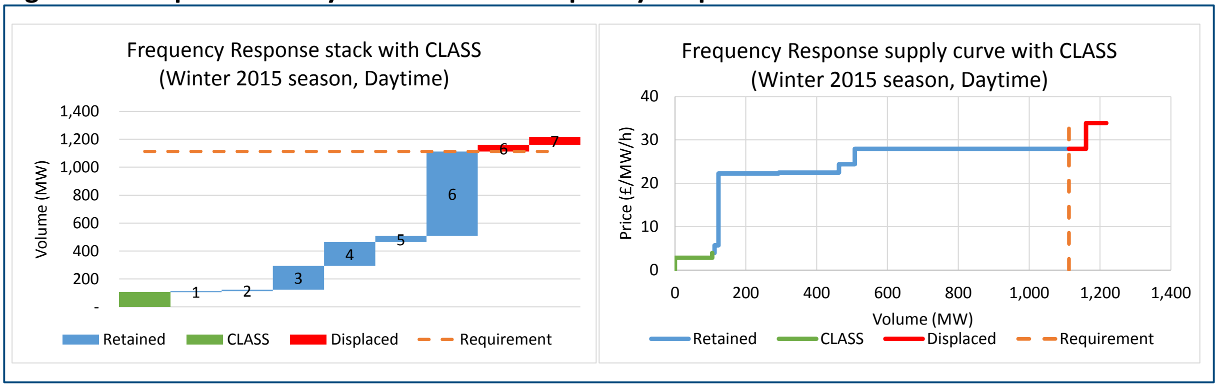
[1] The LCNF was Ofgem's fund that allowed up to £500m to support projects sponsored by Distribution Network Operators (DNOs) to trial new technologies, operating models and commercial projects, to help DNOs understand how manage the transition to a low carbon economy. This independent report is commissioned as an extension to the original CLASS funding decision.

and battery capacity participating in Balancing Services, in addition to increased drivers for demand for Balancing Services, such as the increase in largest infeed loss associated with new nuclear plant on the system).

Within each of these markets, we explore the effect of assuming CLASS is priced either based on its Long Run Marginal Cost (LRMC), or the average price of the plant being displaced (Shadow Marginal Pricing).

The initial stage of our analysis focused on the individual Balancing Services product merit orders, and which providers CLASS is able to displace. We found that even with relatively small volumes of CLASS, the cost of Balancing Services can be significantly reduced since there are relatively expensive providers in the firm and non-tendered markets that could be displaced.

Figure 1 Displacement by CLASS in 2015 Frequency Response market

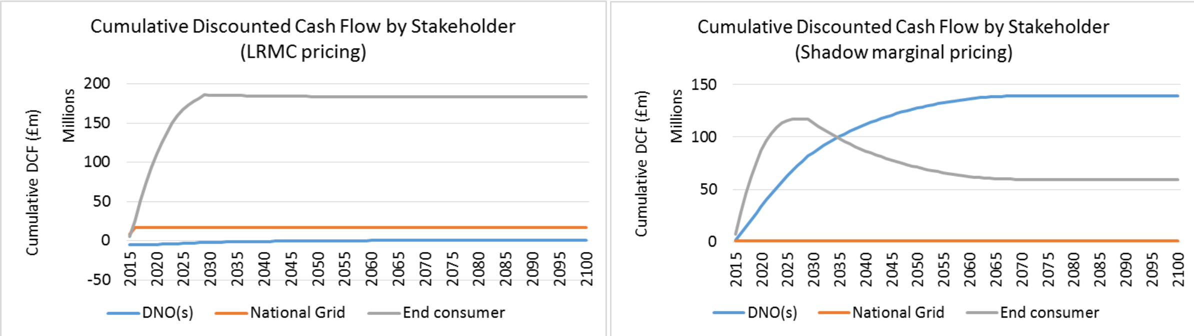


The next stage of our analysis assessed the value of this displacement over multiple years, considering the price at which CLASS is offered and the treatment of the resulting revenues under Ofgem's Price Control Framework. The net effect is a reduction in end consumer electricity bills under the full range of assumptions we have considered.

For the initial tranche of CLASS deployment planned by ENWL, we estimate that on a Net Present Value basis between 2015 and 2029 the total benefit of CLASS could be in the region of £200m, with customers receiving between £60m and £183m of that through reductions in their bills, depending on how CLASS is priced into the Balancing Services markets.

The benefit of a wider roll-out will depend on the timing of new entrants and the overall volume but, based on the estimated CLASS capability across GB being deployed gradually between now and 2027, an overall benefit of between 2015 and 2041 of £466m would be possible, of which between £128m and £445m could accrue to customers through bill reductions.

Figure 2 Cost Benefit Analysis of initial tranche of CLASS to be deployed by ENWL



	Value (£m, 2015 real)
DNO	**0.7**
National Grid	**16.4**
End Consumer	**183.0**
Total	**200.1**

	Value (£m, 2015 real)
DNO	**139.3**
National Grid	**1.3**
End Consumer	**59.5**
Total	**200.1**

Whilst there is a degree of uncertainty over how CLASS will be deployed and how the markets for Balancing Services will evolve, it seems clear that there is significant potential for this technology to reduce consumer costs. In addition, the use of CLASS could result in material reductions in the CO_2 emissions associated with holding and utilising plant for the provision of Balancing Services. The impact on Security of Supply is less certain, but it would appear that the overall effect of delivering more dependable voltage control is a net positive for the security of the overall system.

2 Background to CLASS

2.1 Project background

2.1.1 Overview of previous work on CLASS

CLASS is a second tier LCNF-supported project led by ENWL to investigate the possibility of using voltage management to provide demand reduction, or demand boost, in order to provide ancillary services to NGET.

“CLASS” is a collective term used to describe the use of voltage management technologies on distribution networks, whereby voltage at a primary substation is varied to intentionally alter the level of power consumption at lower voltage connection levels. This change in power consumption can then be used to supply NGET with energy to help balance the wider integrated transmission system.

The field and research elements of the CLASS project ran between January 2013 and September 2015. These elements focused on demonstrating that the method for controlling voltage was effective at providing a response upon instruction, without compromising the quality of power supply for end-consumers.

Following the closedown phase of the initial CLASS project, Ofgem granted ENWL an extension for CLASS, to consider the market impacts of using CLASS capabilities to provide ancillary services to the GB SO. ENWL commissioned Baringa Partners to conduct this work.

2.1.2 CLASS delivery potential

The initial project considered both the potential to deliver CLASS on ENWL’s network, and assessed the potential across GB as a whole. It concluded that CLASS potential could be:

- Up to 200MW in ENWL’s network, and
- Up to 3GW of capability across GB.

ENWL is currently considering roll-out of up to 200MW in the near term (next 1-2 years), while realising the 3GW of capability nationally will require other Distribution Network Operators (DNOs) to conduct studies on their own networks prior to roll-out. The impact assessment accounts for this potential ramp-up in CLASS capability over time by assuming that ENWL’s capability is first introduced to the current market, with the full 3GW capability being rolled out gradually over time.

These figures represent the expected peak capability across the year, which occurs (typically) during periods of peak demand. However, it is expected that the volume of services offered to NGET will be lower since they will likely be based on the minimum level that can be guaranteed over a defined period (e.g. winter daytime, or non-winter overnight).

2.2 Technology description

2.2.1 Introduction

NGET defines the products that it procures for balancing the system in terms of the speed and duration of energy response. Therefore, we need to understand what services a portfolio of CLASS-enabled substations can deliver. This section provides a brief overview of the components of a typical substation, before stepping into the capabilities that have been trialled under CLASS.

2.2.2 Overview of the primary substation

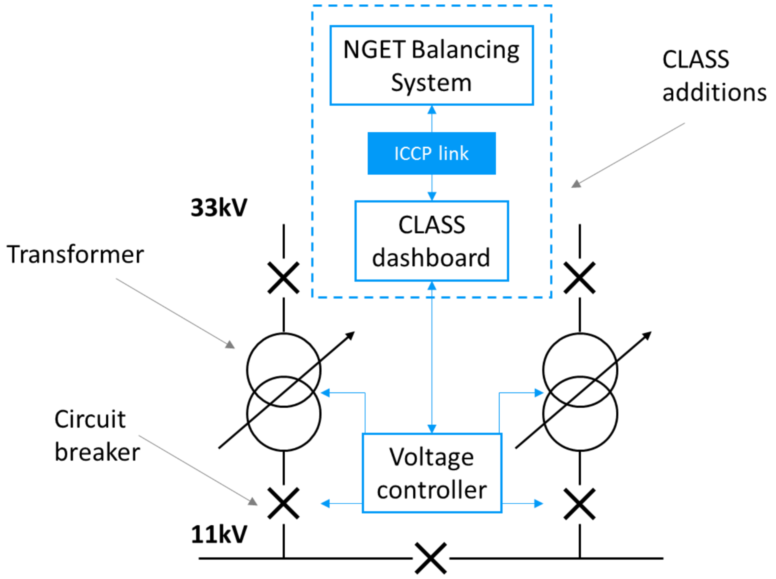
A primary substation is a core component of the distribution network. Power flows onto the distribution network from the grid supply point (GSP) – the connection between the transmission system and the distribution system – normally at voltages of 132 kV. This is stepped down through high voltage transformers to 33 kV, before being stepped down by primary substations to 11 kV (known as High Voltage or HV network). While some consumers have an HV connection (particularly light industry), most customers (i.e. residential consumers) receive energy after it has been stepped down to low voltage (LV), of 1 kV and under.

The components of a primary substation that CLASS is focused on are the two transformers, its circuit breakers, and the control and communications equipment that needs to be installed:

- The transformers perform the function of stepping voltage up or down. Primary substation transformers are adjustable, in that the number of coils used to control the voltage can be varied by changing the position of contacts known as tap changers. Primary substations contain two transformers for n-1 redundancy, that is, the planning standard to ensure security of supply if one route for power is unavailable,
- Circuit breakers are used to route power through the substation and its transformers, and
- The "control equipment" is any power system electronics that are used to operate the tap changers, or the circuit breakers automatically or remotely.

A high level diagram of these components in a CLASS-enabled substation is provided in Figure 3 below.

Figure 3 Illustration of a Primary Substation (CLASS-enabled)



The additional communications and control systems explored under CLASS allow the operator/NGET a direct link to a number of substations, providing the ability to:

- Monitor status, and performance, of individual substations,
- Open a circuit breaker, to disconnect a single transformer in a primary substation,
- Change the position of tap changers on a single transformer, and
- Change the position of tap changers on both transformers.

The switching and tap changer positioning processes, and the response that they provide are described in more detail below.

2.2.3 Circuit breaker activation

Opening circuit breakers on one of the paired transformers results in a voltage drop across the other transformer, and a resulting drop in power consumption, which can be used as a fast-acting Balancing Service (known as Frequency Response) for NGET.

The trial demonstrated that CLASS-enabled substations could activate this demand reduction within 0.5 seconds, and hold the response for 30 minutes.

In the CLASS trial, the CLASS partners calculated that the overall effect achievable on ENWL's network could be between 180 MW – 540 MW (summer minimum demand – winter maximum demand) for a 10% reduction in voltage. When extrapolated to GB, the CLASS partners calculated an overall effect of 2.4 GW – 6.6 GW (summer minimum demand – winter maximum demand).

2.2.4 Tap changer positioning in parallel

By changing the positions of both transformers' sets of tap changers in the Primary Substation, it is possible to vary the voltage of the network to achieve a reduction in power consumption, which can also be used for Frequency Response, and other products procured by NGET.

As tap changers are not instantaneous in their adjustments, the response to an instruction is slower than opening a circuit breaker. The trial demonstrated that CLASS-enabled substations could vary power consumption within 30 seconds of an instruction, and sustain the change for 30 minutes.

In the CLASS trial, the CLASS partners calculated that the overall effect achievable on ENWL's network could be between 70 MW – 200 MW (summer minimum demand – winter maximum demand) for a 10% reduction in voltage. When extrapolated to GB, the CLASS partners calculated an overall effect of 1.2 GW – 3.3 GW (summer minimum demand – winter maximum demand).

2.2.5 Staggered tap changer positioning

By staggering the tap changers' positions relative to one another, (i.e. setting one tap changer 3 "taps" up, and another three down, for example), the primary substation can generate circulating current around the pair of transformers, which absorbs reactive power. NGET can procure reactive power absorption capabilities to reduce the potential for voltage and thermal constraints.

In the CLASS trial, the CLASS partners calculated that the overall effect achievable on ENWL's network could be between 131 MVAr – 167 MVAr (winter minimum demand). When extrapolated to GB, the CLASS partners calculated an overall effect of 1.44 GVAr – 1.83 GVAr (winter maximum demand).

2.2.6 Communications, monitoring and control

It is also envisaged that under CLASS voltage controllers on Primary Substations would be upgraded, and the collection of data (and exercise of remote control) improved for use by DNOs or NGET. New Voltage Controllers will be able to communicate via existing SCADA (Supervisory Control And Data Acquisition) infrastructure, which will first be captured on a CLASS dashboard system to show the operator the level of CLASS response capability.

An Inter-Control Centre Communications Protocol (ICCP) link will provide NGET with access to real time information on the forecast availability of CLASS enabled substations, in addition to monitoring of performance. It will also provide means for direct control of circuit breakers or tap changers, from NGET's control room.

3 GB Balancing Services markets

3.1 Overview

3.1.1 Balancing responsibilities in the GB market

The GB electricity market is designed so that market participants are responsible for balancing their own positions, but with the SO NGET having ultimate responsibility for the real-time balancing of electricity flows across the GB transmission system. From a regulatory perspective, NGET has the following responsibilities:

- It has an obligation to maintain the system frequency[2] at 50 Hz, +/- 1%, as set out in the Electricity Supply Regulations 1998[3],
- Further, it must operate the transmission system so that it is secured against a fault outage of specific transmission equipment, or the largest loss of power infeed as set out in the Security and Quality of Supply Standard (SQSS)[4], and
- More generally, it is responsible for the coordinating and directing the flow of electricity onto and over the national electricity transmission system in an efficient, economic and coordinated manner under its licence[5].

To perform this role, NGET needs access to energy so that it can address imbalances resulting from forecast errors and unforeseen events (such as a fault on a large generator causing it to shut down), and, in the worst case, enabling NGET to restart the system after a complete black-out. As such, NGET has designed products called Balancing Services to enable it to address these requirements.

3.1.2 What are Balancing Services?

The SO is permitted to procure Balancing Services to fulfil its role as residual balancer, as provided by section C16 of the Standard Licence for Electricity Transmission. Balancing Services are energy and capacity products designed by the SO to balance and coordinate power flows on the GB transmission system. The SO procures balancing services from market participants, (i.e. generators, storage providers, and flexible demand).

Most services are focused on altering active power output from a market participant's planned pattern of production/consumption, either up or down in response to an instruction. They are differentiated by the length of notice required to change output, and the duration of time that the service is required for. However other services also exist to inject or reduce the level of reactive power on part of the transmission network to help NGET manage voltage.

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[2] Frequency is affected by the balance of supply and demand for energy on the system, falling if the system is short on generation, while rising if the system is long

[3] See Electricity Supply Regulations 1988, Regulation 30 (1) part C, and (2).

[4] See SQSS, Chapter 5.

[5] See Standard Transmission Licence Condition C16, paragraph 1

NGET procures services from the market in real time through the Balancing Mechanism (BM)[6], where the provision of some Balancing Services[7] is a mandatory obligation in industry codes.

Alternatively, NGET issues regular tenders for services, signing longer-tenor contracts with individual parties of up to 23 months in length. Occasionally, NGET will bilaterally contract with a Balancing Service provider where the service differs from the standard products.

NGET determines the split of its procurement activities based upon the economics of the bids and offers it receives under each procurement method, but also based upon its assessment of the availability to secure sufficient levels of service going forward. Importantly, Ofgem places an incentive on NGET to encourage it to minimise the cost of its Balancing Services (which are charged to all transmission users as Balancing Services Use of System (BSUoS) charges, and are ultimately passed through to end-consumers).

At present, most Balancing Services are procured from resources within GB, with small volumes being traded between Transmission System Operators (TSOs) across interconnectors. However, the European Network of Transmission System Operators for Electricity (ENTSO-E), under the supervision of the Agency for the Cooperation for Energy Regulators (ACER) has recently finalised a draft of the European Network Code on Electricity Balancing (NCEB), which sets out the target model for the sharing of balancing resources across borders. This Code is currently undergoing comitology, but is widely expected to have been fully implemented by the mid-2020s.

3.1.3 How are products defined?

NGET uses different terminology for products, based upon the ramping speed, duration for which they need to be sustained, the means of procurement, and whether the products are intended for energy balancing or whether they are specific to managing system issues such as network constraints in particular locations.

[6] The Balancing Mechanism is NGET's primary tool for adjusting the positions of operating and standby plant in the market, by accepting bids and offers for decrements and increments respectively.

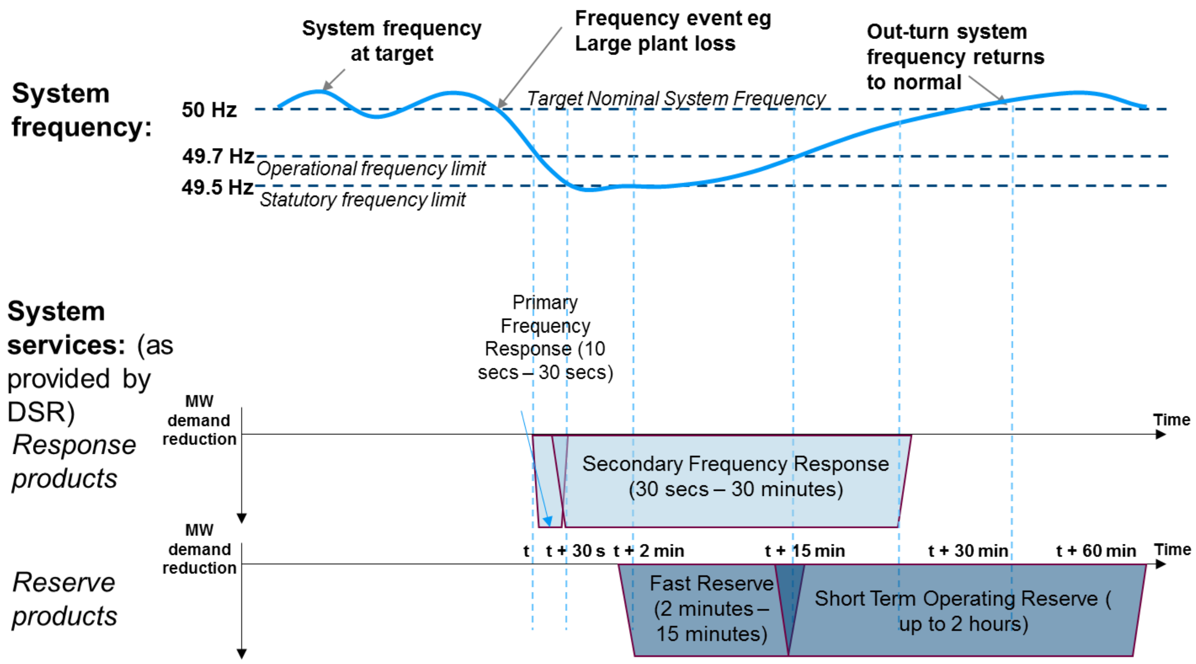
[7] For example, Balancing Mechanism Units (BMUs) must be capable of providing Frequency Response and Reactive Power absorption

Table 1 Summary of all Balancing Services procured by NGET

Name of product procured in the Balancing Mechanism	Name of product procured Forward	Ramping time and duration	Description (written from perspective of a generator)
Mandatory Frequency Response	*Firm Frequency Response*		
Primary	Primary	10 seconds, hold for further 20 seconds	Increase output for frequency containment (Containing the change in system frequency)
Secondary	Secondary	30 seconds, hold for further 29.5 minutes	Increase output for frequency restoration (Restoring the Frequency back to the target 50Hz)
High	High	10 seconds, hold (indefinite)	Decrease output for frequency containment (Containing the change in system frequency)
(No mandatory equivalent)	Rapid (Low and High)	5 seconds, hold for 20 seconds (Low) – indefinite for High	Either increase or decrease output for frequency containment (Containing the change in system frequency)
Non-tendered Fast Reserve	Fast Reserve	2 minutes, hold for 15 minutes	Increase output for replacement reserves (replacing faster Response services to enable them to return to "standby")
Reserve creation (though note reserve creation is held for other services too)	STOR	240 minutes, hold for up to two hours	Replacement Reserves (replacing faster Response services to enable them to return to "standby")
N/A	BM Start-Up	89 minutes, ready for four hours	Starting generators that are otherwise unavailable in the BM and maintaining them in a warm state
N/A	Supplementary Balancing Reserve	89 minutes, ready for four hours	Ensuring there is sufficient generating capacity available to meet the Government's reliability standard
N/A	Demand Side Balancing Reserve	120 minutes, hold for one hour	Ensuring there is sufficient capacity available to meet the Government's reliability standard
N/A	Maximum generation	Generator-specific ramping. Hold for two hours	Instruction to increase generation to mitigate an emergency balancing event

Frequency Response, Fast Reserve, and STOR can be used to overlap with each other, so that slower-responding reserves help to recover the system from an event, in order to restore fastest reacting providers so that they are ready to respond to any further events arising. This is illustrated in Figure 4 below.

Figure 4 Illustration of overlapping Balancing Services managing unexpected imbalance



Other Balancing Services, summarised in Table 2, exist to manage locational constraints (i.e. specific to an area of the network) until the locational constraint is permanently resolved (through network reinforcement, or a long-standing commercial agreement with a local market participant). Because the constraint must be managed locally, NGET is more limited in the market participants from which it can procure these services.

Table 2 Locational Balancing Services

Product	Procurement	Description
Reactive Power	Obligatory (through the Grid Code) and Market-Based for the Enhanced Service	Generation or absorption of reactive power to assist with voltage control
Transmission constraint management	Through the BM, or through bilateral contracts	Increase or reduction in power production/consumption to manage flows around bottlenecks on the transmission network
Intertrips	Operational Intertrips are agreed at the point that a generator is connected, whereas Commercial Intertrips are procured bilaterally as the need arises	Devices which enable the rapid disconnection of a transmission user (normally generation), to be used under specific sequences of events which are either set out in the connection agreement (for an Operational Intertrip) or agreed in contract (for the Commercial Intertrip). Normally used to prevent overload in the event that a fault occurs on the system.
Black Start	Bilateral contracts with generators	In the event of a black-out, NGET has a process for bringing the transmission back online. Black start contracts require generators to be able to self-start in these circumstances, to energise and gradually synchronise their respective network regions.

3.1.4 Focus of this report

CLASS could have the technical capability to perform against a number of the energy and locational Balancing Services listed in the tables above. However, given that one of the key attributes of CLASS is its rapid response and that the trials of the CLASS technology to date have focused on short ramping, short duration Balancing Service products, this report focuses on the following services where the value of CLASS could be greatest:

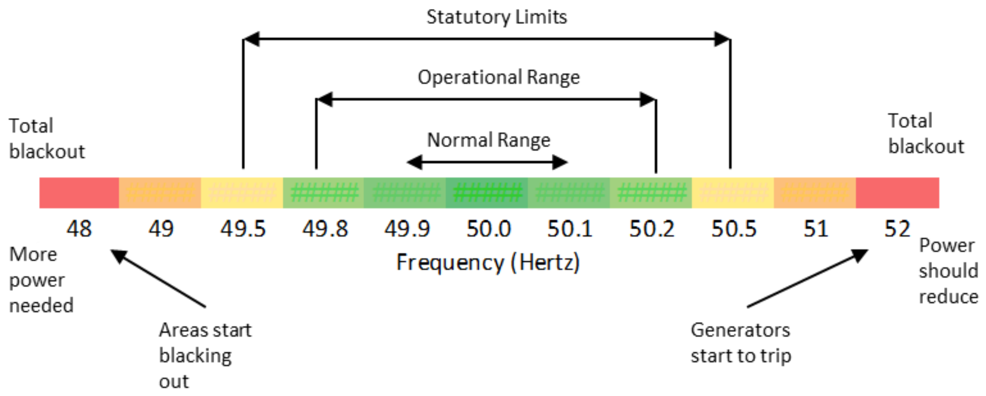
- FFR,
- Fast Reserve,
- STOR, and
- Reactive Power.

3.2 Firm Frequency Response

3.2.1 Purpose of the service

NGET uses Frequency Response for real time control of demand and supply. Providers of Frequency Response are the first port of call for managing unexpected mismatches in the supply and demand balance (e.g. in the event that the system incurs an unscheduled large loss of plant, or unexpected change in demand). The quick response of providers contains the frequency within predefined limits[8]. If the frequency were left to fall, consumers could suffer blackouts. On the other hand, if the frequency were left to rise, generators can begin to trip off of the system.

Figure 5 NGET operating ranges and system behaviour as a function of frequency



Once the change in the frequency is contained (i.e. the rate of change of frequency is slowed or stopped) the focus of the service changes to restore the frequency back to the target 50 Hz. Given the short timescales involved, many providers will be used to both contain and restore the frequency, or will be overlapped by slower-responding services such as STOR.

3.2.2 Product definition

NGET holds FFR as an alternative to the Mandatory Service provided by generators over a certain size. The service is *firm* because, once contracted, it is available to NGET for the duration of the contract, whereas the Mandatory Service is limited by providers' availability, and to an extent, whether the providers are already in a suitable state (i.e. already generating or consuming energy) to provide the service.[9]

The FFR product itself is split by direction of response ("Low" for addressing situations when the frequency is below the target 50 Hz, and "High" for addressing situations when the frequency is above the target), and ramping capability (response time).The Rapid services were introduced in 2014/15. However, there has been limited uptake in these services from existing providers. It is uncertain as to whether NGET will replace Rapid FFR with a new Frequency Response service that is soon to be established (see 3.2.4 for further details).

[8] NGET's Operational limits are +/-0.2Hz, and its Statutory limits are +/-0.5Hz
[9] NGET incurs positioning costs, by accepting bids and offers in the Balancing Mechanism, to ensure that Mandatory providers are in a suitable running state to provide Frequency Response.

It should be noted that while NGET will have specific requirements for Primary, Secondary and High services, it is currently down to bidders to define the bundle of products that they wish to offer (depending on the capability of their plant).

Dynamic vs Static Response

FFR can be provided in one of two ways:

- **Dynamic response**, where providers automatically increase their output in response to changes in frequency around a +/- 0.015Hz deadband, or
- **Static response**, where providers provide their response only when the frequency passes a certain threshold. The level of response provided at this threshold can vary:
  - Some providers will provide a proportion of their response at the threshold (e.g. begin providing output at 49.8Hz, and will gradually step up their response as the frequency deviation worsens (i.e. providing maximum capability by 49.5Hz)
  - Other providers will provide full output once the frequency surpasses a specific threshold.

NGET accepts both dynamic and static response in the Low direction, but only currently requires a dynamic service in the High direction. Of the total Frequency Response requirement, there is a minimum dynamic requirement in the Low direction of around 450MW, and 550MW of High response, although this can vary with time.

3.2.3 Eligibility

Minimum size

Providers of FFR must be a minimum size of 10 MW, but this can be made up of aggregated units. Both Balancing Mechanism Units (BMUs)[10] and Non-BMUs (such as distributed non-licensed generators) are able to participate.

Demand side participation

There has been a considerable effort made to encourage demand side providers of FFR to participate in the market in recent years, given that this could be a lower cost way of providing the necessary response. Two new initiatives have been rolled out to lower barriers to entry and improve clarity and certainty of revenues for DSR providers:

- Frequency Control by Demand Management (FCDM) - a bilaterally negotiated contract open to providers as small as 3 MW, but requiring a faster and longer response (2 second response and 30 minute duration), and
- FFR Bridging Contracts - a mandated-price contract of up to two years in tenor, designed to enable demand-side providers to start with 1 MW, and build an aggregate 10 MW in total so as to participate in the main FFR market. Product definition (i.e. Primary, Secondary, High) is as flexible as the main FFR market.

[10] i.e. those participants registered under the Balancing and Settlement Code and participating in the Balancing Mechanism

Instruction, monitoring and testing

Dynamic providers continuously provide the service with fluctuations in frequency, while static providers provide the service when the frequency moves past an agreed threshold (such as +/-0.2 Hz). Communications equipment is required to provide real-time second-by-second[11] evidence to NGET that the service is being provided.

All providers are subject to testing to demonstrate their response capability ahead of contracting.

3.2.4 Future of the service

Enhanced Frequency Response

In September 2015, NGET announced that it would begin to tender for a new type of Frequency Response with a faster ramp-up time. This product has been named Enhanced Frequency Response (EFR), and has been designed to help to mitigate the challenge of managing frequency with falling levels of inertia on the system (as discussed in NGET's System Operability Framework (SOF) 2015).

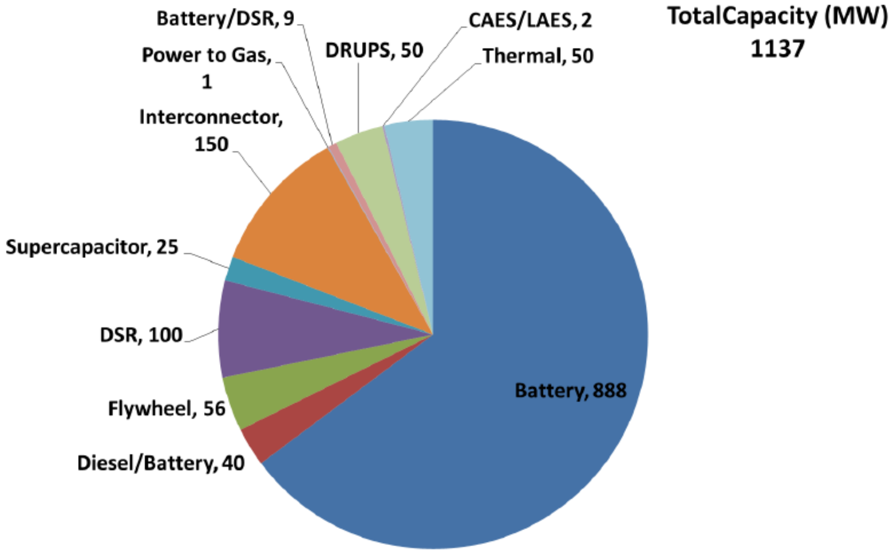
The EFR product is still in the initial design stages. However, emerging contract details suggest that it will be designed as follows[12]:

- Two services will be a procured – "Service 1" and "Service 2",
- It will be a symmetrical product (i.e. both Low and High service will be required),
- Providers must begin producing output within 0.5 seconds of frequency moving outside of a +/- 0.05Hz, or +/-0.015Hz deadband (Service 1 and Service 2 respectively),
- Providers must produce output in proportion to the if the System frequency, reaching full output if the frequency deviates by +/- 0.5Hz from the 50Hz target,
- Providers must be able to sustain the service for at least 15 minutes at max/min output,
- Initial contracts will be for four years, and will be issued to providers who are yet to construct, and
- Penalties will apply for non-availability during nominated windows (where the provider of the service nominates its availability).

The symmetrical directional requirement implies that the EFR product will be suitable for some storage providers such as batteries, mechanical storage devices, and potentially interconnectors, given the fast bidirectional response that these technologies can provide. The expressions of interest received from NGET for the first tender totalled over 1100 MW of capability, broken down between the technologies listed in Figure 6 below.

[11] Or minute-by-minute with second-by-second data to follow.
[12] See NGET, 2015. Enhanced Frequency Response Webinar # 1

Figure 6 EFR expressions of interest by capacity of technology[13]



NGET's initial volume requirement is 200MW, and tenders will be held in mid-2016 for commencement of the service in early 2017. There are indications that NGET will require further enhanced capabilities in the future, as the SOF implies that the Frequency Response requirement may be reduced if enhanced capabilities are used instead.

3.2.4.1 Increasing infeed loss

Outside of the evolution of the product itself, the traditional drivers for the total frequency response requirement are also changing. The overall volumes of frequency response held are proportional to the largest infeed loss on the system which is currently both units of Sizewell B (1,260 MW). However, the largest infeed loss is expected to grow to 1,670 MW when Hinkley C commissions in the mid-2020s. It is feasible for further increases in the infeed loss if Hinkley C is followed by large offshore transmission connections or new interconnectors.

3.3 Fast Reserve

3.3.1 Purpose of Service

Fast Reserve is the quickest of the tendered reserve products, requiring action within 2 minutes of an instruction. NGET describes the product as necessary to manage frequency deviations that arise from sudden changes in generation or demand, for example as a result of "TV pick-ups", unpredictable short-term demand increases (e.g. weather-related), short term frequency control or loss of operational or commercial systems.

[13] National Grid, Enhanced Frequency Response Pre-qualified publication, December 2015.

3.3.2 Product definition

There is only one Fast Reserve product available for tender. However, bidders who have signed up to the Fast Reserve Framework Agreement can also participate in an Optional Fast Reserve product, which is essentially the same product with a slightly different structure.

Table 3 Overview of Fast Reserve product specification

Product	Description
Fast Reserve	▸ Provision of energy within 2 minutes after receiving an electronic instruction from NGET ▸ Ramp-up and ramp-down rate of at least 25MW/minute ▸ Duration of response up to 15 minutes, but normally 2-5 minutes ▸ Required from 0600-2330 Monday-Friday, 0700-2330 Saturday, Sunday and Bank Holidays

3.3.3 Eligibility

Minimum size

Fast Reserve participants must be capable of providing a minimum capacity of 50 MW. Since 2013, it has been possible to meet this requirement with aggregated units. However, there must be a single point of control/communication to take instructions from NGET.

Demand side participation

The Fast Reserve market is open to both generation and demand side market participants, both BMUs and non-BMUs.

Instruction and testing

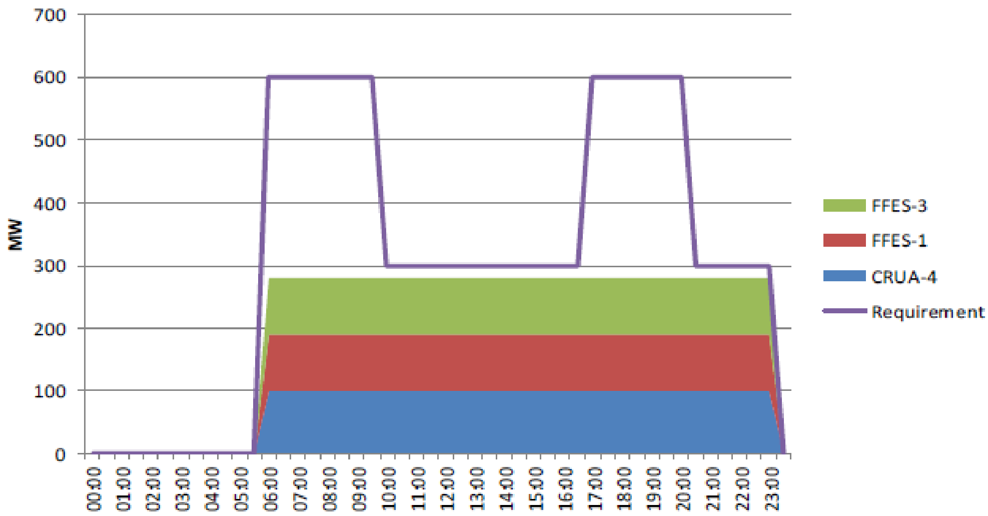
Providers must have the ability to communicate their output on a minute-by-minute basis to provide assurance of service.

As with Frequency Response, Fast Reserve providers must sign a Framework Agreement with NGET where they must demonstrate to NGET's satisfaction that they have the necessary capabilities to provide the service. This can involve pre-qualification assessment tests. Further, at any time after the Framework Agreement has been signed, NGET has the right to request a reproving test to demonstrate continued capability. Failure to pass two tests entitles NGET to terminate the Framework Agreement.

3.3.4 Future of the service

NGET has published its specific requirements from Firm Fast Reserve for 2016, showing a preference for higher levels during morning and evening peaks (as can be seen in Figure 7 below).

Figure 7 Daily Contracted Fast Reserve Position: Mondays - Fridays[14]



NGET has not provided the same level of detail on its expectations for the future of Fast Reserve in the context of inertia and Rate of Change of Frequency (RoCoF) issues. Therefore, it is unclear as to whether its Fast Reserve requirement will grow alongside the reduction in inertia and increase in infeed loss.

3.4 Short Term Operating Reserve

3.4.1 Purpose of service

NGET holds Operating Reserve to manage times when actual demand is greater than forecast demand or there is plant unavailability. As a slower-responding service, it can be used as a second- or third-in-line service to relieve Frequency Response, to restore the responsive capabilities of the system, and to shift load onto lower-cost providers.

Operating reserve can be created through the BM by creating headroom on plant that are already generating energy. However, NGET also procures it forward through STOR.

[14] National Grid, Fast Reserve Market Information, June 2016.

3.4.2 Product definition

The STOR product is defined by the ramping and duration specifications in Table 4 below.

Table 4 Overview of STOR product specification

Product	Description
STOR	▸ Ramp up within 240 minutes of instruction from NGET, (although NGET rarely contracts for longer than 20 minutes, so a sub-20 minute ramp-up is desirable) ▸ Hold for a duration of up to two hours minimum ▸ Have a recovery period of no more than 20 hours ▸ Be able to deliver at least three times per week

NGET contracts STOR throughout the year in thrice yearly auctions, splitting the fiscal year into six STOR seasons of differing lengths. Each STOR season has a set of weekday (WD) and non-weekday (n-WD) diurnal capacity window pairs, where STOR providers must be available to provide STOR capacity if required by NGET.

Table 5 Illustration of STOR Capacity windows, Season 2015/16 [15,16]

		Week Day (WD)		Non-Weekday (n-WD)		Hours/Day type		
STOR Season	**Dates**	**Start Time**	**End Time**	**Start Time**	**End Time**	**WD**	**NWD**	**Total**
1	05:00 on Wednesday 1st Apr 2015 - 05:00 on Monday 27th Apr 2015	07:00	13:30	10:00	14:00	199.5	32.5	232
		19:00	22:00	19:30	22:00			
2	05:00 on Monday 27th Apr 2015 - 05:00 on Monday 24th Aug 2015	07:30	14:00	09:30	13:30	1150	133	1283
		16:00	18:00	19:30	22:30			
		19:30	22:30					
3	05:00 on Monday 24th Aug 2015 - 05:00 on Monday 21st Sep 2015	07:30	14:00	10:30	13:30	276	30	306
		16:00	21:30	19:00	22:00			
4	05:00 on Monday 21st Sep 2015 - 05:00 on Monday 26th Oct 2015	07:00	13:30	10:30	13:30	330	32.5	362.5
		16:30	21:00	17:30	21:00			
5	05:00 on Monday 26th Oct 2015 - 05:00 on Monday 1st Feb 2016	07:00	13:30	10:30	13:30	920	135	1055
		16:00	21:00	16:00	20:30			
6	05:00 on Monday 1st Feb 2016 - 05:00 on Friday 1st Apr 2016	07:00	13:30	10:30	13:30	561	67.5	628.5
		16:30	21:00	16:30	21:00			
				Total Hours		**3436.5**	**430.5**	**3867**

The STOR product is split into 4 sub-products, each of which provides a slightly different service:

[15] STOR Market Information Report, TR 25, Appendix 3

[16] STOR Capacity Windows for Season 2016/17 are included as Annex A

- **Committed STOR –** Committed STOR is the primary STOR product where STOR providers tender to provide capacity during both diurnal STOR windows for a given STOR season.
- **Flexible STOR –** Flexible STOR providers are given the option to opt-out of one, or both of the STOR windows, with STOR providers firming up their position a week ahead of time (available to non-BM plant only). This allows Flexible STOR providers to contract for STOR when it is most profitable for them to do so. For example, Flexible STOR providers can contract for STOR during the STOR season 5 (winter) morning STOR period, and not the afternoon period when other services may be more profitable (e.g. Triad avoidance[17] and peaking services).
- **Premium Flexible STOR –** This is a new service introduced by NGET in Tender Round (TR) 22 (January 2014). The product is similar to Flexible STOR in that providers can choose which STOR windows they will be available in, with the difference being that for providers that tender, and are accepted for set "Premium Windows" (windows which NGET considers to be of greater value) NGET will then commit to accepting 85% of their entire availability payment within that season.
- **STOR Runway –** STOR Runway is another new STOR product introduced in TR25 (January 2015) that is targeted at DSR providers. The aim of this product is to allow DSR to tender for STOR contracts with capacity which they have not yet secured contractually.

  This capacity will be in addition to the capacity contracted for through the main STOR products, and is designed so as not to reduce the capacity procured in the existing STOR products.

3.4.3 Eligibility

Minimum size

STOR providers must have a de minimis capacity of 3 MW, which can be aggregated from smaller sub 3 MW units.

Demand side participation

DSR is able to participate in both the main STOR markets, and in the STOR Runway product, which allows providers to participate ahead of having the contractual arrangements in place with end-load.

Instruction, monitoring and testing

BM providers of STOR are obliged to set their BM bids and offers to match their successful tender parameters in preparation for a STOR window. NGET will dispatch these providers by accepting their bids or offers in the BM, and their performance will be monitored through the Electronic Dispatch Logger (EDL) that BMUs are required to install under the Grid Code.

[17] Triad avoidance is the term used to describe the strategy of distributed generators and DSR to provide output in winter weekday evenings (November – February) in order to assist offtakers reduce their TNUoS bill. Savings are normally shared between the two parties.

Non-BM providers of STOR are instructed to dispatch through the Standing Reserve Dispatch (SRD) mechanism, which is an electronic communications system linked to NGET's control room. This equipment must also be capable of providing minute-by-minute metering of the unit's performance.

NGET can conduct testing during any contracted availability window with 48 hours' notice. Further, in the event that a provider is deemed to not have provided reserve after receiving instruction from NGET, NGET has the right to perform a reproving test to demonstrate that the unit still has the capability to provide STOR, or to proceed with terminating the contract.

3.4.4 Future of the service

In its November 2015 Market Information Report[18], NGET maintains that it typically contracts 2,300 MW of STOR, with around 1800 MW as a minimum. It also explains that the levels of availability provided from different types of STOR providers varies considerably, as shown in Table 6.

Table 6 Availability of different STOR contract types by technology

Technology	STOR contract type	Availability
BMU	Committed	90%
Non-BMU	Committed	85%
Non-BMU	Flexible (non-winter)	50%
Non-BMU	Flexible (winter)	25%

Importantly, NGET is finding that during winter evenings committed units are key to meeting the reserve requirement, as flexible units are often unavailable providing services to other parties. Over the winter of 2015/16, NGET procured "Enhanced Optional STOR" with 300 MW surplus Non-BM plant on a trial basis, to try to resolve this issue. This contract was similar to the Flexible service, except it was only targeted in evening windows, and was not paid an availability fee (only a utilisation fee). It is currently unclear whether this service will continue in future winters.

3.5 Reactive Power services

3.5.1 Purpose of Service

Levels of reactive power on the transmission system vary according to the specific equipment installed in the area; some devices absorb reactive power, while other devices produce reactive power. NGET looks to manage reactive power across the network as it can affect local voltage levels, and potentially cause voltage constraints.

The Reactive Power Service is primarily designed so that generators can produce or absorb reactive power to help to manage system voltages close to the point of their connection.

[18] NGET, 2015. STOR Market Information report TR27.

3.5.2 Product definition

There are two forms of Reactive Power Service:

- The **Obligatory Reactive Power Service**, where generators are required to provide varying Reactive Power output. At any given output the generators may be requested to produce or absorb reactive power to help manage system voltages close to its point of connection. All generators bound by the requirements of the Grid Code are required to have the capability to provide Reactive Power.
- The **ERPS**, which is an optional tendered service for the provision of:
  - Voltage support which exceeds the minimum technical requirement of Obligatory Reactive Power Service (including Synchronous Compensation), or
  - Reactive Power Capability from any other plant or apparatus which can generate or absorb Reactive Power (including static compensation equipment) that is not required to provide the Obligatory Reactive Power Service.

ERPS is not defined tightly as a product, but is simply the provision of enhanced capability over the minimum requirement for the Obligatory service, which is set out in Table 7 below.

Table 7 Overview of Reactive Power Service specification

Product	Description
Reactive Power	▸ Supply rated power output (MW) at any point between the limits 0.85 power factor lagging and 0.95 power factor leading at the BMU terminals ▸ Have a short circuit ratio of the BMU less than 0.5. ▸ Keep the reactive power output under steady state conditions fully available with the voltage range of ±5%. ▸ Have a continuously acting automatic excitation control system to provide constant terminal voltage control of the BMU without instability over the entire operating range of the BMU ▸ Must be able to reach target Reactive Power levels in MVAr within 2 minutes of receiving an electronic instruction from NGET

While the Obligatory service is a Grid Code requirement for compliant BMUs, it is also possible for NGET to procure the Obligatory service from BMUs through its regular tendering process. The differentiation between the two methods is not clear, but the tendered procurement is presumed to provide NGET with certainty that the capability will be available for a certain length of time.

The focus of this section is on ERPS, because this product is theoretically available to participants outside of generators who are signatories to the Grid Code. However, there is little information on whether there has been uptake outside of existing BMUs, and the availability of public information around commercial terms relating to non-generator, non-BMU providers is not as extensive as for the other services.

3.5.3 Eligibility

Minimum size

There is no published minimum size for ERPS provision, although NGET reserves the right to terminate contracts with BMUs if their registered capacity falls below 25 MW. Further, NGET explicitly requests that non-BM providers wishing to compete in a tender make this known to them first.

Demand-side participation

NGET sets out that ERPS is available to demand side participation in addition to generator participation. It also sets out that ERPS can be provided from synchronous compensation or from static compensation equipment, or indeed the provision or enhancement of Reactive Power capability from any other plant or apparatus which can generate or absorb Reactive Power.

While NGET allows substitution of BMUs sharing the same site, it is not clear whether aggregated units across a wide geography would be permitted, given the locational requirement for voltage control.

Instruction and testing

NGET will send providers contracted under ERPS a target MVAr level that sits within the Reactive Performance capability that has been pre-determined between NGET and the provider. While for the Obligatory service this is calculated from reactive power capability at full output using a standardised methodology, the ERPS allows users to specify an alternative level of capability in their tender submission.

NGET uses operational metering data to monitor the level of service being provided by a generator. While there is little mention of testing regimes for ERPS in the public domain, the terms of the Obligatory service allow for NGET to request up to two Reactive tests per year to confirm the unit's capability, and will revise the unit's capability if it is deemed to fail against those values of Reactive Power capability that are currently being used. It is reasonable to assume that such a regime could also apply to ERPS, with the reactive capability either being adjusted or contract withdrawn if a unit is not found to be able to perform above the capabilities of the Obligatory service.

3.5.4 Future of the service

While overall levels of Reactive Power utilisation have reduced in the last decade, in the SOF 2015 NGET sets out that it considered voltage and reactive power management to be a challenge that is likely to escalate significantly in severity in the future, possible requiring an increase in the level of reactive compensation on the system, which could include voltage control from distributed resources such as embedded generation.

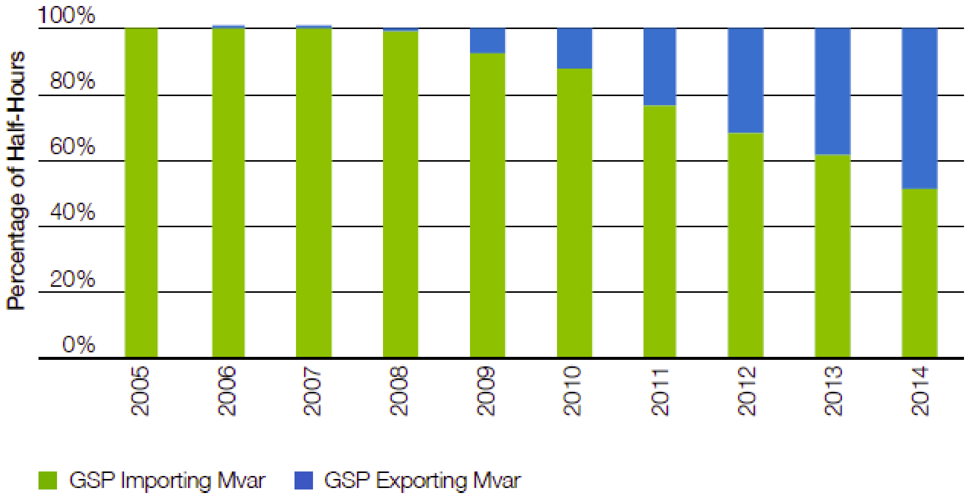
The challenge seems to stem from low reactive power demand on the system itself, which in turn drives high voltages on parts of the transmission system. There does not seem to be a single cause for the reduction in reactive power demand, however, NGET lists the following as potential causes:

- Increasing use of cables in distribution and transmission networks,

- Changes in line loading patterns due to increase in embedded generation, including solar generation, particularly in the South of England,
- Voltage profile management,
- Voltage control asset capability in certain areas,
- Energy efficiency measures (e.g. switch to energy efficient lighting), and
- Changes in load characteristics (e.g. shifts between industrial and domestic loads).

NGET has also observed that Grid Supply Points with DNOs are increasingly exporting reactive power on to the transmission system, whereas before they would typically only import it (as shown in Figure 8 below).

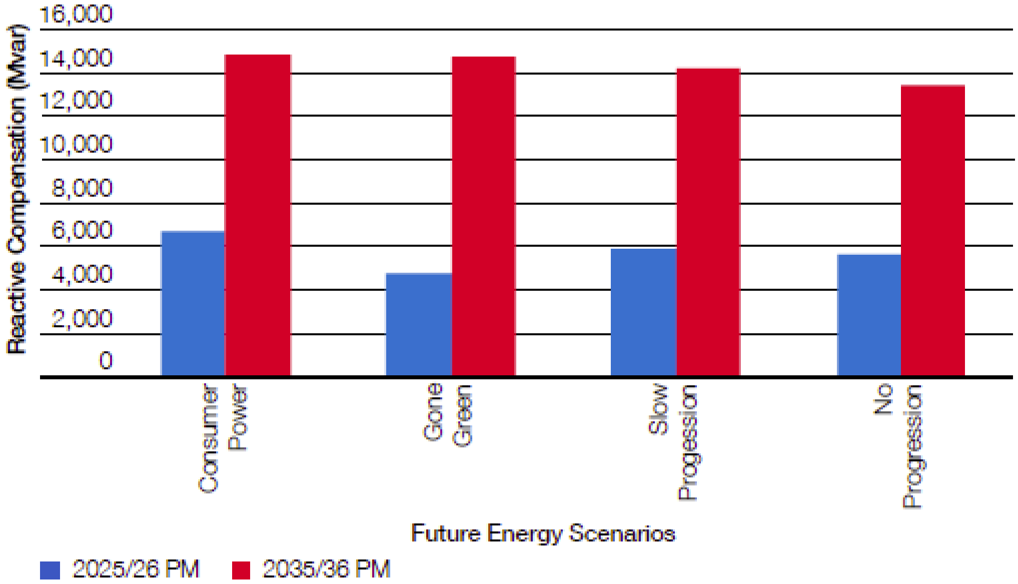
Figure 8 Historic exchange of Reactive Power across GSPs[19]



NGET has had to take increasing numbers of actions to control Reactive Power in the last year, including constraining generation onto the system overnight, when reactive power levels can be at their greatest. NGET expects this trend to continue in all of its Future Energy Scenarios, so that Reactive Power Compensation requirements increase by a factor of two or three compared to current levels by 2025, and by a factor of 5 to 6 in 2035 (see Figure 9 below).

[19] National Grid, System Operability Framework, November 2015.

Figure 9 Reactive compensation required to contain transmission system voltage[20]



NGET sets out that possible mitigation mechanisms could include:

- Increased reactive power compensation on the transmission system
- Distribution System Operator[21] (DSO) services, including:
  - DSR for voltage control via contracting for embedded generation de-loading, or directly to provide reactive power, and
  - Services from the DNOs' network components (transformers tapping, tap staggering, circuit switching, or installation of reactive compensation devices at the DNO network), which would be the mechanism by which CLASS provided this service.

[20] National Grid, System Operability Framework, November 2015.

[21] The DSO is a role widely anticipated for the active management of flows of energy across distribution networks (as opposed to the relatively passive roles that these networks have had to date).

4 Eligibility of CLASS to provide GB Balancing Services

Working assumptions on CLASS' eligibility to provide the Balancing Services are set out as a summary traffic light assessment in Table 8, and in detail in Table 9.

These assessments are based on a comparison of the delivery specifications that were demonstrated by CLASS in the trials, and the service specifications set out in Section 3. Actual eligibility to perform each service will need to be confirmed by NGET at the point at which CLASS providers sign a Framework Agreement for each service (which then enables them to submit bids into forward markets).

Table 8 Eligibility assessment – summary table

Product	Eligibility	Summary
Firm Frequency Response		
Primary (Low)		10 MW de minimis deliverable through aggregation. Technical delivery through switching out a transformer
Secondary (Low)		10 MW de minimis deliverable through aggregation. Service delivery through changing positions of tap changers
High		10 MW de minimis deliverable through aggregation. Service delivery not covered as part of CLASS trial – though tap stagger could unlock a high service at the ramp rates that NGET requires
Fast Reserve		50 MW de minimis deliverable through aggregation. Service delivery through changing positions of tap changers
STOR		Meets 1 MW de minimis. Service delivery through changing positions of tap changers, though erosion of provision from changing baseline, or compensation of equipment working on switched power supplies (for example) may require derating/layering of CLASS to maintain a response for the duration
Reactive Power		Absorption achievable through varying degree of tap stagger. CLASS trials achieved this manually, though working assumption is that this would be deliverable under ICCP control for any roll-out.

Table 9 Eligibility assessment – detailed review

Product	Eligibility assessment
Firm Frequency Response	
Overview	Overall, CLASS appears well-positioned to provide Low Frequency Response to NGET, having a fast ramping ability (well within 10 seconds by disconnecting a transformer, or within 30 seconds by tapping down on a transformer). ENWL is also investigating whether a High service can be provided (which was outside of the scope of the original trial – details of this work are included below). The most pertinent question for the treatment of CLASS in Frequency Response is whether it is treated as a dynamic or static provider. If it is treated as a dynamic provider, then the size of the Frequency Response market available for CLASS to compete in will be larger (and potentially up to the full requirement, depending on the price that CLASS offers). However, if treated as a static provider, then the market is expected to be smaller (between 27% and 60% of the total Primary and Secondary requirement[22], depending on the time of day) because NGET needs to hold a minimum level of Frequency Response as dynamic at all times. This also affects how much of the CLASS capacity is assumed to be able to participate in the Fast Reserve and STOR markets. A pseudo-dynamic form of response may be achievable by configuring the relays that control a CLASS response at different target levels of frequency, so that NGET receives a greater level of response for larger frequency deviations. Baringa understands that such a control system is currently under discussion between ENWL and NGET, but Baringa is unable to confirm how NGET would treat this form of Frequency Response. As such, the Impact Assessment accounts for CLASS being treated as dynamic, or static.
Assessment against eligibility criteria set out in Section 3	**De minimis:** CLASS operators could be able to achieve the 10MW de minimis through aggregation of a number of substations through a central point of control.

[22] Based on the proportion of dynamic reserves comprising the annual primary and secondary requirements, as published by NGET in its report: Firm Frequency Response Market Information, March 2016.

Product	Eligibility assessment
	Instruction, monitoring and testing: CLASS operation could be triggered at different frequency excursion thresholds, including varying the level of response delivered at different thresholds to achieve a pseudo dynamic response as described above. The ICCP link used with CLASS to exchange real-time data, and to provide NGET with control functionality, is a suitable communication means to provide NGET's performance monitoring requirements.
Primary (Low), and Rapid (Low)	A CLASS-controlled substation would be able to provide Primary Frequency Response through disconnecting one primary transformer, as this action can deliver a response within 0.5 seconds of an instruction, and is sustainable for 30 minutes.
Secondary (Low)	A CLASS-controlled substation would be able to provide Secondary Frequency Response through tapping down a primary transformer, as this action can deliver a response within 30 seconds of an instruction, and is sustainable for 30 minutes. Note that it is also possible to provide Secondary Frequency Response through switching out a primary transformer for Primary Frequency (as detailed above) but then leaving that transformer disconnected for a longer duration than required for the Primary service.
High, and Rapid (High)	The provision of High Frequency Response was not a focus area for the original CLASS trial. However, ENWL has since been exploring the ability to provide High Frequency Response through the use of tap stagger, which would enable the disconnection of the transformer operating at a lower voltage, to provide an instantaneous increase in consumption behind the substation.

Fast Reserve

Overview	CLASS appears well-suited to providing the Fast Reserve service, as the two minute ramp time allows for provision of response through either switching out a transformer, or tapping down.
Assessment against eligibility criteria set out in Section 3	**De minimis:** While a higher de minimis than Frequency Response, CLASS will be able to meet the 50MW requirement through aggregation of the service through multiple substations (and whole DNO networks). **Instruction, monitoring and testing:** A group of aggregated substations can be monitored both when in standby, and during

Product	Eligibility assessment
	dispatch, on a real time basis using the ICCP link that was deployed during the CLASS trials.

STOR

Overview	While CLASS can meet the ramp times for STOR through either switching out a transformer, or tapping up or down, the duration of the service of up to two hours may be more challenging to perform consistently against. This is because the level of baseline demand behind the substation could change over the utilisation period (perhaps substantially) which would make measurement of response more difficult. Further, CLASS' performance for long periods may be eroded where voltage changes require certain appliances to work harder for longer, which would also have the effect of changing CLASS' baseline demand. However, to account for these potential performance issues, DNOs and NGET could look to derate CLASS capacity for participation in these longer duration products, increasing the number of substations set aside to deliver a given capacity of STOR capability.
Assessment against eligibility criteria set out in Section 3	**De minimis:** CLASS could potentially meet the STOR de minimis level of 1 MW with one primary substation, or provide a scale service through aggregation. **Instruction, monitoring and testing:** CLASS' ICCP link provides the minute-by-minute information that NGET will need to monitor CLASS either during utilisation, or during a standby state.

Enhanced Reactive Power Service (ERPS)

Overview	The CLASS trial demonstrated that CLASS is able to provide reactive power absorption at the levels of absorption that NGET requires, through the use varying degrees of tap stagger (positioning the transformers' tap changers at different, rather than parallel, tap positions). However the trials found that a greater level of stagger was required than was deliverable by the control equipment used. As the capability has been demonstrated, the working assumption is that the control equipment could be addressed to achieve the level of

Product	Eligibility assessment
	stagger required to meet NGET’s reactive power service requirements.
Assessment against eligibility criteria set out in Section 3	**De minimis:** It is assumed that CLASS operators would agree a level of ERPS with NGET, which is scalable through aggregation (though constrained by the number of primary substations that a CLASS provider has in a certain area, noting that Reactive Power requirements tend to be regional. **Instruction, monitoring and testing:** NGET was able to use the ICCP link to remotely monitor and operate tap stagger on ENWL’s substations during the CLASS trials. It is assumed that this level of communication and control would be sufficient to meet NGET’s communication requirements for ERPS.

5 Baseline service provision

5.1 Introduction

The remainder of this report sets out the expected effect of introducing CLASS into the Balancing Service markets. The underlying assumption we have made for the Cost Benefit Analysis (CBA) is that CLASS can displace some existing Balancing Service providers[23], thereby reducing the cost to NGET, and ultimately to customers through lower use of system charges. These use of system charge reductions can be achieved in two ways:

- Direct savings BSUoS charges – the mechanism that NGET uses to recover the costs of balancing services from market participants, which is passed through to consumers' bills, and/or
- Savings in Distribution Use of System (DUoS) charges, achieved through sharing DNO-generated revenues (in this case, the revenues earned for providing NGET Balancing Services) – as provided for by the Price Control.

Understanding the composition of the underlying supply stack is therefore a critical component of the CBA. This section describes the baseline supply stack for each of the applicable Balancing Services (FFR, Fast Reserve and STOR) in two timeframes:

1. The 2014-15 period is based on historic market information, taking averages over the winter and non-winter periods, and over the daytime and overnight hours.
2. The comparable stacks for 2027 are also shown, which have been constructed using assumptions surrounding the evolution of available providers, asset costs and bidding behaviours; these assumptions are described in Appendix B.

5.2 Frequency Response baseline supply stacks

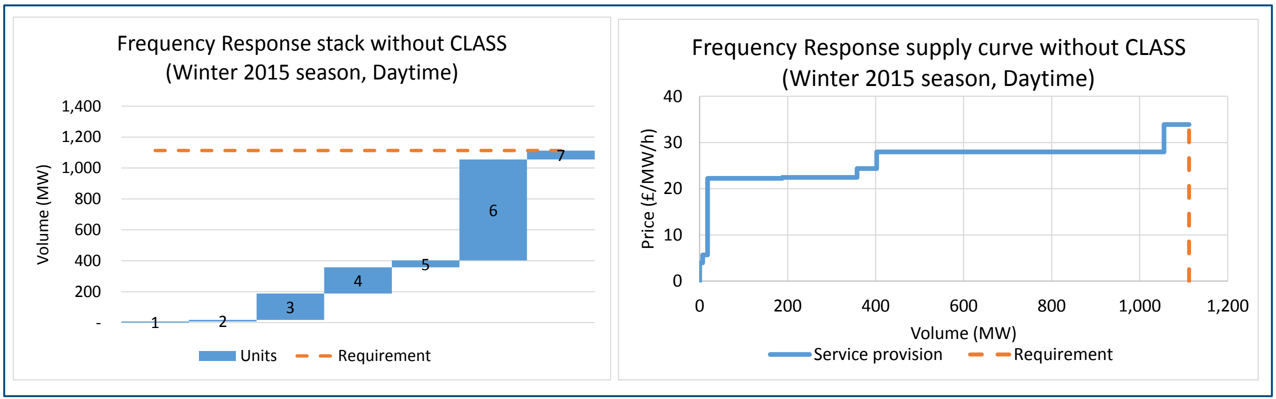
5.2.1 2014-15 baseline supply stacks

As shown in Figure 10, in the daytime period (defined here as being between 7am and 11pm), the 1,110 MW requirement for Frequency Response is predominantly met by mandatory providers (698 MW)[24] and two Pumped Storage units, contributing 340 MW of the 1,100 MW total requirement. The remaining service is provided by a Combined Cycle Gas Turbine (CCGT), and a small amount of lower-cost static response from diesel engines and DSR.

[23] We do not advise using this analysis to assess the effects on specific competitor technology. The use of historic data and some simplifying assumptions have been made to estimate the overall effect of CLASS, but are not appropriate to make judgements about the effect on any given competitor in any given Balancing Service market.

[24] Note that mandatory providers themselves do not receive the full value shown, as this reflects the total cost to NGET, which includes the reserve creation cost, which arises from the need to bring on out-of-merit plant to replace the lost energy from mandatory plant instructed to part load.

Figure 10   Baseline Frequency Response stack (winter 2015 daytime)



In the non-winter period[25], the supply curve is similar, although with some differences:

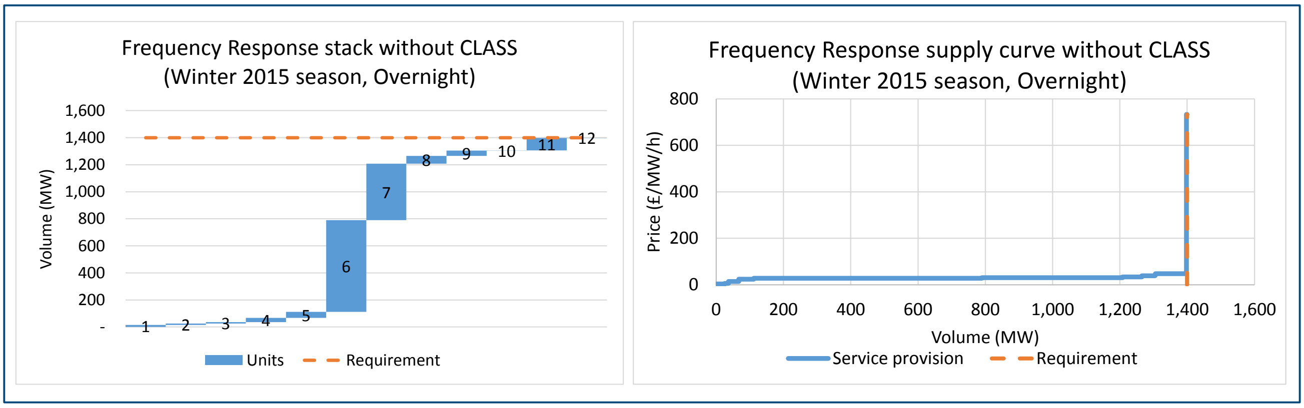
- The DSR provider does not bid,
- A coal plant participates, offering an average of 4.5 MW (this low average reflecting the fact that it only offers volume for a small part of the non-winter season), and
- The NGET requirement is slightly higher, at 1,260 MW, with this additional need being predominantly being met by mandatory Frequency Response providers.

In the winter overnight periods, the Frequency Response stack is more markedly different, including a higher requirement by NGET (1,400 MW) and with an absence of the Pumped Storage units, which only tend to offer into this market during the day.

This shortfall is partly met through additional diesel engines and CCGT generation, but the majority of the overnight requirement is met through mandatory provision. As a result, more expensive mandatory providers need to be used, thereby driving up the cost of this service. For a small number of periods, the cost of this provision can exceed £50/MW/h for the most expensive generator, although because this only occurs rarely the average volume is small.

[25] For reasons of brevity the stacks and supply curves for the non-winter periods are not shown in this section since they are not materially different from the winter periods. However, these can be seen in the tool published alongside this report.

Figure 11 Baseline Frequency Response stack and supply curve (winter 2015 overnight)



Again, in the non-winter period the requirement and stack is similar to the winter period, with a coal plant participating for a short period, averaging 4.5 MW.

5.2.2 2027 baseline supply stacks

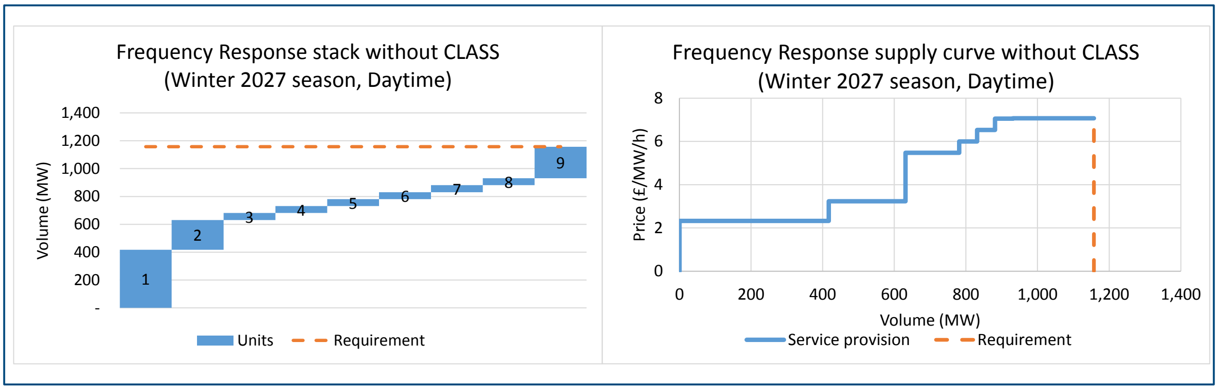
Whereas the 2014-15 stacks were based on actual historic data, the comparable stacks for 2027 are projections based on assumptions about available providers, technology costs and future bidding strategies. This rationale is explored in detail in Appendix B, but in this section the stacks that emerge from those assumptions are described.

Note that we have made no attempt to distinguish between Firm and Mandatory provision of Frequency Response in this timeframe. In part this is because there is no sound basis on which to make such a distinction. However, it may also be reasonable to assume that, with the increasing availability of low-cost FFR providers, the economic case for holding large volumes of thermal plant in the Mandatory service becomes weaker.

As Figure 12 shows, the 2027 provision of Frequency Response is from four technology types:

- Pumped storage, which is assumed to be drawn from the existing fleet, rather than new plant; the bid price is assumed to have been reduced from current levels in order to compete with the new-entrant technologies,
- DSR, which is based on the existing levels of provision with an additional 50MW being made available each year until 2027,
- Battery storage, which is new-build and hence is aiming to recover its LRMC; newer plant benefits from reduced capex, based on the steep learning curve assumed for battery technologies, and
- Diesel engines, which are also attempting to recover their LRMC.

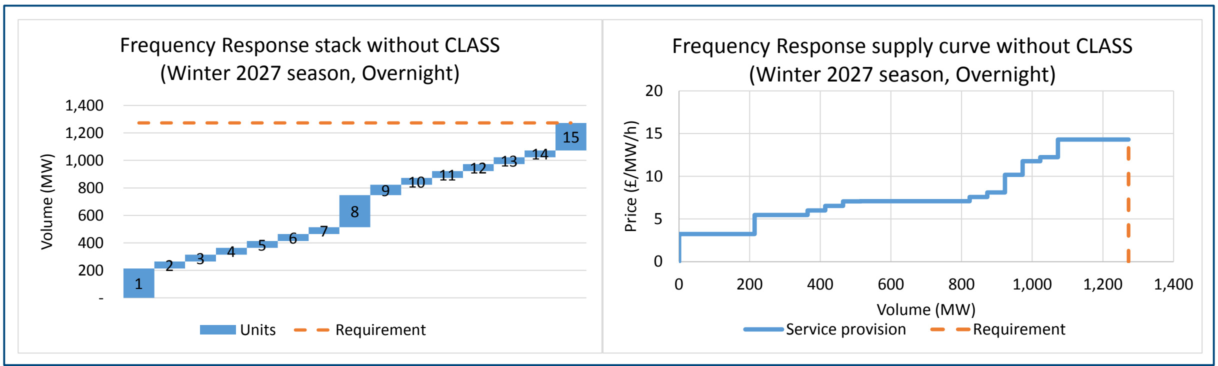
Figure 12 Baseline Frequency Response stack and supply curve (winter 2027 daytime)



During the overnight periods, as was the case in 2014-15, we have assumed that Pumped Storage units do not export. However, we make no other distinction between the daytime and overnight periods in 2027.

As shown in Figure 13, the absence of Pumped Storage results in the use of more diesel engines, older (and hence more expensive) batteries, CCGTs and interconnection. This increases the prices in the overnight period, but again the competitive pressure is assumed to drive bids down either to the plants' LRMC, or to the opportunity cost of participating in the wholesale market.

Figure 13 Baseline Frequency Response stack and supply curve (winter 2027 overnight)

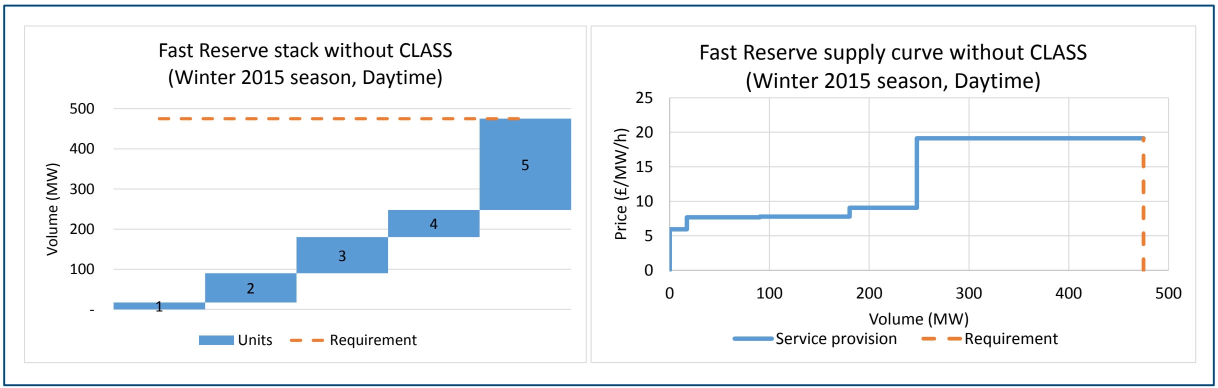


5.3 Fast Reserve baseline supply stacks

5.3.1 2014-15 baseline supply stacks

The tendered market for Fast Reserve is made up of only Pumped Storage units, offering the service at a price of £5.9-9.1/MW/h. However, almost half of the NGET 475 MW requirement for Fast Reserve is met through the non-tendered service. The units participating in this non-tendered service are not declared publicly, so we have used the total cost and volume faced by NGET for procuring non-tendered services to create a proxy "non-tendered" unit. Note, that this is likely to result in a conservative estimate of the benefit of CLASS, at least for small volumes, since there is expected to be some shape within this market, and it would be the more expensive providers who are displaced first.

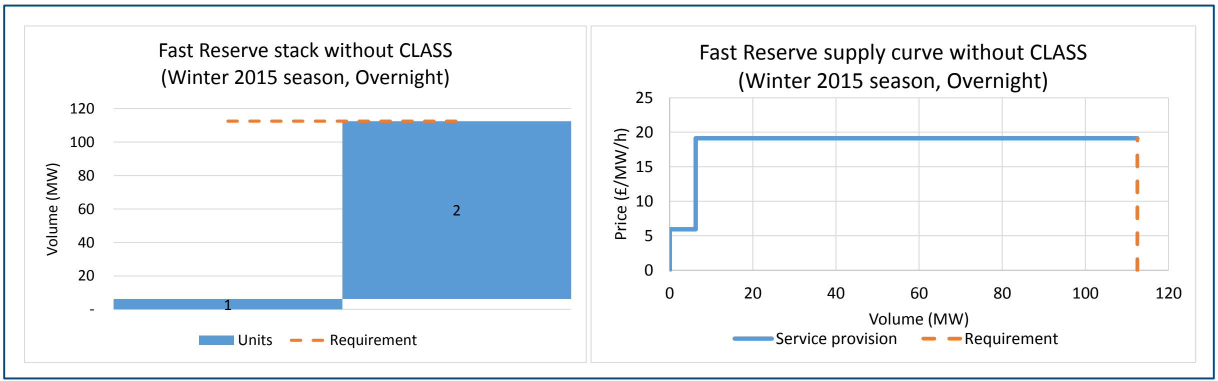
Figure 14 Baseline Fast Reserve stack and supply curve (winter 2015 daytime)



In the non-winter period, the same providers are seen in the Fast Reserve, with one additional Pumped Storage unit being offered. However, the average capacity from the tendered market across this season is higher, and the requirement is lower, meaning that only 46 MW of non-tendered service is required.

The requirement for Fast Reserve in the overnight period is significantly reduced, with NGET's stated requirement averaging only 113 MW. However, there is little or no Pumped Storage provision in this period, as shown by Figure 15. The listed Pumped Storage unit has a capacity of 100 MW, but is offered from 6am and until 11.30pm, which includes some "overnight" hours, hence the small non-zero contribution to this service when averaged over the period. A similar mix is seen in the non-winter season.

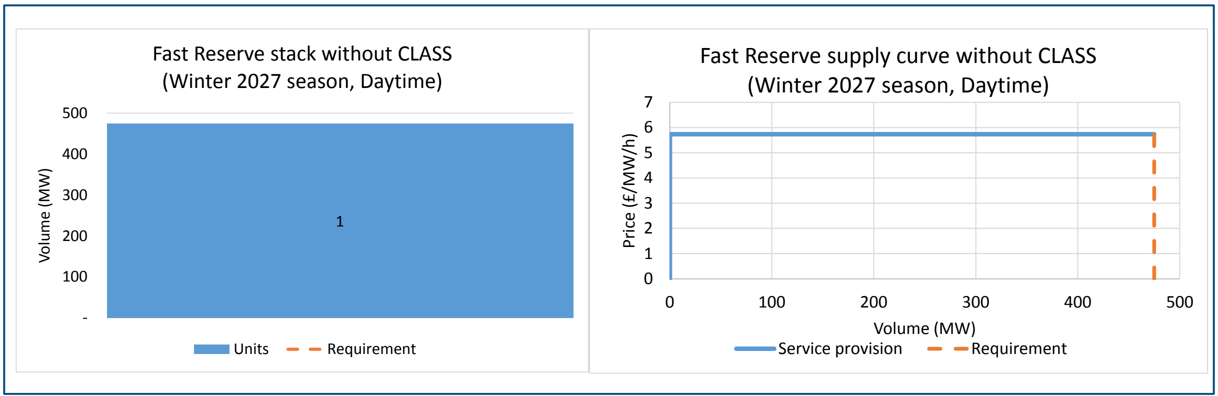
Figure 15 Baseline Fast Reserve stack and supply curve (winter 2015 overnight)



5.3.2 2027 baseline supply stacks

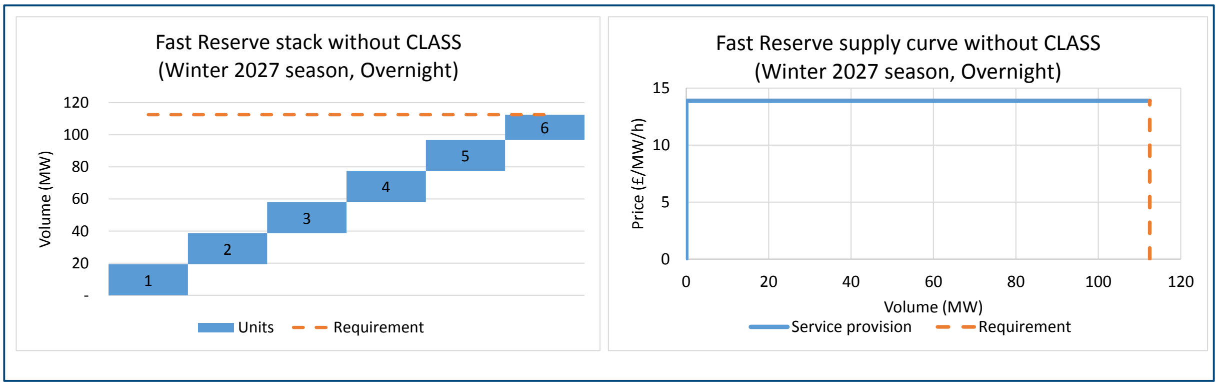
As in 2014-15, the 2027 Fast Reserve stack is dominated by Pumped Storage in the daytime hours of both seasons, albeit at a lower price because of competition from new-entrant technologies.

Figure 16 Baseline Fast Reserve stack and supply curve (winter 2027 daytime)



In the overnight period, we again assume that Pumped Storage do not operate, providing an opportunity for those competing technologies. In this case NGET's overnight requirement (for both seasons) is met through gas engines.

Figure 17 Baseline Fast Reserve stack and supply curve (winter 2027 overnight)



5.4 STOR baseline supply stacks

The STOR market is more complicated than Frequency Response or Fast Reserve in the sense that plant are accepted and prioritised based on both their availability and their utilisation bids. Plant will attempt to recover their costs through the combination of availability and utilisation payments, but because NGET will dispatch STOR plant with the lower utilisation costs more frequently, there is a complex relationship between the bids and revenues. For example:

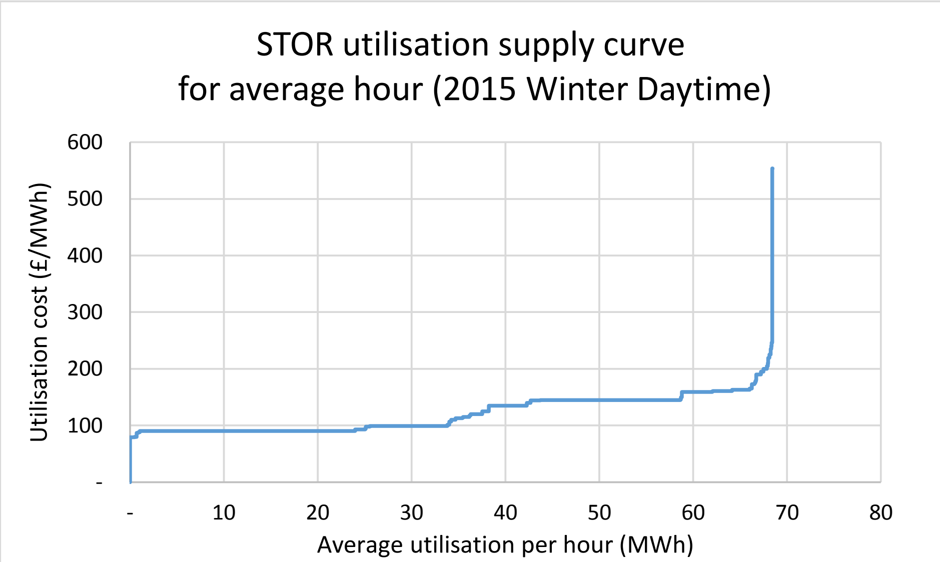
- A plant with a high Short Run Marginal Cost (SRMC) may bid a correspondingly high utilisation price, but will then expect to be utilised rarely and hence may need to offer a relatively high availability price, particularly since its utilisation volumes will be highly volatile, but
- A plant with low LRMC can offer a low utilisation price, resulting in high expected utilisation, and can then offer a low availability price.

5.4.1 2014-15 baseline supply stacks

For 2014-15 the publicly available information does not disaggregate availability bids by plant, so we have taken an average figure based on the overall availability volume and cost to NGET. In winter this is £3.26/MW/h, whereas in the non-winter period this increases to £4.20/MW/h.

Because the assumed availability fee is flat across all providers in 2014-15, we assume the supply curve is based only on the utilisation bids. The resulting supply curve for the daytime[26] winter period is shown in Figure 18. A similar curve exists for the non-winter period.

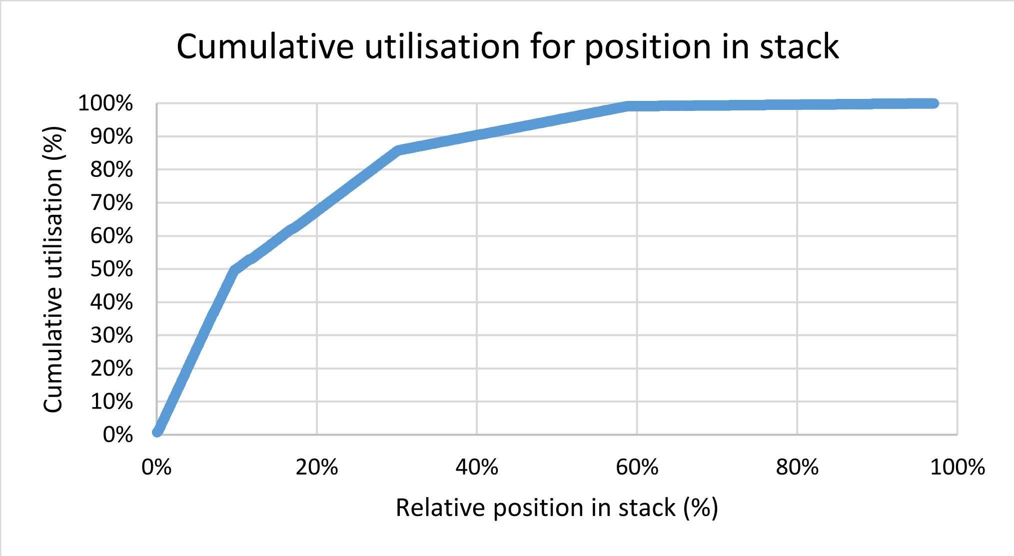
Figure 18 Baseline STOR utilisation supply curve (winter 2015 daytime)



As Figure 19 shows, in 2014-15 the cheapest 10% of plant provides 50% of the total utilisation requirement, and the cheapest 40% provides 90% of the requirement. This indicates that even a moderately high utilisation bid will result in very low levels of utilisation in the STOR market.

[26] Note there is no overnight requirement for STOR

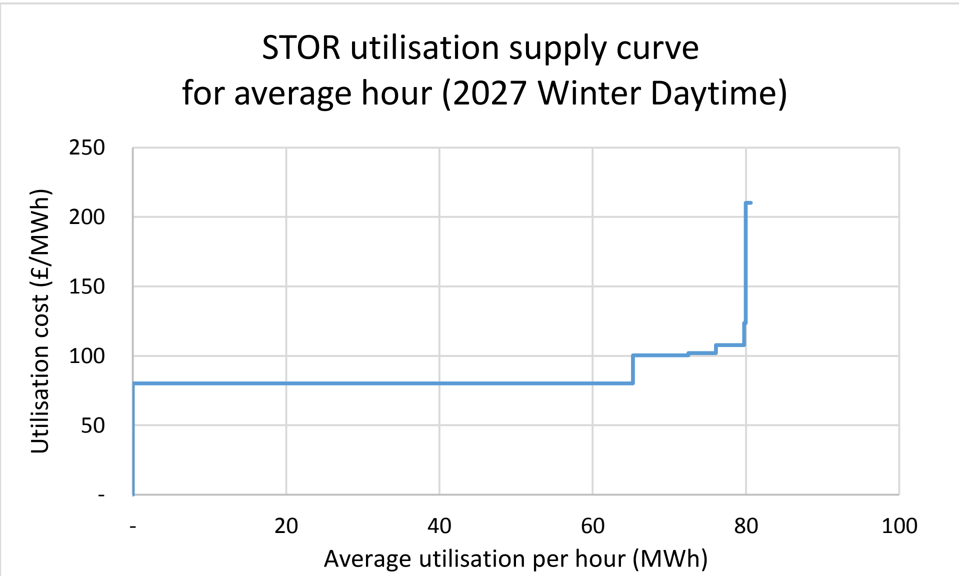
Figure 19 Relationship between utilisation price and utilisation volume in 2014-15



5.4.2 2027 baseline supply stacks

For 2027 the STOR stack is based on the underlying technology cost and bidding strategy assumptions discussed in Appendix B. It is assumed that plant set their utilisation bid equal to their SRMC, and then use their availability bid to recover either their LRMC or any opportunity costs incurred from not participating in the wholesale market. This results in the utilisation supply curve shown in Figure 20.

Figure 20 Baseline STOR utilisation supply curve (winter 2027 daytime)



6 CLASS single-year impact assessment

6.1 Approach overview

This section of the report assesses the overall impact of CLASS participating in the market for Balancing Services. This assessment is performed both in the current market structure (from the 2014/15 full year of balancing services results), and in a future scenario (2027), where NGET's requirements have changed, and where the stack of providers has a different composition from currently.

This section focuses only on the quantifiable impacts of introducing CLASS into the Balancing Service markets. The underlying assumption is that CLASS displaces the most expensive existing providers of those services, and that once displaced these providers no longer operate. In reality, these providers may change their bidding strategy or enter into other markets, in which case the impact of CLASS will be mitigated to some extent. These dynamics are explored in Section 8.

In this section, the benefit of CLASS is given in terms of reduced Balancing Service costs. The net benefit to the different stakeholders (NGET, DNOs and end consumers) is in part a function of the price at which CLASS is offered into the Balancing Service markets of CLASS is given under a range of pricing strategies. This section considers the effect of offering CLASS under what we consider to be the two extremes:

- **LRMC pricing:** DNOs offer CLASS at a cost that allows them to recover their initial capex and ongoing opex assuming a regulated Weighted Average Cost of Capital (WACC) and discount rate, and
- **Shadow marginal pricing:** DNOs offer CLASS at the volume-weighted average price of the firm Balancing Service providers that they would be displacing[27].

However, as discussed in Section 5, the apportionment of those benefits to the different stakeholders (NGET, DNOs and end consumers) is not only a function of price, but also of the regulatory treatment of the resulting revenues under the DNO and NGET price controls. Because these are calculated over multiple years it is not meaningful to consider the distribution of costs and benefits on the basis of a single-year snapshot. This distributional analysis, therefore, is revisited in more detail in Section 7 where the multi-year effect of CLASS is analysed.

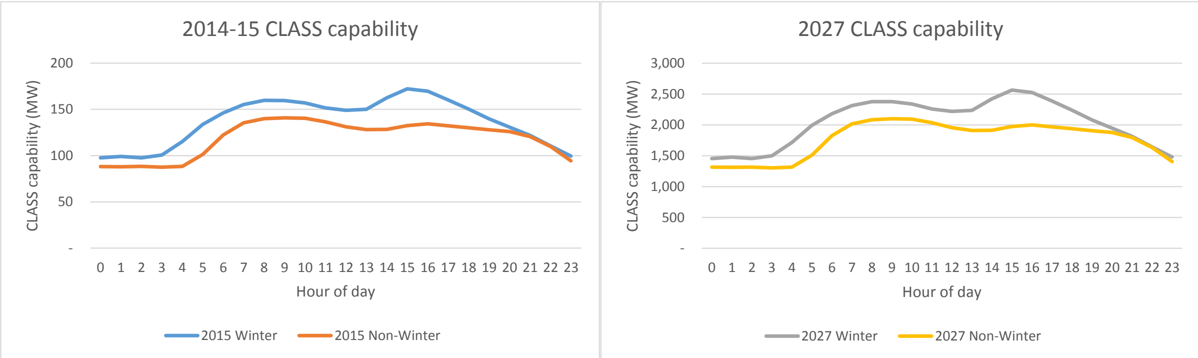
The remainder of this section includes Section 6.2, which describes the contribution CLASS can make to each of the Balancing Services markets, and Section 6.3 which describes the impact of this contribution on those markets in the chosen spot years.

[27] Note that this is not intended to describe a bidding strategy for a DNO. Rather it is intended to show the maximum average price that a DNO or DNOs could achieve given the bids of competitor providers. In the case of large volumes of CLASS, this pricing strategy implicitly bids CLASS as a single block priced at the average of the displaced providers. In reality, this may only be achievable if CLASS volumes can be subdivided and bid in at different prices, as may be the case when multiple DNOs offer CLASS independently.

6.2 CLASS capability

In the short-term it is assumed that 200 MW of peak CLASS capability will be deployed, so this figure is used as the basis of the 2014-15 impact assessment. By 2027 it is assumed that 3,000 MW of peak CLASS capability could be deployed. The capability at any specific period in time will be lower than this maximum level, since capability varies as a function of the underlying demand. We have based the de-rating profile on those observed in the CLASS trials. Figure 21 shows the estimate capability for the two years considered, split by season and by time of day.

Figure 21 CLASS capability in 2014-15 and in 2027



We have assumed that CLASS is offered as four products covering daytime and overnight hours for the winter and non-winter seasons, which is consistent with the approach taken by a number of existing Balancing Service market participants. When offering CLASS to NGET a DNO needs to be confident that it can deliver the full offering over the specified period. As a result, we assume that the volume of CLASS offered in each of these periods cannot exceed the minimum CLASS capability in that period. The volumes offered are therefore lower than the theoretical capability at any given point in time, as shown in Figure 22 and in Table 10.

Figure 22 Assumed CLASS offering in 2014-15 and in 2027

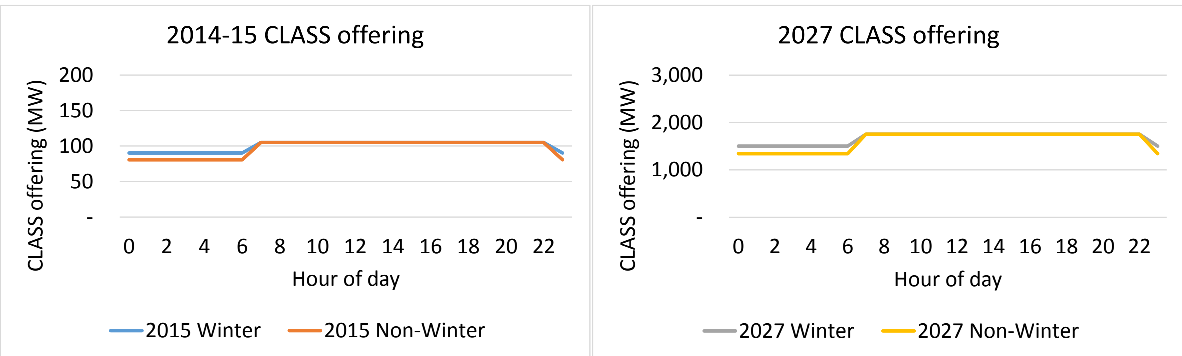


Table 10 Assumed CLASS Balancing Service offering in 2014-15 and in 2027

	2014-15	2027
Winter daytime	105 MW	1,753 MW
Non-winter daytime	105 MW	1,752 MW
Winter overnight	90 MW	1,503 MW
Non-winter overnight	81 MW	1,342 MW

6.3 Single-year impact of CLASS

6.3.1 Deriving the optimal strategy

This section assesses the effect of the expected CLASS capability has on the Balancing Services market. It assumes that:

- CLASS will displace the most expensive providers in a service first, and
- A given unit of CLASS cannot participate in Frequency Response, Fast Reserve and STOR simultaneously, so must be apportioned between these services.

For the 2014-15 analysis the volume of CLASS available is less than the total requirement for Frequency Response. Since this is the most valuable service, we assume that all of the CLASS capability is offered into the Frequency Response market.

By contrast, the volumes in 2027 exceed the requirement for any one service, so volumes are distributed across Frequency Response, Fast Reserve and STOR. Note that because CLASS has only be proven to deliver DSR for relatively short periods[28], in order to deliver STOR for the timescales required by NGET we assume that the CLASS provider would need to cycle through multiple substations. To reflect this, any STOR volume is derated by 50% (e.g. in order to deliver 100MW of STOR, 200MW of CLASS capability must be used). NGET's requirement for each service, and the assumed offering by CLASS is summarised in Table 11.

[28] It may be that CLASS is capable of longer-term response without the impact on demand eroding over time, and that this can be adequately measured, but we are being conservative in our assumptions at this stage.

Table 11 NGET Balancing Service requirement and assumed CLASS offering

MW		2014-15				2027			
		Winter Daytime	Non-winter Daytime	Winter Overnight	Non-winter Overnight	Winter Daytime	Non-winter Daytime	Winter Overnight	Non-winter Overnight
Requirement (MW)	Response	1,113	1,263	1,400	1,400	1,157	1,313	1,273	1,273
	Fast Reserve	475	425	113	150	475	425	113	150
	STOR	2,341	2,160	-	-	2,650	2,446	-	-
CLASS offering (MW)	Response	105	105	90	81	1,157	1,313	1,273	1,273
	Fast Reserve	-	-	-	-	475	425	113	70
	STOR	-	-	-	-	60	7	-	-
	Total	**105**	**105**	**90**	**81**	**1,753**	**1,752**	**1,503**	**1,342**

6.3.2 2014-15 impact assessment

6.3.2.1 Impact of displacing existing Frequency Response providers with pseudo-dynamic CLASS

As discussed in Section 4, there is an ongoing discussion over whether CLASS should be treated as a static or a pseudo-dynamic Frequency Response provider. If the latter, CLASS can displace any existing Frequency Response provider without adversely affecting NGET's Minimum Dynamic Requirement (MDR). However, if CLASS is deemed to be a static provider, it can only displace dynamic provision above the MDR, and otherwise can only displace other static providers. A similar discussion is being held over whether CLASS can provide High Frequency Response within the Primary timescales – a capability that was not investigated during the CLASS trials. In this first section we assume that CLASS is pseudo-dynamic and is capable of providing the full set of Frequency Response actions, but the impact of restricting CLASS to static, non-High provision is described in Section 6.3.2.2.

During the daytime hours, the majority of the Firm service is provided by Pumped Storage, but there is still a significant amount of Mandatory provision that is more costly to NGET. Thermal generation makes up the most expensive Firm provision. It is therefore these thermal plants and the more expensive mandatory providers that are displaced by CLASS, with the resulting effect shown in Figure 23 and Figure 24.[29]

[29] Note that these charts illustrate the effect of CLASS being bid under LRMC pricing, but the impact on displaced plant is unchanged if a marginal pricing strategy is assumed since in both cases the price is sufficiently low to justify NGET choosing CLASS over these displaced providers.

Figure 23 2014-15 CLASS in Frequency Response market (winter daytime)

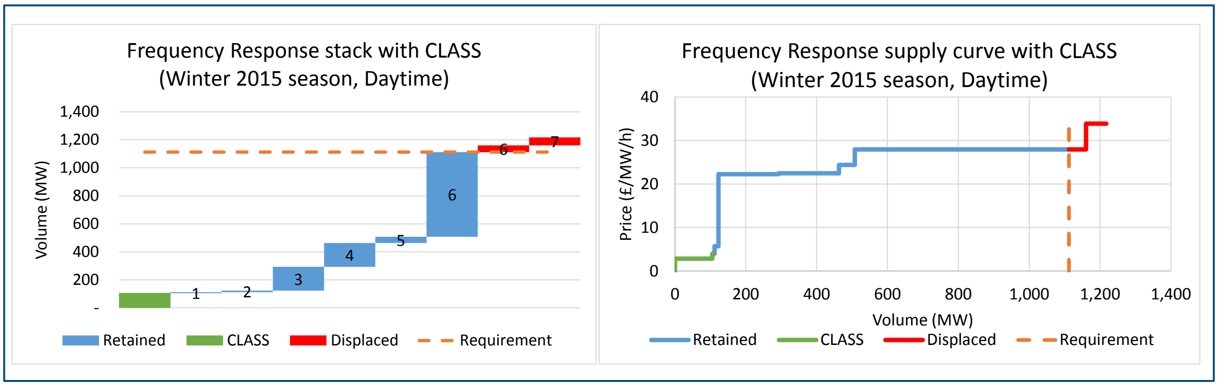
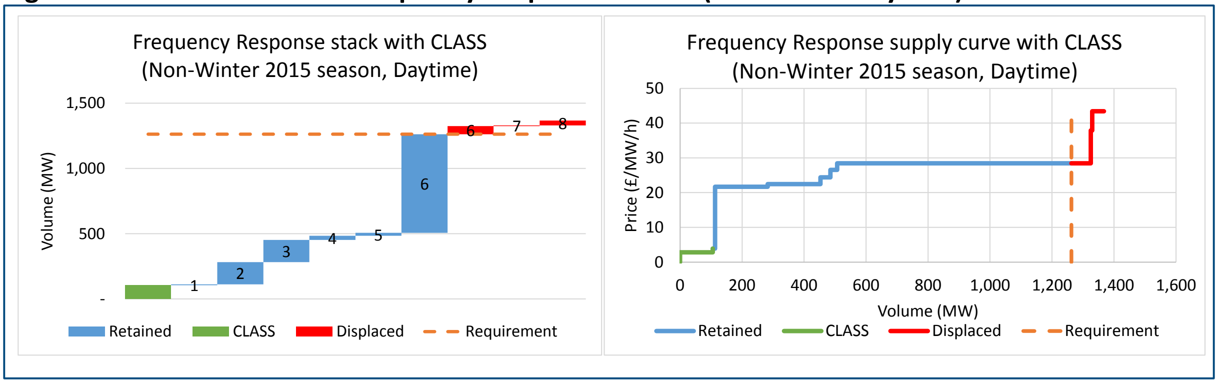


Figure 24 2014-15 CLASS in Frequency Response market (non-winter daytime)



In the overnight periods, the most significant difference is that the Pumped Storage units are not participating in the market. There is some more participation by low-cost DSR and diesel providers, but these are unaffected by CLASS. As Figure 25 and Figure 26 show, the majority of the displaced volume is from the mandatory market, which includes more costly providers than were observed during the daytime hours. In addition, the more expensive CCGT and coal units are displaced by CLASS.

Figure 25 2014-15 CLASS impact on Frequency Response market (winter overnight)

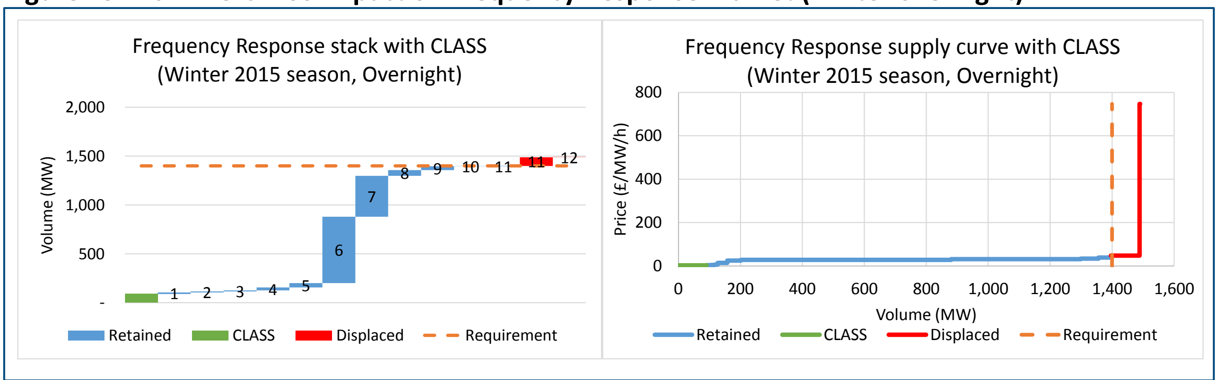
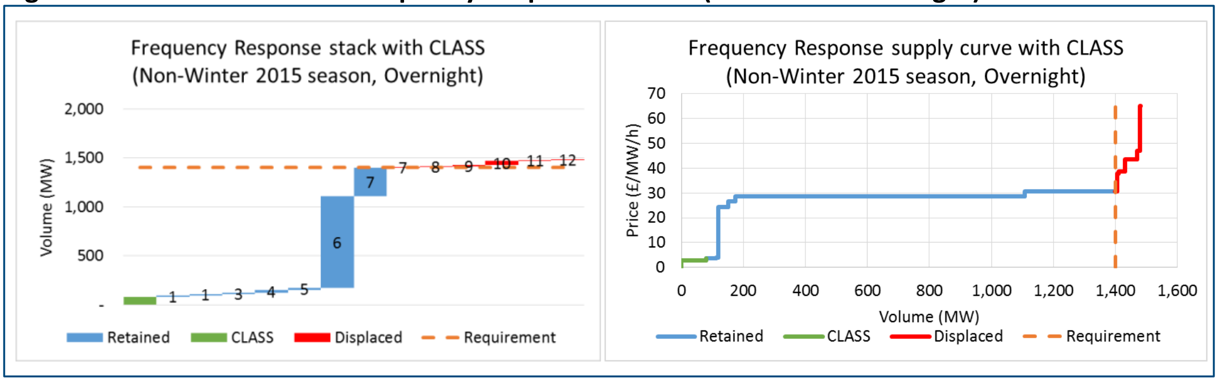


Figure 26   2014-15 CLASS in Frequency Response market (non-winter overnight)



The cost associated with those existing providers displaced from the Frequency Response market amounts to £32.2m in 2014-15. The LRMC of CLASS is estimated to be £2.4m, resulting in a net benefit of £29.8m, which can be allocated in at least two ways:

- Under a LRMC bidding strategy the benefit accrues to NGET and BSUoS customers through lower Balancing Services costs, or
- Under a marginal pricing strategy the majority of the benefit (£27.5m) would accrue to the DNO and DUoS customers (before being shared with consumers), with only £2.3m accruing to NGET and BSUoS customers.

Note that in this section we do not describe the way in which Balancing Service reductions are shared between NGET and BSUoS customers, or the way in which DNO revenues are shared with DUoS customers. This is because to calculate these properly it is necessary to apply the regulatory treatment to the costs and revenues of over multiple years. For this reason, this calculation is done in Section 7, where we consider the multi-year effect of CLASS.

6.3.2.2 Impact of displacing existing Frequency Response providers with static CLASS

As discussed above, the ability of CLASS to displace dynamic and High Frequency Response providers is limited if CLASS itself cannot provide pseudo-dynamic and High response. However, in 2014-15 the volume of CLASS is relatively small, and NGET appears to be over-procuring dynamic and High Frequency Response. As a result, there is no difference between the pseudo-dynamic High case and the static non-High case in this year.

6.3.2.3 Other quantified 2014-15 costs and benefits

Whilst the primary benefit of CLASS in our 2014-15 scenario would come from displacing the most expensive existing providers of Frequency Response, CLASS has a number of other costs and benefits, which are summarised below:

- **Reactive Power:** As described above, CLASS may be able to provide reactive power absorption to NGET, but this will be dependent on NGET's local requirement for the service. The Reactive Power capability of CLASS over 2014-15 is estimated to be 694 GVArh, with a maximum value of £1.78m, apportioned between the DNO and NGET depending on the pricing strategy. However, it is expected that only a proportion of that capability could be useful to NGET given this locational need.

- **Carbon reduction:** Using thermal plant to provide frequency response is carbon intensive for four reasons.
  1. The provision of either Mandatory or Firm frequency response from thermal plant requires part loading which leads to lower efficiency
  2. Part loading these plant requires utilisation of out of merit capacity, which also tends to be lower efficiency. In some cases, this plant too will be part-loaded, which further increases carbon intensity.
  3. Mandatory plant that would otherwise participate in the wholesale market is turned down, meaning that it is operating at lower efficiency.
  4. Utilisation of thermal plant has associated carbon emissions.

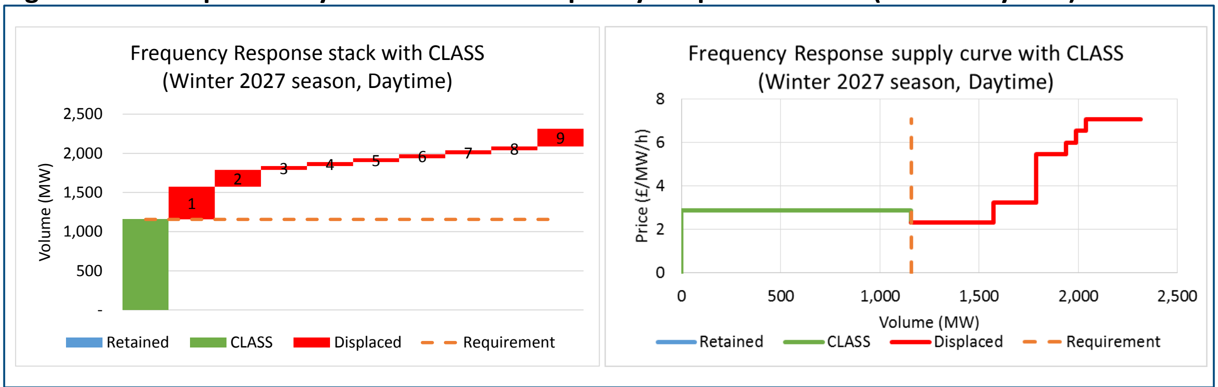
  By reducing the need for thermal plant in the Firm and Mandatory Frequency Response, we estimate that 28,000 tons of carbon emissions are avoided annually, with a value of £168k[30].
- **Customer Minutes Lost:** In order to provide Frequency Response, CLASS requires that some transformers be tripped, reducing the n-1 redundancy of the system. How often this happens depends on the way in which CLASS is used, but assuming an average of 98 MW of CLASS across the year, that 5% of substations are in a trip state at any one time, using historically-observed network failure rates (3.5% per circuit per year) and assuming a post-fault recovery time of 3 minutes (to reclose the affected transformer) this corresponds to 0.0086 MWh/year. At Ofgem's Value of Lost Load (£6,000/MWh), this corresponds to a cost of just £51.

6.3.3 2027 impact assessment

6.3.3.1 Impact of displacing existing Frequency Response providers with pseudo-dynamic CLASS

In this section we assume that CLASS is pseudo-dynamic and is capable of providing the full set of Frequency Response actions (the alternative view is considered in Section 6.3.3.2). Assuming that NGET is willing to have CLASS provide 100% of the Frequency Response service, all other providers could be displaced, including Pumped Storage, DSR, batteries and diesel engines, as shown for the winter daytime period in Figure 27. A similar effect is seen for the non-winter daytime period.

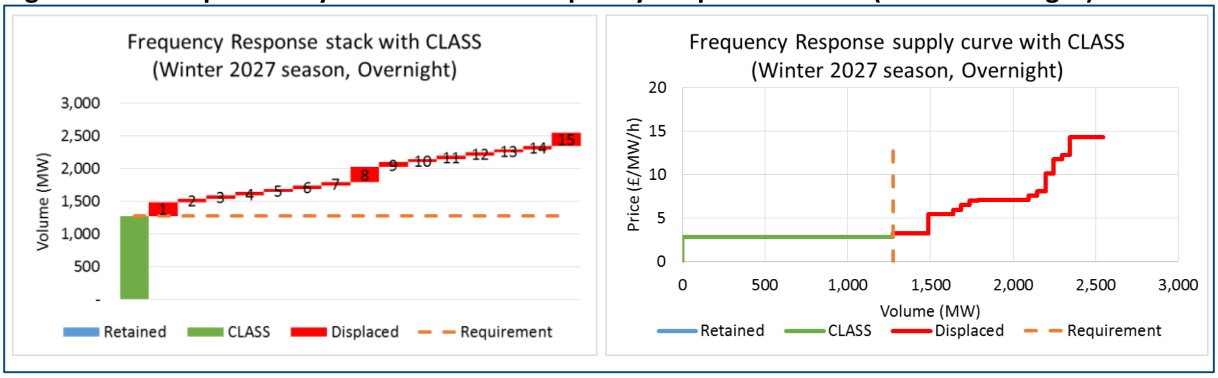
Figure 27 2027 pseudo-dynamic CLASS in Frequency Response market (winter daytime)



30 Based on DECC Updated energy and emissions Projections – CO_2 price for electricity sector

Overnight, because Pumped Storage does not participate, CLASS displaces a wider range of technologies, including DSR, batteries, diesel engines, CCGTs and interconnection.

Figure 28 2027 pseudo-dynamic CLASS in Frequency Response market (winter overnight)



Assuming CLASS is a pseudo-dynamic, "High" provider it can displace £63.3m in 2027 at a cost of £31.8-63.2m to NGET depending on the pricing strategy, resulting in a net saving for NGET and BSUoS customers of £0.1-31.5m.

6.3.3.2 Impact of displacing existing Frequency Response providers with static CLASS

If CLASS is not treated as a pseudo-dynamic and "High" provider of Frequency Response its potential benefit in 2027 is much more limited. For example, whereas the winter daytime requirement for Frequency Response is 1,157 MW, the capacity that CLASS could displace falls to just 276 MW. In this case, only 226 MW of diesel engines and 50 MW of battery storage can be displaced, significantly reducing the value to NGET and BSUoS customers.

In the winter overnight period the drop is from 1,273 MW to 759 MW, which is less significant. This is because pumped storage is replaced by batteries in the overnight period, and unlike pumped storage these are able to provide the required "High" response. Because of this, NGET can meet both its dynamic and high response requirements with less overall capacity. In this case, all but 214 MW of DSR and 300 MW of battery storage can be displaced.

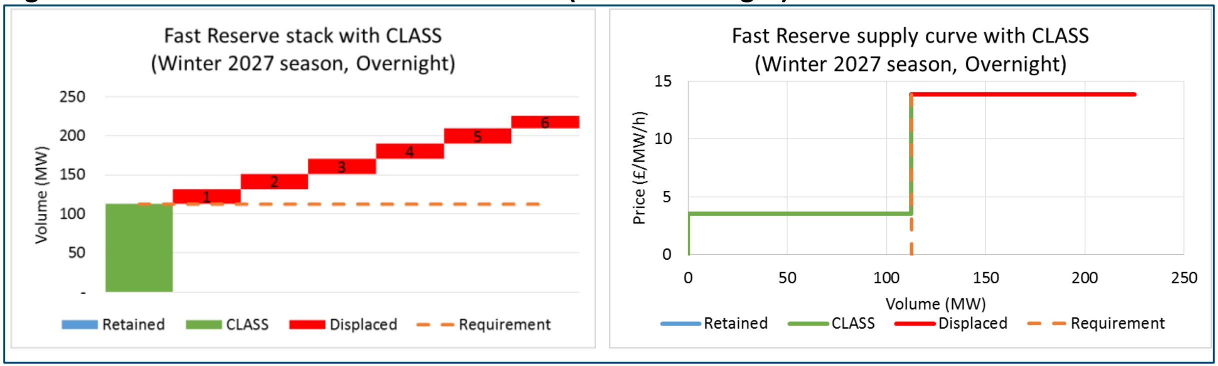
The effect of restricting CLASS to a static non-High service is to reduce the amount of existing providers that can be displaced. Whereas the cost to NGET of the displaced providers was £63.3m, this falls to £37.9m. There is a strong incentive on DNOs and NGET, therefore, to ensure that CLASS has the right technical characteristics to provide the more valuable pseudo-dynamic and High Frequency Response service. Otherwise, this is likely to be a significant constraint in the future once large volumes of CLASS are offered to the market.

6.3.3.3 Displacement of other providers of Fast Reserve

For the remainder of this section, we assume that CLASS is categorised as a pseudo-dynamic provider. However, it should be noted that if this were not the case there would be more CLASS available for the other Balancing Service markets.

In our 2027 scenario the Fast Reserve market can be saturated by CLASS. In both winter and non-winter daytime hours this means that the Pumped Storage plant is displaced, which it is assumed has bid at £3.0/MW/h. Because the Pumped Storage plant does not bid in the overnight periods, it is gas engines that are displaced, as shown in Figure 29. £8.6m of cost is displaced by CLASS from this market, with CLASS itself costing NGET £7.6-8.5m depending on the pricing strategy, resulting in a net benefit to NGET and BSUoS customers of £0.1-1.0m from this market.

Figure 29   2027 CLASS in Fast Reserve market (winter overnight)



6.3.3.4 Displacement of other providers of STOR

In principle there are sufficient volumes of CLASS available for some providers to participate in the STOR market. This will be particularly true if CLASS is treated as a static provider in the Frequency Response market. However, under our assumptions for 2027, the LRMC for CLASS exceeds the price at which the displaced plant could bid. This is partly a result of the derating that has been applied to CLASS providing STOR, which increases the number of substations needed to deliver a given magnitude of response.

It is assumed, therefore, that CLASS does not participate in the 2027 STOR market. It should be noted that a small change to the assumptions could make CLASS viable in this market, but we would still expect the margins to be small.

6.3.3.5 Other quantified 2027 costs and benefits

As in the 2014-15 scenario, CLASS brings has other costs and benefits:

- **Reactive Power:** It is estimated that 10.9TVArh could be delivered, based on 3,000 MW of CLASS deployment, although this will be very location-specific. This would have a value of up to £27.7m based on current prices, but the actual value is likely to be considerably lower than this.
- **Carbon reduction:** The carbon impact from Frequency Response is lower than in the 2014-15 scenario because, despite the CLASS volumes being larger, there is less thermal plant providing Frequency Response in the baseline stack, and more DSR being displaced. CLASS reduces carbon emissions by 8,500 tons.

  However, as CLASS is assumed to be present in larger volumes, it can also participate in the Fast Reserve market, displacing Pumped Storage units, whose carbon emissions arise because they are less than 100% efficient and draw their energy from the grid. Displacing these plant reduces carbon emissions by 58,000 tons. The overall value of this carbon reduction is £3.4m in 2027.

- **Customer Minutes Lost:** Using the same assumptions on the operation of the CLASS substations as were used for 2014-15, it is estimated that customers would face a cost of just £664.

7 Cost Benefit Analysis

7.1 Introduction

This section gives a Cost Benefit Analysis (CBA) of CLASS over multiple years based on the analysis described in Section 6. It reflects all of the quantified impacts discussed in the previous section, and shows how the costs and benefits accrue to different network stakeholders. For reference, the single-year results are summarised in Table 12.[31]

Table 12 Single-year CLASS cost and benefit summary (real 2015 prices)

	2014-15	2027
# substations (cumulative to date)	354	5,900
CLASS capex (cumulative to date)	£21.8m	£362.5m
CLASS opex (annual)	£0.5m	£8.4m
Saving from displaced providers (annual)	£32.2m	£71.9m
Cost of CLASS to NGET (annual)	£2.4-29.9m	£39.4-71.8m
NGET Balancing Service cost reduction (annual)	£2.3-29.8m	£0.1-32.5m
Non-bill (carbon) benefit (annual)	£0.2m	£3.5m

The analysis in this section is carried out in two steps:

- First, the initial tranche of CLASS is investigated, showing how the costs and revenues flow between the DNO, NGET, BSUoS customers and DUoS customers, and
- Second, the analysis is repeated for the projected deployment of CLASS between 2014-15 and 2027.

7.2 Key assumptions

The following assumptions have been made in order to produce the results described in this section:

- Between the deployed levels of CLASS assumed in 2014-15 and 2027, it is assumed that there is a linear growth in the intervening years, with the per-MW cost being constant,
- The baseline cost to NGET of procuring the various Balancing Services are similarly linearly interpolated,
- The regulatory treatment of CLASS revenues is consistent with "Directly Remunerated Service 8 DRS8, Valued Added Services", meaning that initial costs and future revenues for

[31] Note that the Security of Supply cost less than £1,000 in all years so is not included in this summary table. Reactive Power services may be more valuable, but this value cannot be stated without knowing the locational requirements by NGET, so these are excluded from this section of the report.

DNOs are shared with customers as per a regulated sharing factor. The full regulatory treatment can be seen in the model accompanying this report,

- Suppliers are assumed to pass through any BSUoS or DUoS savings to their customers,
- No new CLASS deployment occurs beyond 2027. All CLASS technology is assumed to have a lifetime of 15 years, which affects the period over which capex is annuitised, and also results in a ramping down of CLASS capability post-2027. This does not mean that CLASS will ramp down in reality, but by not replacing lost CLASS capacity the full lifetime cost of the technology can be observed, and
- The analysis is shown for both the LRMC and shadow marginal pricing strategies, which bound the range of possible prices at which CLASS could feasibly be offered to NGET.

7.3 CBA of initial tranche of CLASS

The initial tranche of CLASS is assumed to cost £21.8m to deploy, plus £506k in annual capex. Depending on the pricing strategy, an amount of revenue is generated from providing CLASS. The three parties incur costs and revenues by the following logic:

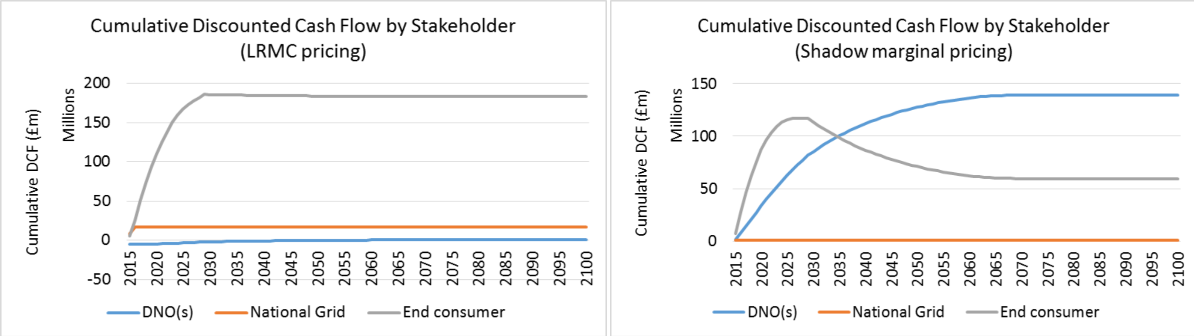
- **DNO:** Under DRS8, the cost of CLASS and any payments from NGET are netted off and shared between the DNO and the DUoS customer. The DNO receives some revenue (or incurs some cost) in year 1 as “fast money”, while some is added to its Regulated Asset Value (RAV), resulting in payments from DUoS customers (through increased DUoS charges) over 45 years[32].
- **NGET:** The majority of the savings seen from reduced Balancing Services costs are passed through to customers, but for the first two years it is assumed that NGET receives 30% of the net benefit through incentive payments.
- **Customers:** Customers benefit through two routes. They receive reduced BSUoS charges from the reduced cost of Balancing Services (net of any NGET incentive). Whilst they share the cost of CLASS with the DNO, they also share in the benefit. Because of the “slow money” approach, however, they incur a long tail of obligations to the DNO.

Figure 30 shows the Cumulative Discounted Cash Flow (DCF) and Net Present Value (NPV) by party. The overall NPV £200.1m, which is accrues to the different parties differently depending on the DNO’s assumed pricing strategy:

- Under **LRMC pricing** the DNO is approximately neutral. However, it has a negative NPV until 2055. NGET sees a larger share of the benefit in this case. The end consumer sees the maximum benefit.
- Under **shadow marginal pricing** the DNO receives the majority of the net benefit. NGET sees a small positive NPV. The end consumer benefit is approximately one third of its benefit under the LRMC strategy since the reduced benefit it sees as a BSUoS customer is not matched by the increased revenue it sees as a DUoS customer.

[32] Strictly, the time assumed for calculating depreciation payments is changing from 40 to 45 years over the course of the RIIO-ED1 Price Control period, but 45 years is used for the purpose of this analysis

Figure 30 CBA for initial trance of CLASS under two pricing strategies



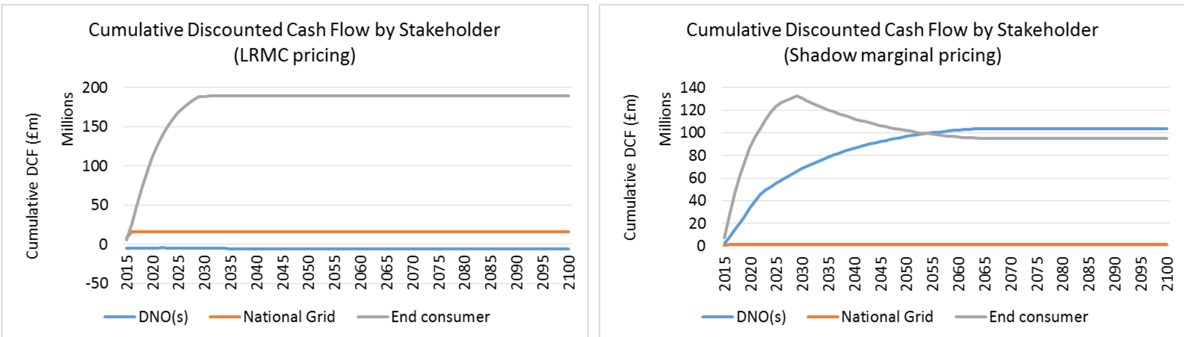
	Value (£m, 2015 real)
DNO	0.7
National Grid	16.4
End Consumer	183.0
Total	200.1

	Value (£m, 2015 real)
DNO	139.3
National Grid	1.3
End Consumer	59.5
Total	200.1

The above analysis assumed, however, that revenue from CLASS can be received for the duration of its installation (assumed to be 15 years). It is possible that future revenues from CLASS will be passed straight through to customers. This would improve the NPV for the end consumers under both pricing strategies, but could mean that DNOs fail to reach a positive NPV in some cases.

As shown in Figure 31, if CLASS revenues are restricted from 2023 onwards the NPV for the DNO decreases. Note that because pre-2023 revenues have in part been added to the RAV, the NPV can still increase over time. However, if CLASS has been sold at the LRMC price (assuming no revenue curtailment), restricting future revenues would result in a negative DNO NPV.

Figure 31 CBA for initial trance of CLASS under two pricing strategies (revenue restriction)



	Value (£m, 2015 real)
DNO	(6.0)
National Grid	16.4
End Consumer	189.6
Total	200.1

	Value (£m, 2015 real)
DNO	103.8
National Grid	1.3
End Consumer	95.0
Total	200.1

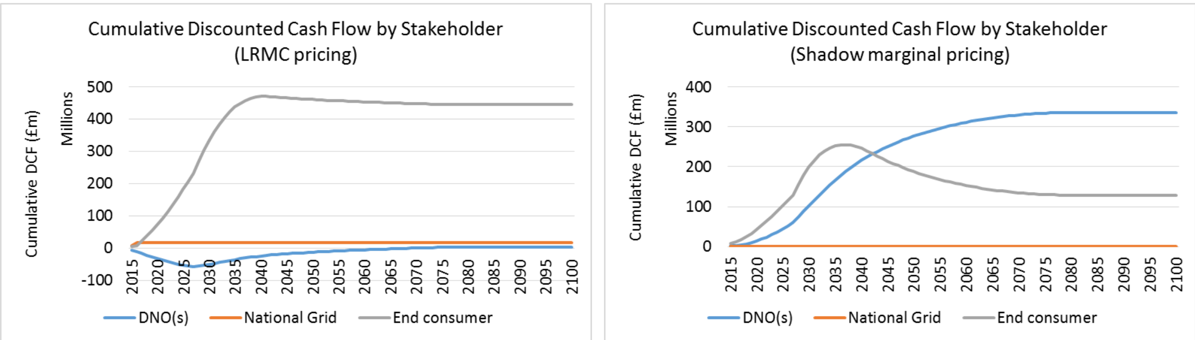
7.4 CBA of projected deployment of CLASS

The same analysis can be carried out for the estimated projection of CLASS deployment. In this case, we assume that CLASS volume is added incrementally in each year, following a linear path from 2014-15 to 2027. Note that no attempt has been made to distinguish between the different DNOs that may deploy CLASS, so a single NPV value will not describe the range of NPVs that each would actually receive in practice.

As Figure 32 shows, the overall benefit of £466.1m. Note that the benefit does not scale linearly with the capacity of CLASS installed, which is because it is assumed that even without CLASS the cost of Balancing Services to NGET decreases over time as alternative technologies and commercial arrangements such as DSR and batteries become more prevalent.

As with the single tranche example, under LRMC pricing the DNOs are almost neutral in NPV terms, with most benefit passing to end consumers via reduced BSUoS payments, whilst under shadow marginal pricing DNOs are the main beneficiaries. However, it should be reiterated that in reality this volume of CLASS will not be provided by a single DNO. Future DNOs, faced with competition from existing CLASS providers and expecting future declines in value from the Balancing Services markets, may not be able to form a positive business case for CLASS. In practice, this means that late-adopting DNOs may be unable to create a positive business case for CLASS unless the market or regulatory regime changes.

Figure 32 CBA for projected CLASS deployment under two pricing strategies



	Value (£m, 2015 real)
DNO	3.9
National Grid	17.0
End Consumer	445.1
Total	466.1

	Value (£m, 2015 real)
DNO	336.3
National Grid	1.3
End Consumer	128.5
Total	466.1

8 Qualitative aspects

The analysis described in the previous sections was based on assumptions and estimates that could reasonably be quantified. However, the behaviour of these markets is not predictable, and there are dynamics which were not considered as part of the quantitative evaluation. Instead, these areas have been explored in discussions with CLASS stakeholders at stakeholder events, and in bilateral meetings between Baringa and industry participants with an active interest in CLASS' impact on Balancing Services markets.

This section describes those qualitative aspects of CLASS that should be considered in order to have a more complete understanding of its impact on the market.

This section is divided into five parts:

- Improved alignment of CLASS and NGET requirements,
- Impacts on customers' quality of service,
- Behaviour of displaced parties,
- Security of supply impacts, and
- Other smaller effects.

8.1 Improved alignment of CLASS and NGET requirements

It has been assumed throughout this analysis that CLASS would offer one or more of the existing Balancing Services procured by NGET. However, whilst the types of services that NGET requires are broadly a function of the physical behaviour of the system, the way in which those services are packaged is as much a function of the technologies available to deliver them.

It is our understanding that the characteristics of CLASS can be configured in a number of ways (e.g. by adapting its response characteristics). One option is indeed to configure the service in such a way that it meets NGET's stated requirements. However, as CLASS becomes more prevalent it may be in the interest of NGET to either:

- Repackage or redefine some of its service requirements to take full advantage of what CLASS offers, or
- To procure existing Balancing Service products, but after accounting for the level of CLASS available at any one time (this option being particularly suited to a situation where NGET has direct control of CLASS across the GB system.

Initially, NGET could enter into bilateral agreements with DNOs to procure CLASS services, which would also allow it to tailor their procurement to CLASS' particular characteristics, as these are experienced over time. It is not known how different a tailored offering might look from the existing mix of Balancing Services. However, it is reasonable to expect that any move to align CLASS capabilities and NGET requirements would result in more value overall than has been assumed in this analysis.

8.2 Impacts on customers' quality of service

Impacts on quality of service in this section are considered to be any changes in the quality of energy product delivered, caused by the holding, or utilisation of CLASS, and in the level of reliability provided to customers.

On the first point relating to the quality of energy product delivered, it is necessary to isolate how CLASS could affect the customer experience, and then assess the quantum of these impacts. The main types of consumer devices affected by varying voltage are resistive loads, as switched-mode power-supplied devices will adjust their current draw in response to varying voltage. Taking primary or secondary response as an example, by reducing the voltage on the system to provide these services, a resistive load, such as an electric heater, or oven, will take longer to perform their tasks than would otherwise be the case. This means that:

- Customers may have to wait longer to achieve their intended outcome from using energy in the first place, and
- The consumption of energy extends for a longer period than planned – particularly for those parties who forecast and balance a customer's load (mainly suppliers). While the overall level of power consumed by a particular consumer affected by CLASS does not change, the profile of consumption will change, and left unaddressed, this could have imbalance repercussions which are likely to be passed back into retail bills. These settlement issues are addressed separately in section 8.5.

The CLASS trials addressed the issue of time with engaged customers by breaking down the impact of voltage variations into analogies based around the time it takes to boil a kettle[33]. The analogy said that for a kettle that takes three minutes to boil, a +/- 2 % change in voltage would increase or decrease the boiling time by +/- 8 seconds respectively. It is understood that this was not considered to be a significant issue with customers during the trial.

Further, while the CLASS trials experimented with a voltage level of up to 5%, (which would have a greater impact on time taken), it should be noted that even in this instance, CLASS would not reduce the quality of service past the voltage range set out in legislation as 230 V +10%/-6%[34]. In addition, if DNOs successfully demonstrate that CLASS can also be used to provide a "High" service (say, in Frequency Response), then resistive loads would perform their function more quickly, to the extent that a customer experience would be improved. Whether the two would net over time would depend on whether CLASS were contracted and used for both services in equal volumes.

The lack of discernible impact from voltage changes was also demonstrated in the CLASS trials, which indicated that customers in ENWL's network did not notice when CLASS was being utilised, with more customers saying that they noticed a difference in their power quality in the baseline study than when CLASS was actually being trialled (21% vs 15%, respectively[35]), and of the 15% of customers who said that they noticed difference during the trials, only 3% of customers were actually exposed to CLASS-driven changes in quality of service. It may be that as CLASS is deployed more widely that there are specific customer types that are more affected, but the potential scale of this effect, if it exists, cannot be estimated.

[33] ENWL, CLASS Customer Leaflet, September 2013
[34] Electricity Safety, Quality and Continuity Regulations 2002 s.27 (2)
[35] ENWL, CLASS Customer Survey Report, July 2015

On the latter point of reliability of service, the impact assessment estimated the number of customer minutes lost to be low, at 0.0086 MWh for the initial 200 MW roll-out, rising to 0.11 MWh per annum for a full 3 GW roll out. This is based on the likelihood of a circuit experiencing a fault when one transformer in a primary substation is tripped out because of having been used for primary Frequency Response. However, an additional consideration is whether the increased utilisation of tap changes and circuit breakers to provide CLASS increases the likelihood of a component failure in a circuit, thereby reducing reliability on those specific circuits further.

Discussions with ENWL indicate that the increased tap changes expected under various services would reduce the time interval between services (service life). The increased cost associated with more regular maintenance of the assets is recovered in the planned opex recovery under the CLASS pricing strategy. Therefore, it is reasonable to assume reliability will not be significantly affected if service life is adjusted to suit the new utilisation schedule on the transformer assets.

8.3 Behaviour of displaced parties

The main analysis in this report assumed that when CLASS offered volumes into the Balancing Service markets, the most expensive existing providers would be displaced. In practice, it may be that some or all of those displaced assets would instead lower their bids into the market. This presupposes that those assets are currently bidding above the cost incurred from withholding capacity to provide balancing services[36], and are therefore able to reduce their bid. In practice, this may reduce the maximum price at which CLASS could be offered (the shadow marginal price), but it should have little effect on the overall NPV, and may increase the benefit to the end consumer (since it has been shown that the end consumer tends to benefit from a lower CLASS price).

If, however, those existing assets are displaced there is uncertainty over their subsequent behaviour. Assuming they had been executing their optimal strategy, by being displaced they will face a net loss. However, that loss will not be large to offset the overall benefit provided by CLASS for two reasons:

1. The displaced providers would save on any cost associated with providing the service, so have only lost the spread between their costs and their revenues
2. They have the opportunity to participate or change their behaviour in alternative markets

On this second point, there are at least three ways in which they may offset their losses:

1. They may change their bidding strategy in the Capacity Market (to reflect their increased missing money) and may still be successful in this market
2. They may participate in alternative Balancing Services
3. They may participate in the wholesale market

It is uncertain what strategy will be adopted, and hence what the overall impact on the displaced providers will be, but it is nevertheless likely that the overall case for CLASS will be positive, even when the costs imposed on these displaced providers are taken into account.

[36] Such as the opportunity cost from foregone profit from operating in other markets, and/or the short run marginal costs of actually providing energy in a balancing service (utilisation).

8.4 Security of supply

Because CLASS is offering capacity and energy into Balancing Services, in one sense it is increasing security of supply. However, it may be that there are secondary effects that also affect the overall security of supply for the electricity system. In particular, the use of CLASS may have an effect on the overall system margin, which is a key focus for policy makers in maintaining security of supply. As such, the areas that need to be considered are:

- CLASS' consideration within the Capacity Market (CM),
- Whether CLASS has an impact on the existing OC6 requirement, and
- The impact of displaced incumbents on security of supply.

Capacity mechanism

Baringa understands that ENWL, in its role exploring the implementation potential for CLASS, does not plan to offer the capability into the upcoming CM auctions. If ENWL, or other DNOs were to offer their CLASS capabilities into the CM in the future, then it could be considered either as an increase in low-cost supply of capacity (thereby shifting the existing supply curve out, and reducing the likely clearing price of capacity, or alternatively, as CLASS has a capability similar in effect to DSR, its capability could be considered as having the potential to reduce the overall CM requirement by reduce the maximum demand on the system.

Baringa also understands that CLASS capabilities will not be formally factored into the capacity requirement calculations. It is more likely, therefore, that CLASS's contribution to the overall margin would be in addition to the capacity procured through the CM.

OC6 requirements

The OC6 requirement refers to a Grid Code requirement for DNOs, whereby NGET can instruct DNOs to perform voltage reductions and/or demand disconnections on their networks (depending on what the DNO has previously specified as available for demand control). Demand control reduces overall system demand to help NGET relieve balancing issues on the transmission system. In theory, these provisions allow NGET to reduce demand by up to 20%[37].

Focusing on the OC6 voltage control requirements, the Code provisions allow for NGET to instruct DNOs to perform two voltage reductions of between 2-4%, which should deliver a demand reduction of 1.5% for each reduction. Once NGET has issued an instruction, DNOs have:

- 2 minutes to initiate the voltage control (i.e. which could include moving tap changers on primary substations), and
- 10 minutes to fully achieve the voltage reduction.

The interaction of CLASS with the OC6 specifications has two possible effects. First, there is the concern that the activation of CLASS could erode the margin of voltage reduction that a DNO holds on its network at any time, which could mean that if NGET were to issue an instruction for demand control, the DNO's voltage reductions that followed might not deliver the level of demand reduction anticipated. Baringa understands that ENWL has considered this issue, and plans to configure CLASS so that it always retains enough of a margin of voltage control to meet its OC6 requirements.

[37] See OC6.5.3 of the Grid Code

The second possible effect is that CLASS improves performance under the OC6 arrangement in two key areas:

- The first relates to the information that CLASS provides NGET, if rolled out at scale. If provided with access to the CLASS dashboard, NGET should have an improved view on the level of voltage control available in real time, and the corresponding demand reduction that voltage control could achieve. This seems preferable to the current arrangement set out in OC6, where DNOs have to write to NGET once a year, stipulating the methods that they plan to use in the event of a demand control event, and the level of demand reduction that would be delivered.
- The second area relates to DNOs becoming better at responding to OC6 instructions (through improved internal processes, and refitting of primary substations) as a side-effect of participating in CLASS. Note that the DNOs participated in Operation Juniper in 2013, which tested the level of demand reduction that could be delivered through demand control instructions under OC6. This study found that the level of demand reduction was generally slower, and smaller, than the previous drafting of the Grid Code has assumed, with a wide range in performance across the different networks. It is reasonable to assume that regular participation in Balancing Services (i.e. monitoring voltage and demand reduction potential, and becoming familiar with the fastest and most sensitive primary substations) will help DNOs deliver a faster, and likely more effective response to NGET, than if they were not participating at all.

Effect of displaced balancing participants

Lastly, linking to section 8.1, the strategies chosen by market participants who are displaced by CLASS out of their existing Balancing Service markets could also impact on security of supply, depending on the strategy chosen:

- Clearly, if market participants simply move to a non-saturated Balancing Service, or move into the wholesale market, then the impact on security of supply is negligible, provided that their shifting into these markets does not cause a further knock-on effect for other incumbents in those markets.
- However, if those displaced market participants were to also increase their bid into the CM, (say, to recover missing money that was otherwise recovered through a mixture of Balancing Services, CM, and wholesale market participation), then while security of supply would remain the same, then there is potential for one of the costs of security of supply (the CM) to increase in clearing price as a result – though we note the risk is likely to be small[38].
- In the worst case, these displaced market participants may decide that operations without the Balancing Services revenues that they were earning prior to CLASS' introduction is not commercially viable, so could look to exit the market altogether. This would have a detrimental impact on security of supply, particularly if CLASS is not considered a capacity resource, as discussed under the CM section above.

[38] For example, bidding restrictions in the CM (such as the price-taker threshold) may prevent existing providers from having a significant impact on the CM auction price.

8.5 Other considerations

Other, smaller effects of CLASS have been considered as part of this study. These include:

- Potential settlement distortions, and
- Impacts on network reinforcement costs.

These are described below.

Potential settlement distortions

The use of CLASS may distort settlement calculations for market participants using the network underneath a CLASS-enabled substation, which could affect imbalance positions, or performance monitoring for balancing services. For example:

- Suppliers will procure sufficient energy to serve their portion of customers being served by a CLASS-enabled substation. Where CLASS is activated, and these customers' consumption is reduced on resistive appliances, then the supplier would appear to have over-procured against its customers' actual consumption, for which it is likely to face cash-out charges. Further, where CLASS forces consumption on resistive loads to cross two settlement periods in order to serve the same original load, then the supplier could face further cash-out charges in the following settlement period.
- A similar issue is where a DSR provider is paid on performance for delivering a reduction in demand against a baseline level of consumption. Where CLASS is activated, the level of energy delivered by a DSR provider will be proportionately less, which could cause compensation and performance issues.

In theory, settlement issues can be worked through to ensure that CLASS utilisation is automatically reflected in all consumers' physical positions (similar to how NGET is able to adjust positions for use of certain Balancing Services under the submission of Applicable Balancing Services Volume Data (ABSVD)). However, this may require a modification to the BSC to be raised to align with introduction of CLASS.

Impacts on network reinforcement costs

While the focus of CLASS is on Balancing Services for the transmission system, it is clear that the service could also be used to reduce the need for reinforcing both the transmission and distribution networks, through reducing peak consumption, which would reduce the need to size the network for those peaks.

The CLASS trials demonstrated that the service was able to reduce consumption during the winter peak by as much as 6%, which would defer transformer asset upgrades by three years, based on DECC's load growth scenarios. A similar effect may be achievable on the transmission network in the long run, however, any coordinated demand reduction at peak in the short term is likely to focus the recovery of transmission costs over a smaller volume of energy (at least under the current Transmission Network Use of System (TNUoS) charging methodology).

At present, Baringa understands that ENWL is focusing on ancillary services over demand reduction in its considerations for the potential commercial roll-out of CLASS.

9 Conclusions

Whilst there is a degree of uncertainty over how CLASS will be deployed and how the markets for Balancing Services will evolve, it seems clear that there is significant potential for this technology to reduce consumers' electricity bills:

- The initial deployment of CLASS planned by ENWL alone delivers £200m of benefits between 2015 and 2029 in NPV terms (2015 real prices), with the end consumer receiving between £60m and £183m of that benefit through bill reductions.
- The full projected deployment of CLASS (which will depend on the adoption by other DNOs) could deliver £466m of benefit between 2015 and 2041, with the end consumer receiving between £128m and £445m through reduced bills.

In addition, the use of CLASS could result in material reductions in the CO_2 emissions associated with holding and utilising plant for the provision of Balancing Services. The impact on Security of Supply is less certain, but it would appear that the overall effect of delivering more dependable voltage control is a net positive for the security of the overall system.

CLASS is most valuable in the near-term given that there is a strong expectation that new-entrant technologies will, in the future, reduce the cost to NGET of procuring those Balancing Services. The value of CLASS will be particularly restricted in the future if it is deemed to be only a static provider of Frequency Response, so this should be a focus of the technical discussions between NGET and potential CLASS providers.

The regulatory treatment of revenues received from CLASS participating in Balancing Services has been agreed to be considered under DSR8. DNOs considering a roll-out of CLASS will now have to consider a suitable pricing approach. The key risk to consider is around ensuring payback of investment costs, especially in the context of the following market risks:

- The potential for CLASS being classified as a static provider (reduces the range of pricing options available to CLASS while retaining a competitive edge),
- New market entry from other providers of CLASS (which could lower market prices),
- New market entry from other low cost providers (DSR, and potentially some storage business models) (which again could lower market prices), and
- The risk of re-baselining of these revenues as part of the underlying regulatory regime (say in RIIO ED2).

Assuming that DNOs develop an approach that satisfies their investment case, and that the implementation issues raised in Section 8 are addressed (particularly concerning settlement), then CLASS is well-placed to make a significant contribution to addressing the growing need for Balancing Services in the future, while simultaneously providing DNOs with a new value stream to the benefit of GB consumers.

Appendix A Further detail on Balancing Services products

This appendix provides further background on the procurement, penalties, and current market dynamics for FFR, Fast Reserve, STOR and Reactive Power markets.

A.1 Firm Frequency Response

A.1.1 Procurement

Procurement process

NGET runs electronic tenders for FFR monthly, for the service to be provided in the following month (e.g. tender in January to start providing in February). Ahead of competing in tenders, FFR providers must agree to the FFR Framework Agreement stipulating the terms under which they will contract with NGET.

Providers can contract ahead of having equipment in place, but need to account for time required to self-test their response capabilities, and have NGET independently verify these tests.

Bid formation

Bidders can bid for contracts between 1 and 23 months long, and can stipulate the hours and days within these windows that they are available to provide the service for. Bids have to stipulate whether the response will be dynamic, or static, and what level of response can be provided within Primary and Secondary timescales (i.e. 10 seconds and 30 seconds).

A relatively complex fee structure is in place consisting of Main and Optional fees. However, in practice only the Main fees are actively competed on by providers.

Table 13 Fee structure for FFR

	FFR Tender Items	Description
Main fees	**Availability Fee (£/h)**	This is paid to the provider for the hours for which a provider has tendered to make the service available, the "FFR Contracted Frame"
	Nomination Fee (£/h)	NGET nominates hours within the frame that it requires providers to be responsive. It pays nomination fees for each hour that the provider is utilised (i.e. held in Frequency Sensitive mode if a dynamic provider, or with automatic relays armed if a static provider).
Optional fees	**Window Initiation Fee (£/window)**	NGET will notify 'windows' during which it requires FFR to be provided, for which a Window Initiation Payment will be made.

	Window Revision fee (£/hr)	NGET notifies providers of window nominations in advance and, if the provider allows, this payment is payable if NGET subsequently revises this nomination.
	Response Energy Fee (£/MW/h)	This is based upon the actual response energy provided in the nominated window, as per Connection and Use of System Code (CUSC) section 4.1.3.9A for BMU Providers and as per tendered parameter for Non-BMU providers.

Response Energy Fees (or Utilisation fees) can offer a further source of value for providers:

- BMUs receive a factor of 1.25 of the prevailing Market Index Price for any response energy provided in low frequency conditions (as set out in the CUSC),
- BMUs pay a factor of 0.75 of the prevailing Market Index Price for any response energy reduction in high frequency conditions (as set out in the CUSC), and
- Non BMUs have the option to compete on utilisation fees. However, these are normally zero given that overall energy volumes for static providers are low, and given the level of competition these participants can face.

Selection

NGET uses a number of criteria in selection of FFR bids in its monthly tenders. The most important of these is cost. NGET will consider both the cost of the contract against its competing bids (i.e. the **contract cost**) and the offset cost of otherwise procuring the service through the Mandatory Frequency Response service. This "counterfactual" cost is NGET's forecast of the costs incurred from instructing generators to operate in frequency sensitive mode in the Balancing Mechanism. These costs are made up from:

Table 14 Cost constituents for NGET using Mandatory Frequency Response

Cost component	Description
Holding fees	Holding fees are paid directly to the generator when it is selected to operate in frequency responsive mode. They are competitively bid by generators, and understood to recover the increased costs associated with increased wear and tear on a generator from supporting the system frequency. Separate fees are bid for Primary, Secondary, and High services
Positioning costs	Positioning costs are the sum of the bids and offers that NGET accepts to "deload" a running plant in order for it to be in a suitable position to provide frequency response
Reserve creation costs	Reserve creation costs are the portion of Operating Reserve that is procured in order to provide headroom for balancing the system, after positioning has occurred

NGET's forecasts of these costs will change depending on the season and time of day that the bidder offers response. If the bidder is also capable of providing the Mandatory service, than NGET will consider whether the costs or available volumes in the Mandatory service are likely to change significantly (as a BMU providing FFR is essentially excluded from the Mandatory service for the period in which it is contracted).

Forecasts are also likely to evolve going forward, as the generation mix on the system changes, meaning that potentially fewer conventional thermal generators will be running to provide frequency response.

Outside of these cost considerations, NGET will also assess whether a bidder is reliable provider of response (from previous provision and any testing performed).

A.1.2 Penalties

The penalty for non-delivery or unavailability is a deduction in nomination and availability fees. Actual performance is calculated as follows:

P = C/D * 100

Where:

C = highest level of generation, and D = contracted response.

The fee deduction which corresponds to this performance level, as shown in the below table:

Table 15 FFR Penalty regime[39]

Percentage Performance (%)	Percentage Deduction in Fee (%)
< 10%	100%
≥ 10%, < 60%	50%
≥60%, <95%	25%
≥95%	0%

A.1.3 Market size and composition of providers

Market size

NGET regularly publishes its overall frequency response requirement at the month-ahead stage, showing the volumes it already holds under contract and the volumes it has left to procure. The volumes of response required are sized around the largest infeed loss, so that in the event that the largest plant unexpectedly falls off the system there is enough plant available to quickly contain the resulting drop in frequency, and then restore it to the target 50Hz. The current largest infeed loss is 1260MW[40].

Inertia on the system (i.e. the mechanical energy stored in the rotating mass of synchronous generators) helps to slow the rate of change of frequency in an infeed loss event. Therefore, in peak demand conditions, when the majority of conventional plant are being used to satisfy demand, the level of response required can be reduced. Conversely, the level of response requirement is highest when there is little inertia on the system (such as overnight conditions, and during the summer). This can be seen in Table 16 below, where requirements from NGET's market reports for January and July 2015 are summarised.

[39] National Grid FFR product design document
[40] Assumed to be planned around Sizewell B.

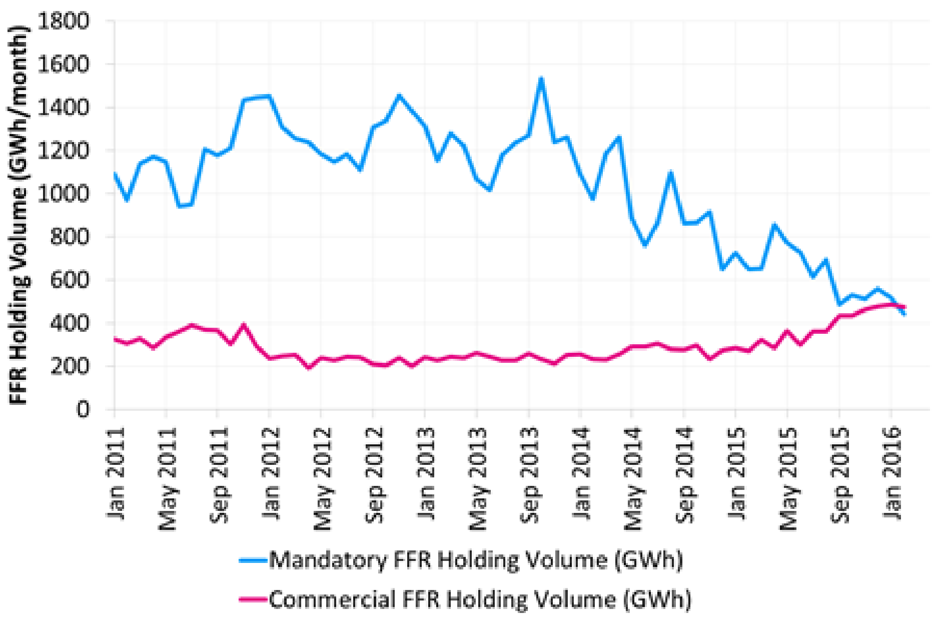
Table 16 Total Frequency Response requirements in January and July 2015 (MW)

Service	Jan 15 min.	Jan 15 max.	*Min dynamic requirement (Jan/June)*	July 15 min.	July 15 max.	*Min dynamic requirement*
Primary	450	850	*450/550*	650	1350	*450*
Secondary	1150	1500	*450/550*	1450	1650	*450*
High	600	825	*450/600*	150	375	*450*

Historically, Secondary Low response is NGET's largest response requirement. NGET also often collects Primary response as a bundled product with Secondary, as the majority of incumbent providers in both the Mandatory and Firm markets are capable of ramping within Primary timescales and holding the response for Secondary-length timescales.

It should be noted that NGET does not commit to a split of the total requirement between Mandatory and Firm providers, but makes this decision on the relative economics, based upon the bids it receives and its forecasts of Mandatory holding fee costs and positioning costs. Historically, holding volumes have favoured the Mandatory service, but this balance has shifted recently to NGET procuring roughly equal volumes from Mandatory and Firm providers.

Figure 33 Frequency Response Holding volume[41]



In May 2015 NGET provided a forward view of the maximum levels of frequency response that it would need to hold in any month across the next five years. The chart showed that the levels of response required are broadly similar to those required in 2015. However, following this, in November 2015, NGET published its SOF 2015, where it explored the implications of lower levels of

[41] Baringa, based on data extracted from National Grid MBSS reports.

inertia on the system as a result of increasing penetration of renewable generation[42], and closures of large generation units. In this document, it set out that the level of Primary response may need to increase at least threefold by 2030, unless providers with enhanced capabilities (i.e. faster response times) are used.

Figure 34 Estimated Frequency Response Requirement, 2016-2020 [43]

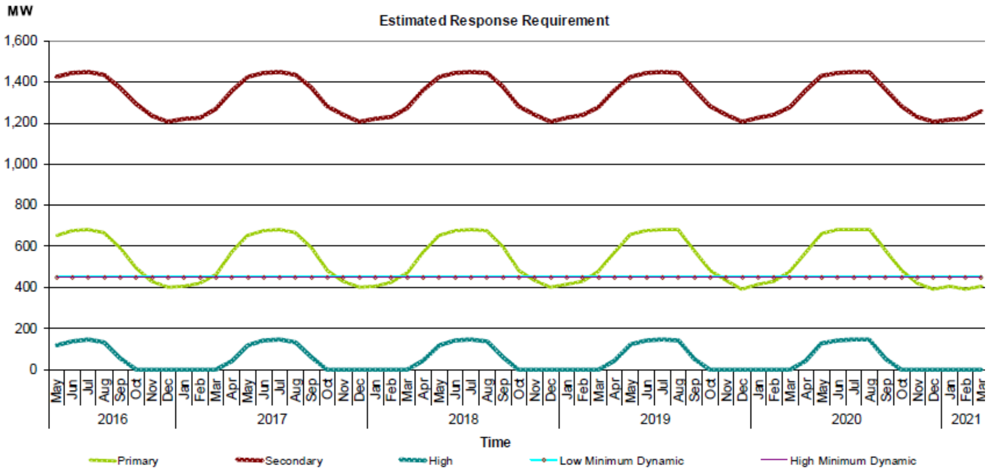
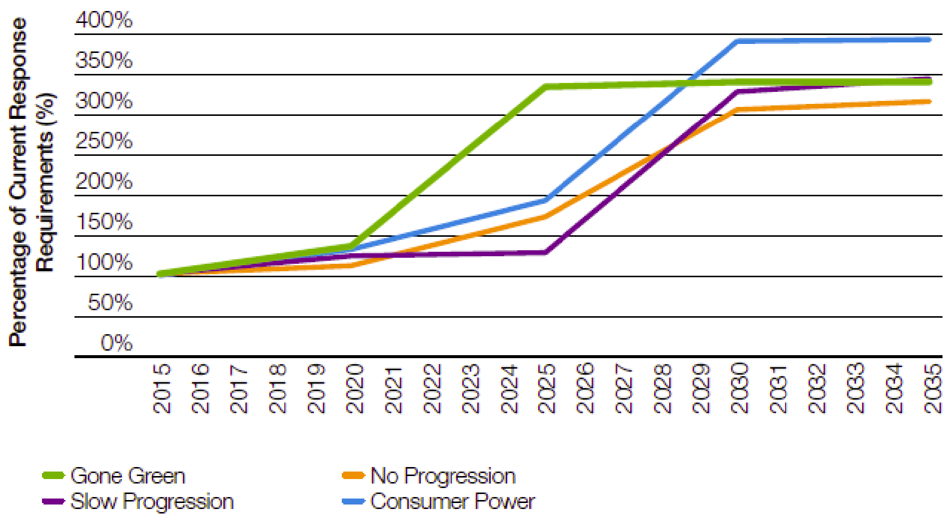


Figure 35 NGET forecast of total Primary Response Requirement (summer minimum)[44]



[42] Note that wind and solar are generally not synchronous machines, and so cannot provide inertia without additional equipment.
[43] National Grid, FFR FAQs, v1.2, December 2015
[44] National Grid, System Operability Framework 2015, Figure 18

Providers

Current providers in the FFR market consist of pumped storage technologies, thermal plant (both coal and CCGT), diesel engines and DSR. The typical services provided by these technologies are summarised in Table 17 below (informed by FFR tender results from the past 3 years).

Table 17 Typical response services provided by current FFR providers

Technologies	Services offered	Type of response	Typical volume offered	Times offered
Pumped Storage	Primary, Secondary	Dynamic	Up to 340MW per provider	0700 – 2300, all year
Thermal	Primary, Secondary, and High	Dynamic	Can be up to 150MW per provider, but generally around 50MW	24 hours a day, up to six months at a time
Diesel engines	Secondary	Static	Around 10-20MW per provider	24 hours a day, but avoiding 1600-1900 in the winter, typically for four to eight months
DSR	Secondary	Static	Around 10MW per provider	Varies – overnight provision is quite common

Note that this table does not cover FFR provided through FCDM or Bridging contracts. FCDM contracts are bilaterally negotiated and not available publically, while Bridging contracts are a 2015 initiative that has yet to report on levels of procurement.

In the last quarter of 2015, there has been a significant increase in the level of Secondary static providers. These are believed to be diesel engines or DSR/behind the meter providers[45].

A.1.4 Market prices

Successful bids are set out in Table 18. There is a clear differentiation in price achieved between dynamic providers and static providers, and between dynamic providers themselves. NGET does not provide its procurement rationale alongside results, but the differences in bids are presumably a function of the availability of the service (24/7 vs fewer hours), the services offered (Primary, Secondary and High vs just one service), and the level of competition faced by providers with other providers offering similar "bundled" products.

[45] Behind the meter providers are (typically small) generators or storage technologies that locate on site with a customer, so that power is both generated and consumed onsite without being transported across the common grid. This results in avoided network and environmental costs.

Table 18 Historical successful FFR tender availability prices[46]

FFR service	Price acceptance (Jan 2013- Jan 2016)
Primary, Secondary and High	£25 to 45/MW/hr
Primary and Secondary	£15 to 22/MW/hr
Secondary only (mostly static providers)	£2 to 5/MW/hr

A.2 Fast Reserve

A.2.1 Procurement

Procurement process

NGET runs monthly tenders for Fast Reserve for the service commencing the following month. Only providers who have an existing Fast Reserve Framework Agreement in place with NGET can submit bids.

Bid formation

Bids are classified as either:

- Single month,
- Multiple month (in other places called "Medium term"), from 1 to 23 months, or
- Long term, for up to 10 years.

If NGET receives a Long term bid, it is obliged to inform all other providers holding a Framework Agreement of the term that has been applied for, to allow providers to offer adjusted bids accordingly.

Tendering parties submit complex bids for a "Tendered Window", which are the days in the week, and times that they wish to be available to provide the service. Bids are made up from Availability, Positional, Window Initiation and Utilisation fees, which are described below in Table 19. Bidders are also required to set out any utilisation restrictions that will apply to their bid, such as how many times the unit can be utilised within a given time period. These are also described in the same table.

[46] Baringa, from FFR market reports between January 2013 and January 2016.

Table 19 **Fast Reserve fee breakdown**

	FFR Tender Items	Description
Tendered fees	**Availability Fee (£/h)**	The price in £/hr that providers wish to be paid for making Fast Reserve available against for each hour in a Tendered Service Period where the service is available
	Positional Fee (£/h)	This parameter provides the ability should providers wish to specify a Positional Fee (the cost of putting plant in a position where Fast Reserve may be provided)
	Window Initiation Fee (£/window)	NGET will notify 'windows' during which it requires the Fast Reserve service to be provided, for which a Window Initiation Payment will be made
	Utilisation (energy) Fees (£/MWh)	For BMUs, this is a capped bid or offer price which providers will operate within during applicable Fast Reserve periods, in case they are dispatched for Fast Reserve utilisation For Non-BMUs, this fee is simply the energy price in £/MWh that providers wish to be paid if NGET dispatches them
Utilisation restrictions	**Unit Size (MW)**	Capacity to be made available for Fast Reserve
	Maximum energy utilisation (MWh) in minutes	The maximum time in minutes or alternatively ticking one of the time periods for which a provider will allow NGET to utilise Fast Reserve in any single utilisation (note that this must be a minimum of 15 minutes)
	Maximum No. of Utilisations	The maximum number of times Fast Reserve can be utilised in any the appropriate time period for which Contracted MWs are being offered
	Recovery Period (Seconds)	The maximum time in whole minutes it takes to make Fast Reserve available again after it has been utilised
	MW Profile	Dates of planned outages across the Tendered Service Periods.

Firm vs Optional Fast Reserve

The tendered service described above is often called "Firm" Fast Reserve – similar to Firm Frequency Response, it is considered by NGET to be firm for the contract period.

However, another form of Fast Reserve exists named "Optional Fast Reserve" (also called Non-Tendered Fast Reserve), which is often made open to bidders who are unsuccessful in gaining a firm contract with NGET. Optional Fast Reserve allows for NGET to access these additional resources on the operational day provided that the unit agrees to be available, with contractual terms then binding the two parties as specified under the Framework Agreement.

While similar in terms of service provision, and basic fee structure, the levels paid can be slightly different to the firm product:

- Availability payments differ as follows:

  - BMUs receive "**Enhanced rate**" availability payments. Rather than a tendered parameter, these are agreed and set out in the Fast Reserve Framework Agreement at the point the provider qualifies to provide the product.
  - Non-BMUs receive "**Optional Fast Reserve Availability Payments**", which are also agreed in the Fast Reserve Framework Agreement, rather than a tendered parameter.
- Utilisation/Energy payments differ as follows:
  - (No difference for BMUs from the firm service – the capped bid-offer price is still used)
  - Non-BMUs receive "**Optional Fast Reserve Utilisation Payments**", which again are also agreed in the Fast Reserve Framework Agreement, rather than a tendered parameter.

Note that providers participating in the Optional service are not permitted to receive positional or window initiation fees, so these costs must be accounted for in the Enhanced Rates and Optional Payments. These pre-determined fees can be updated with minimum one week's advance notice with NGET.

Selection

NGET's selection for Fast Reserve is similar to FFR, in that it assesses the economics of bids against the alternative means of providing the capability. NGET has published a document[47] setting out the alternative cost that would be considered, which is the total of:

- The cost of operating alternative Fast Reserve service x Total hours that the tendered unit is forecast to displace[48], and
- The cost of operating alternative reserve margin service x Total hours that the tendered unit is forecast to displace, and
- The avoided utilisation price from Balancing Mechanism for Fast Reserve x Utilisation volume the tendered unit is forecast to displace.

NGET also sets out that it considers past performance and utilisation restrictions in its tender assessment, in addition to whether providers are behind transmission constraints, and whether there are any additional dependencies that need to be considered between providers and the market as a result of contracting with a provider.

A.2.2 Penalties

In the Firm service, penalties apply where providers:

- Do not abide by the terms of their Framework Agreement and successful bid,
- Do not submit a bid/offer for energy that aligns with their utilisation fee,
- Do not run their unit in the agreed state for providing Fast Reserve, or

[47] NGET, February 2013. Firm Fast Reserve – Assessment Principles
[48] Note – this information could be derived from the Enhanced and Optional fees in existing Framework Agreements

- Where they make a change to the unit's position during a notified window without NGET's instruction.

In such cases, providers lose the availability, positioning and window nomination fees that would otherwise have applied in that settlement period. NGET has the right to cancel a Firm service contract where any two events happen within the same Fast Reserve month, or within a 30 day period from one another, or where three events happen within any 365 day window during the contract.

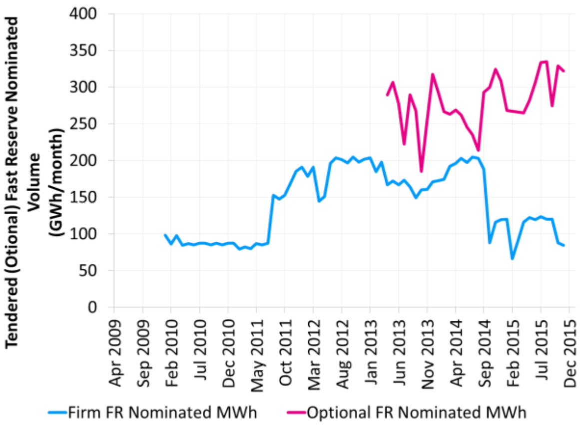
The only penalties that apply for the Optional service are the loss of the Enhanced Rates/Optional Availability fees.

A.2.3 Market size and composition of providers

Market size

The Fast Reserve market is small relative to other balancing services markets, with NGET only carrying around 300-400MW of Firm contracts at any one time, while using the Optional service to procure a further 400MW (approximate).

Figure 36 Fast Reserve nominated volume per month[49]



Composition of providers

Historical providers of Fast Reserve consist a number of units from one of two pumped storage participants. In the last six months, a distributed engine portfolio owner/manager has been actively participating in the market, and has been successful in winning contracts.

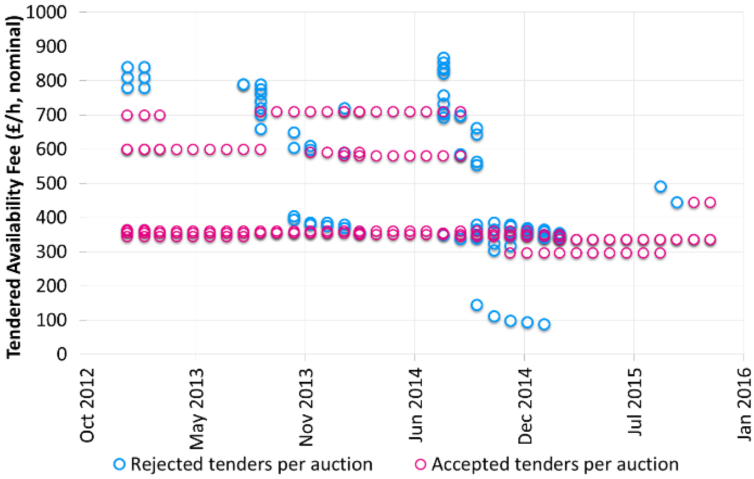
A.2.4 Market prices

Availability prices

Tendered availability fees have varied from £350/hr to over £800/hr (or 3.50 £/kW/h to 4 £/kW/h[50]), but have remained relatively constant by individual parties since 2012.

[49] Baringa analysis, National Grid MBSS reports
[50] Allowing for the capacities of the units tendering

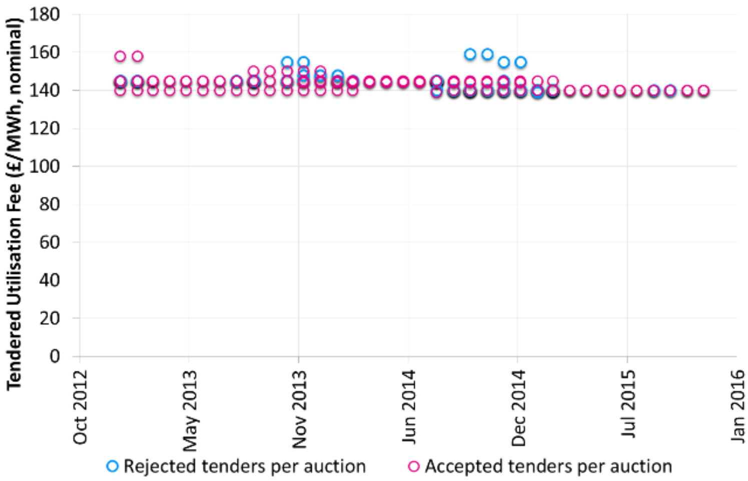
Figure 37 Monthly Fast Reserve (tendered) availability fees (nominal) by tendering unit[51]



Utilisation prices

Fast Reserve utilisation prices have remained flat at approximately 140 £/MWh since late 2012, with little or no difference between tender prices of the respective Fast Reserve parties, as is shown in Figure 38.

Figure 38 FR (tendered) utilisation fees (nominal) for each tendering unit (per month)[52]



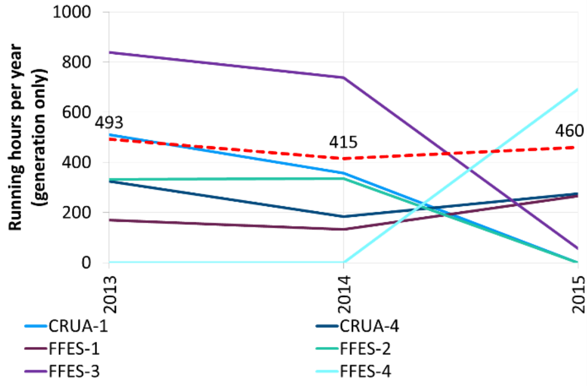
Historically running hours in Fast Reserve have varied considerably by unit, but units were dispatched for 493 hours and 415 hours on average for tendered Fast Reserve in 2013 and 2014 respectively (including ramping periods)[53].

[51] Baringa analysis, National Grid MBSS reports

[52] Baringa analysis, National Grid MBSS reports, Elexon SO action data

[53] FR running hours would be 673 hours and 560 hours in 2013 and 2014 respectively if all run hours within the day are considered (i.e. not only the FR period, typically 6am to 11pm)

Figure 39 Fast Reserve utilisation hours by year, including ramping [54]



A.3 Short Term Operating Reserve

A.3.1 Procurement

Procurement process

NGET runs STOR procurement rounds three times a year. Ahead of competing in tenders, providers must sign a STOR Framework Agreement with NGET.

Bid formation

Bidders are allowed to bid for one or more STOR seasons, up to a total contracted period of two years.

Bids must specify the product that the provider will offer (e.g. Committed, Flexible, Premium Flexible etc) and specify:

- An availability payment, in £/MW/hr and
- A utilisation payment, in £/MWh.

Selection

NGET assesses the economics of STOR bids received against the forecast cost of creating Operating Reserve in the Balancing Mechanism. This is created in a similar way to "positioning" units for Frequency Response, i.e. if there is no "free" headroom available on part-loaded generation with bids and offers in the Balancing Mechanism, then NGET must create it by lowering the output of some generators to create headroom, while replacing the energy using other resources. NGET's forecast cost of creating Operating Reserve will therefore depend on its assessment of:

- BMU utilisation patterns during STOR windows, and
- Likely levels of bids and offers during STOR windows.

[54] Baringa analysis, Elexon SO action data

While the economic assessment is NGET's main consideration, where the economics between units are more marginal, it can consider other criteria, including:

- Response time,
- Size,
- Historic reliability (if no action has been taken to remedy poor performance), and
- Geographical location of the STOR Unit.

A.3.2 Penalties

If a STOR provider successfully tenders for an availability window, but is then unavailable, or is seen to be dispatching for other services, then that STOR Provider would be issued with an Event of Default (EoD) notice. This EoD notice carries various payment penalties:

In the event of one or more failures within a month, then the availability price paid to that participant for that month will be reduced. For each Availability Window containing a failure the availability payment would be reduced by 1%, subject to a limit of 30% (i.e. participants can lose up to 30% of their monthly availability payment in any given month if they were to have 30 individual EoDs). A detailed list of NGET's EoDs can be found on the National Grid website.

A.3.3 Market size and composition of providers

Market size

NGET typically aims to procure a minimum of 1,800 MW of STOR, and says that it generally holds around 2,300 MW, but has been seen to hold up to 3,100 MW at any one time in the last two years.

In contrast to FFR and Fast Reserve, the STOR requirement is not considered as a MW for MW replacement with Operating Reserve – rather, the volumes that NGET holds account for:

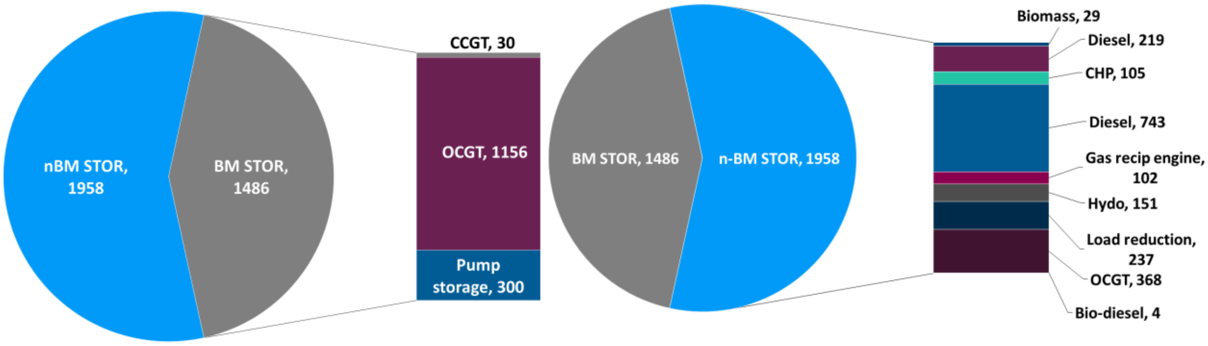
- The split of the STOR product (Committed vs Flexible),
- Recovery periods of different plant,
- The ramp rates of different plant, and
- The reliability of plant.

This also means that within contracted STOR volumes, the level that different providers are used can vary significantly.

Composition of providers

STOR capacity has historically been provided by a mix of BM and n-BM capacity. NGET publishes the technology types that were contracted for STOR in its fuel type summary reports, the latest of which was published for STOR season 8.5 (Jan 2015).

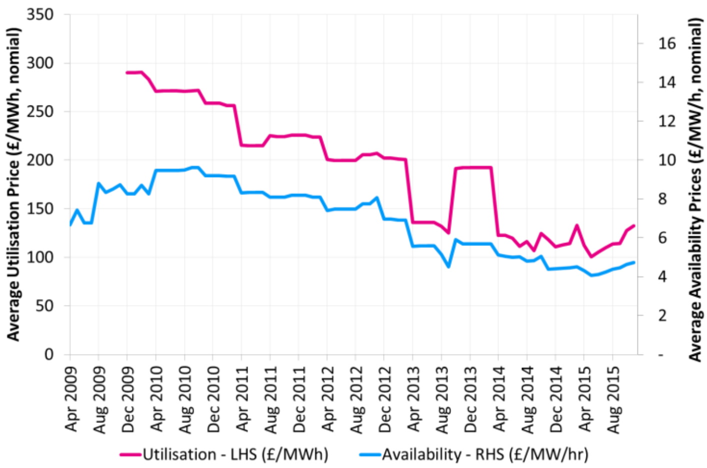
Figure 40 Contracted STOR capacity by technology type, January 2015[55]



A.3.4 Market prices

The average contracted STOR availability and utilisation price (monthly) has decreased steadily since 2010 (this includes all contracted capacity, including BM plant). This drop has occurred for a number of reasons, namely increased STOR market competition from low SRMC n-BM plant, and non-BM generators increasingly contracting their utilisation price more competitively.

Figure 41 Historical average monthly STOR utilisation and availability prices[56]

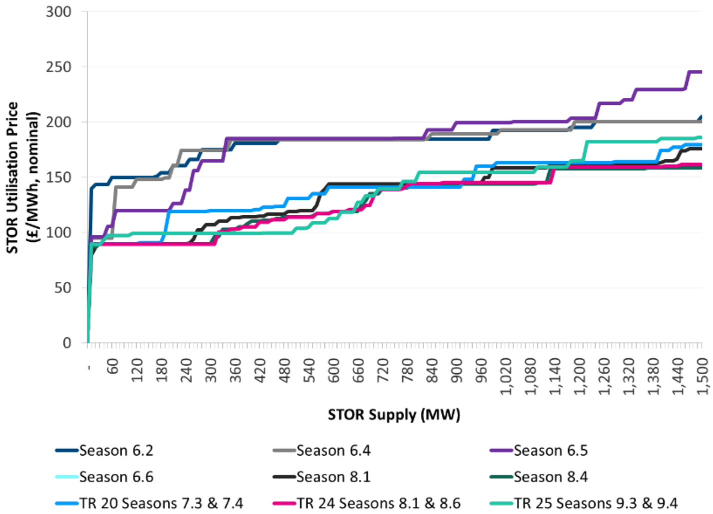


Similarly, the average monthly price does not show the spread of utilisation prices in the market, and the increased competitiveness at lower utilisation prices. This is shown in the increased volume contracted at low utilisation prices from 2012/13 through to 2014/15 Figure 42. Plant with lower utilisation prices tend to be considered to receive more utilisation, explaining competition at the front of the curve.

[55] National Grid fuel type summary reports, Season 8.5

[56] Baringa analysis, National Grid MBSS reports, Elexon n-BM STOR utilisation data

Figure 42 STOR Tendered Utilisation prices Seasons 6 (2012/13) and 9 (2015/16)[57]



A.4 Reactive Power services

A.4.1 Procurement

Procurement process

NGET runs tenders for ERPS every six months. NGET will announce a new tender by publication on its website. In general, ERPS contracts for successful bidders will start around six weeks after submission of bids.

Bid formation

ERPS bidders must bid a minimum of 12 months, and can extend this in six month blocks (no maximum tenor is specified). Bidders have the option of requesting one or more of the following fee categories in their tender submissions:

- An **Available Capability Price** (£/MVAr/hr) and/or
- A **Synchronised Capability Price** (£/MVAr/hr) and/or
- A **Utilisation Price** (£/MVAr/hr)

Selection

Similar to the other response and reserve services described, NGET assesses the economics of ERPS bids against the costs of utilising the Obligatory service instead, using a forecast of available BMUs that are able to provide the Obligatory service.

[57] National Grid, STOR Tender Round Reports

The Obligatory service receives a utilisation payment only, the value of which is calculated using a codified formula in the CUSC known as the "Default Payment Rate". The Default payment rate for a fully available BMU in January 2016 is £2.68/MVArh[58].

A.4.2 Penalties

Providers receive zero payment (across all fees) for a settlement period where:

- The provider fails a reactive or contract test in that settlement period,
- The provider fails to set its unit in voltage following mode,
- The provider is unable to react to a Reactive Dispatch Instruction from NGET,
- The provider has no MVAr range available to be able to contribute to voltage management, or
- The provider is affected by a "Reactive dispatch to zero MVAr network restriction".

Further, NGET has the right to terminate ERPS contracts under the following circumstances (note that these are written to apply to BMUs):

- Where the registered capacity of a BMU provider falls below 25 MW,
- Where a provider is unavailable for more than 84 consecutive days, after receiving instruction from NGET,
- Where a provider's reactive power capabilities are re-declared to be lower than the tendered value, or found to be lower than the tendered value, for a period of 28 consecutive days, ot
- Where a provider's reactive power capabilities are re-declared to be lower than the tendered value, or found to be lower than the tendered value, for a period of 45 aggregate days within a 365 day period.

A.4.3 Market size and composition of providers

Market size

Since April 2015, NGET has utilised between 2,300 GVArh and 2,800 GVArh per month to manage reactive power on the transmission system[59]. However, all of the capability was provided through the Obligatory (non-tendered) service (referred to as the Default Payment Mechanism or DPM). Importantly, NGET has not received any ERPS market tenders since October 2011, and no BMU has provided ERPS since October 2009.

NGET says that utilisation has reduced over the last decade as a result of more distributed generation and lower power flows across the system which has resulted in reduced reactive losses on the transmission network.

[58] NGET, 2015. Obligatory Reactive Power Service, Default Payment Rates.
[59] NGET, October 2015. 36th Reactive Market Report.

A.4.4 Market prices

There are no ERPS prices available given the absence of market bids. However, For the Obligatory (non-tendered) service, between April and November 2015, NGET spent £2.49/ MVArh on average. This is lower than the Default Payment Rates for these months, which varied between £2.65 and £2.75/ MVArh, suggesting that some units were paid a lower rate for lower performance.

Appendix B Assumptions used for modelling Balancing Services markets in 2027

B.1 Purpose of this section

To assess the impact of CLASS in 2027, it is necessary to make assumptions around the fundamental market dynamics at that point in time, so that a baseline stack of Balancing Services providers can be developed. This means making assumptions on:

- NGET's balancing requirements in 2027,
- The composition of the Balancing Services supply curves in 2027, and
- The underlying costs that providers are recovering in those markets.

This appendix describes these assumptions under each of these areas, and the supporting logic.

B.2 Demand for Balancing Services in 2027

While the specific design of Balancing Services products may change from what is required from providers today, it is unlikely that the design will move away from the need for a fast-acting form of response, followed by replacement reserves from slower-acting resources. Therefore, the 2014/15 market structure (i.e. Frequency Response markets, Fast Reserve Markets, and STOR markets) has been used for 2027 to form the baseline market assumptions.

However, the volume requirements of Balancing Services is expected to change in the future, as system undergoes a transition from most electricity being produced at scale at a few sites in the country, to a system has significant penetration of distributed generation, and renewable generation.

Two key drivers that are expected to increase demand for Balancing Services are the increase in largest infeed loss, and a reduction in inertia on the transmission system:

- Sizewell B is currently the largest infeed loss, at 1260 MW, but this it is expected to be superseded by the 1400 MW NSN interconnector when this commissions in 2020/21. At 1670 MW per unit, Hinkley C is expected to have a larger impact on holding volumes when it commissions, expected in the late 2020s.
- Inertia contained in large spinning conventional generators is expected to fall as a large portion of thermal plant retires over the next ten years. The effect of reducing inertia can be a faster rate of change of frequency as the system encounters imbalances between supply and demand, potentially reaching system thresholds more quickly. It is likely that NGET will have to take mitigating actions to contain such frequency events (e.g. by procuring inertia from market participants, or designing almost instantaneous balancing services[60]).

The volume calculations used for the 2027 analysis focus on the change in requirements driven by increase in infeed loss, as it is not yet clear what effect inertia will have on average volumes of

[60] The new Enhanced Frequency Response product is an example of a near-instantaneous responding product.

balancing services procured[61]. To derive a volume for 2027, Baringa has used a five year forecast of NGET's Balancing Services Requirements produced in draft document for the Power Responsive campaign. From this, the relationship between overall volumes and increase in infeed loss with the introduction of NSN was extrapolated forward to derive an overall volume requirement when 1670 MW of Hinkley C is commissioned (which is assumed to have occurred by 2027 in this analysis). This produces the following average year-round holding requirements:

Table 20 Assumed 2027 Balancing Services requirements (year-round average)

Balancing Service product	Volume (MW)
Frequency Response (sized on secondary requirement[62])	1,189
Fast Reserve	290
STOR	3,186

B.3 Supply of Balancing Services in 2027

Baseline stacks of Balancing Services providers in each of Frequency Response, Fast Reserve and STOR markets are constructed, based on new entrant and incumbent provider expectations, assumed technology capabilities, and underlying cost assumptions.

Provision from transmission connected thermal generation, and pumped storage

A growing development in the current markets is increasing participation in distributed generation, and aggregators of smaller market participants. NGET has released a statement[63] to the market which states that it believes this will continue, so that its current reliance on large transmission-connected generators for the provision of some services will reduce over time. Therefore, it is assumed that NGET will still rely on some provision of Balancing Services from current incumbent providers to an extent. The key players to be considered are CCGT and Pumped Storage providers (given that the majority of coal-fired power stations should have retired by 2027).

- For CCGT, the assumption is that a "Mandatory" or BM stack still exists in Frequency Response, but is used much less frequently than in the current market, as provision from Firm providers is found to be more cost effective for NGET (see Section B.4 below on cost assumptions). It is also assumed that the levels of CCGT participation in the current FFR

[61] In the System Operability Framework 2015, NGET published its view that it would need higher levels of Primary Frequency Response to manage lower levels of inertia on the system, but focused on the "Summer Minimum" (i.e. when most Frequency Response is needed) – rather than average year-round values, as this impact assessment is focused on).

[62] NGET currently sizes its overall holdings of frequency response on its secondary response requirement, as this is generally the greatest. The same calculations conducted on NGET's primary frequency response forecast imply that the annual average secondary holding requirement would still be greater than the average primary response requirement in 2027. However, it is noted that NGET could manage the issue of reducing inertia by procuring significantly more primary response (as implied in the System Operability Framework 2015), such that primary response could become the binding requirement – this is not captured by the infeed loss sizing methodology.

[63] See note: "Future Balancing Services", National Grid, 1 October 2015. (Published under the Power Responsive campaign).

market are maintained at the same levels as seen today, but again these are out-competed by new entrants.

- Pumped storage providers are assumed to participate using the same strategy that can be observed in the markets today, as it is assumed that there is an operational reason for the split of different Pumped Storage providers across the different products (e.g. FFR provision requires running at part load, which makes available storage capacity a constraint on the number of units that can provide Frequency Response). Note that Pumped storage providers are currently split across the FFR and Fast Reserve markets, with two providers currently participating in FFR and Fast Reserve respectively, and a third provider participating across the two markets.
- Other existing providers of balancing services in 2027 are assumed to include:
  - 700 MW of diesel engines (75% of diesel engines that NGET's Future Energy Scenarios (FES) scenarios assume to exist in 2020),
  - 400 MW of open cycle gas turbine (OCGT) capacity (as evidenced in NGET's STOR Fuel Type Reports)[64],
  - 50 MW of biomass capacity (similarly evidenced in NGET's STOR Fuel Type Reports),
  - 100 MW of Combined Heat and Power (CHP) capacity (similarly evidenced in NGET's STOR Fuel Type Reports), and
  - 150 MW of Hydro capacity (similarly evidenced in NGET's STOR Fuel Type Reports).

New entrants

The approach to defining new entrants is to develop an assumption for new entry for the whole market (i.e. on a MW installed basis), and then develop a further assumption on the proportion of this capacity that would be participating in Balancing Services (as opposed to other mutually exclusive products, such as sales of energy in the wholesale market, behind the meter services, or local grid management issues).

- **Gas and diesel engines:** The use of reciprocating engines (either standalone or in aggregate) is a trend that is expected to increase following the outcome of the first two Capacity Market auctions, where new build gas and diesel engines were able to secure long term contracts. NGET has taken a view on the level of distributed capacity that could exist on the system in 2020, and 2035 as part of its FES 2015 work, so it has been possible to interpolate a value for 2027 for both gas and diesel engine penetration by taking an average of installed capacity for each technology across the four FES 2015 scenarios. The difference in fuel prices has historically means that gas engines are more competitive than diesel engines in the wholesale energy market. It is assumed that this difference continues in 2027, and is reflected by assuming that 75% of installed diesel engine capacity participates in Balancing Services, while only 50% of installed gas engine capacity participates.
- **Electrochemical storage (batteries):** There are significant expectations for the level of battery installations (mainly lithium ion) that could connect to the GB system in the next decade. The call for expressions of interest for 200 MW of contracts for a sub-product of

[64] Last published in 2014. This value is rounded to the nearest

Frequency Response (Enhanced Frequency Response) attracted interest from over 800 MW of potential battery projects[65]. To reflect this, the working assumption for the baseline stacks is that there is initial entry of 200 MW of battery capacity into Balancing Services in 2017, which is followed by a simple assumed ramp-up in penetration over time by 100 MW per annum, to reach 1200 MW by 2027.

While Frequency Response is the current driver for new entry of batteries onto the system, it is expected that battery operators will be able to complement this in the future by providing other products to the market, such as time shifting of demand and supply, wholesale arbitrage, and grid management capabilities. To reflect this, the 2027 stack assumes that the initial 200 MW of battery capacity is fully dedicated to Balancing Services, while 50% of the assumed penetration of battery capacity thereafter is assumed to participate in Balancing Services (i.e. 700 MW in total participating in Balancing Services by 2027).

- **DSR:** NGET also has strong expectations for the level of DSR participating in all three markets, as evidenced in the same statement on the Future of Balancing Services. To reflect this, the total DSR capacity clearing the Transitional Capacity Auction in January 2016 (621 MW) is assumed to participate in markets, which is supplemented by a 50 MW per annum increase in capability, to deliver 1071 MW of DSR capacity by 2027. This is split into two types of DSR for modelling purposes "reduction only" meaning a demand turn-down service[66], and "low and high", meaning a symmetrical service to either increase or reduce consumption upon instruction.

  The assumed split between "reduction only" and "low and high" is 80%/20% of all installed capacity respectively, reflecting the current uncertainty around whether DSR can (or will be considered to be able to) provide a dynamic Frequency Response service.

- **Interconnection:** The NCEB is still undergoing comitology, but is expected to fully come into force well ahead of 2027. The NCEB provides for common merit orders of balancing products, and the reservation of interconnection capacity, for the sharing of Balancing Services across borders.

  TSOs will be responsible for defining the methodologies used to assess the case, and for the actual reservation of interconnector capacity following the adoption of the code. However, it has been assumed that reserving interconnector capacity to provide available capacity for Balancing Services will likely be uneconomic for the majority of borders with GB, for the majority of the time[67]. To reflect this trade-off, a simplified 50MW[68] of non-

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[65] See EFR Invitation to Tender, National Grid, April 2016

[66] For the purposes of Frequency Response modelling, the "reduction only" DSR capacity is assumed to offer static response, while the low and high is assumed to be treated as a dynamic capability.

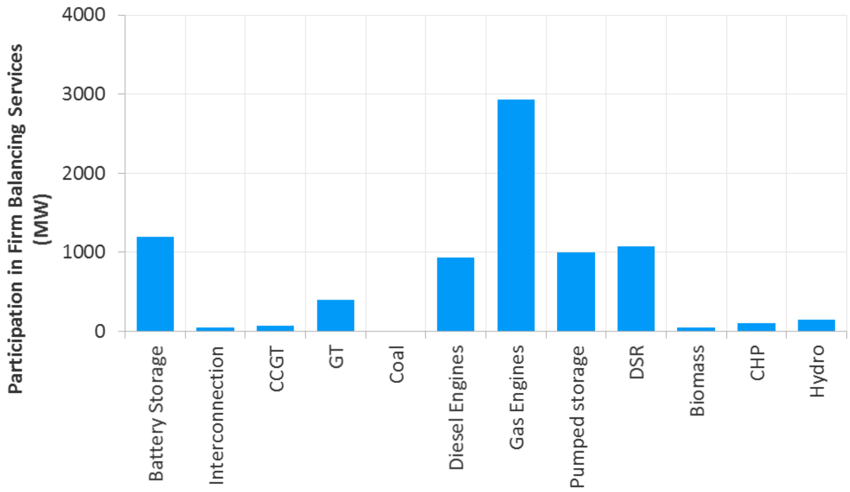
[67] The TSOs' comparison will be the anticipated total cost of procuring balancing capacity in GB (i.e. availability and expected utilisation costs), versus the projected value of interconnector spreads over the same time horizon, and the cost of utilising energy for utilisation from the neighbouring market. Assuming that utilisation costs from a flexible provider of energy in GB and, say, France, are around a similar level, the comparison is focused on GB availability fee, and the value of the interconnector spread in that same hour.

[68] 50 MW is used because NGET has previously indicated that it would not look to procure more than 50MW of Frequency Response from a single neighbouring market, to avoid creating knock-on balancing issues in those markets.

border-specific interconnection capacity has been assumed to participate in balancing services at any one time.

- **Renewables:** It is understood that renewable generation operators are increasingly looking at the potential to modify new or existing assets to provide Balancing Services, with this concept being explored under the DS3 programme in Ireland[69], and under the SOF 2015 in GB. However, the level of uncertainty around whether this will be taken up by TSOs, and whether it would be competitive with more conventional forms of flexibility, is still to be confirmed[70]. Therefore, the provision of flexibility from renewables has been omitted from the 2027 stack.
- There may also be increased participation from renewables capacity, where it has the technical capabilities to meet Balancing Services product specifications. It is currently uncertain as to whether this will be progressed, therefore no assumptions have been made as to the level of participation from renewable capacity.

Figure 43 Assumed capacity by technology participating in firm Balancing Services in 2027



Technology capabilities

The make-up of supply curves of Balancing Services markets is to a large extent defined by the ramping speed of different providers' technologies, and to a lesser extent, by the duration of service that can be provided by different technologies.

In 2027, it has been assumed that the same capabilities apply as in the current markets, though new assumptions have been developed for the participation of battery and interconnection capacity. These assumptions have been set out in Table 21 below.

[69] Delivering a Secure, Sustainable Electricity System – a programme of work that is addressing the challenges of integrating renewable generation onto the Irish system, part of which focuses on the introduction of new Balancing Services (Ancillary Services), and provision from new technologies.

[70] For example, some ancillary services may require retrofitting investments to existing plant, or additional investments to be made to new plant.

Table 21 Capabilities of different Balancing Services providers in 2027

Technology	FFR	Fast Reserve	STOR	Rationale
Battery Storage	Yes	-	-	Capable of near-instantaneous response; short durations suit small levels of storage capacity
Interconnection	Yes	-	-	High Voltage Direct Current (HVDC) interconnectors are capable of instantaneous response – though uncertain as to whether capacity will be utilised/reserved for longer duration products
CCGT	Yes	-	-	Observed in the current FFR market, but not in Fast Reserve and less so in STOR (assumed to provide these services through the Balancing Mechanism)
OCGT	-	-	Yes	As observed in current STOR market
Coal	(retired)	(retired)	(retired)	
Diesel Engines	Yes	-	Yes	As observed in current FFR and STOR markets
Gas Engines	-	Yes	Yes	As observed in current FR and STOR markets
Pumped storage	Yes	Yes	-	As observed in current FFR and Fast Reserve markets
DSR	Yes	-	Yes	As observed in current FFR and STOR markets
Biomass	-	-	Yes	As observed in current STOR markets
CHP	-	-	Yes	As observed in current STOR markets
Hydro	-	-	Yes	As observed in current STOR markets

B.4 Assumed bidding strategy for providers in 2027

Overview

To develop bid stacks for 2027, it is necessary to develop bids for individual providers of balancing services, both those deemed to be “existing” and “new”.

New providers (i.e. those that are deemed to still be in their payback period in 2027) are assumed to bid on the basis of the greater of either:

- Their “**Net LRMC**”, i.e. the level of revenue that needs to be recovered on an annuitised basis to recover capital, financing, and fixed operations and maintenance costs, net of any other fixed revenues that they can accrue alongside their participation in Balancing Services (e.g. TNUoS Triad avoidance, and Capacity Market revenues), or

- Their **opportunity cost**, being the foregone profit that would have be accrued from operating in the wholesale market during the hours within which Balancing Services are offered instead.

Existing providers of Balancing Services are assumed to bid on the basis of their opportunity costs (as defined above) only.

The following sections discuss how these bids were constructed.

Calculating Net LRMC-based bids

The following steps are used to calculate Net LRMC-based bids for new providers of balancing services (consisting of new batteries, and diesel engines):

- The annuitised revenue requirement is calculated, using capex, and fixed cost assumptions from Lazard's levelised cost of energy and storage analyses[71], and simplified 15% pre-tax real hurdle rates assumed across a payback period of 15 years.
- Next, fixed revenues are subtracted from the annuitised revenue requirement. Only a £30/kW value is used for CM revenues in 2027. No Triad value is assumed for the CLASS CBA.
- Then, the annuitised revenue requirement for each provider is split across the number of hours that the provider would likely look to make available for each balancing service. For example, provision of FFR across the entire year except for 255 hours in winter weekday evenings (to provide peaking energy for Triads) would result in the annuitised revenue requirement being divided over 8760-255 = 8505 hours.

Note that as the capex of batteries in particular is expected to decrease over time, the range of costs of batteries operating in the market in 2027 has been covered by calculating Net LRMCs for all the new entrants in each year leading up to 2027. This tends to have the effect that older batteries appear at the top of the bidding stack, compared to newer batteries which are more cost competitive and so appear in the middle of the stack.

Calculating Opportunity cost-based bids

Opportunity cost-based bids are calculated using a simplified 2027 wholesale market dispatch calculation as follows:

- DECC's forecast average electricity price for 2027[72] (£69/MWh, real 2015) is used alongside the shape observed in the N2EX day ahead hourly price for 2014/15, to develop an hourly price profile for 2027,

[71] Lazard, Levelised Cost of Energy Analysis – Version 9.0. November 2015. And Lazard, Levelised Cost of Storage Analysis – Version 1.0, also November 2015

[72] DECC Updated Energy and Emissions Projections, 2015 (February 2016 update)

- Each technology's efficiency, carbon intensity, and variable operations and maintenance costs are used alongside DECC's assumed fuel and carbon prices to determine a specific SRMC in 2027,
- The 2027 SRMCs are compared against the hourly prices to determine whether a typical plant would be economically viable to run, and the inframarginal rent that it would earn in each hour as a result. Note that as this is a simplified model, no start costs or minimum run times are assumed,
- It follows that the gross margin that each technology is assumed to need to recover in a Balancing Service, is the sum of the inframarginal rent lost across the year in the hours specific to providing that Balancing Service product. These opportunity costs are then divided across the number of hours of availability assumed for each Service:
  - For FFR this is the full year (8760 hours), or 8505 hours for technologies that are likely to be participating in Triad avoidance.
  - For Fast Reserve, 6692 hours per year of availability are assumed (reflecting NGET's current procurement window).
  - For STOR, providers are assumed to target all available windows in the year (i.e. 4135 hours per year, based on the 2014/15 year).