State of Charge Modelling and Analysis

May 2018

EXECUTIVE SUMMARY

This analysis has been undertaken to determine if any allowances outside the contracted response curve can be made for providers with battery assets in the Firm Frequency Response (FFR) market. The purpose is to test whether these allowances could assist with the battery asset's State of Charge (SoC) Management.

The modelling involved simulating events with modified FFR delivery profiles that better allow SoC management either by charging in the frequency deadband or by over-delivery of response.

The outputs of this analysis show that introducing these envelopes could potentially:

1. Reduce the maximum amount of response available in the event of a fault on the system
2. Cause frequency disturbances following an event
3. Result in an overall increase in frequency response requirements

Therefore we suggest that the FFR delivery envelope is not be altered to allow for SoC management.

BACKGROUND

Providers have asked for advice on how they can best manage state of charge (SoC) for battery assets providing FFR services. National Grid believes that providers are in the best position to manage their asset, however it is recognised that parameters for allowing SoC management may be required in certain situations.

We have therefore consulted with providers about the options that could aid SoC management. The ideas put forward have been modelled to understand the impacts on the electricity network.

ANALYSIS

Three suggestions for managing SoC were put forward by providers. The first is to allow charging in the frequency deadband (± 0.015 Hz). The second suggestion was over-delivery of response within an expanding or 'Type A' envelope or over-delivery in a gap or 'Type B' envelope as shown in Figure 1. For the purposes of this analysis the Type B is overdelivery by 20%. The third suggestion was to over- or under-deliver by a relatively small percentage (~ 5%) for all frequency deviations or 'Type C'. All three of these suggestions have been considered and various scenarios have been tested within our modelling suite.

The first suggestion; to charge in the frequency deadband, has been discounted as frequency does not spend enough time within the deadband (~ 9 to 15%) for this to make a significant impact on an asset's SoC. In order for this allowance to be effective for managing SoC it would need to be a high percentage of charging (~ 50%) which leads to adverse effects on the frequency when it moves in and out of the deadband. This suggestion was therefore discounted and not pursued any further in our analysis.

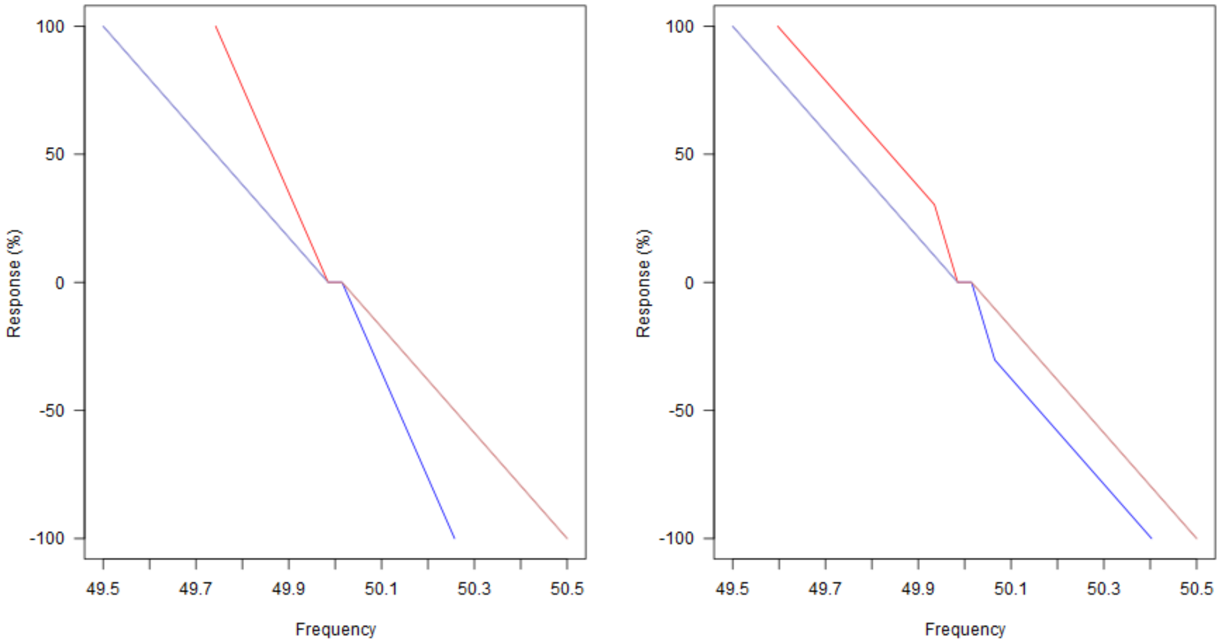

Figure 1 Proposed response envelopes: Type A (left) and Type B (right) showing contracted FFR response in grey and over-delivery from - 0.015 Hz in red and + 0.015 Hz in blue.

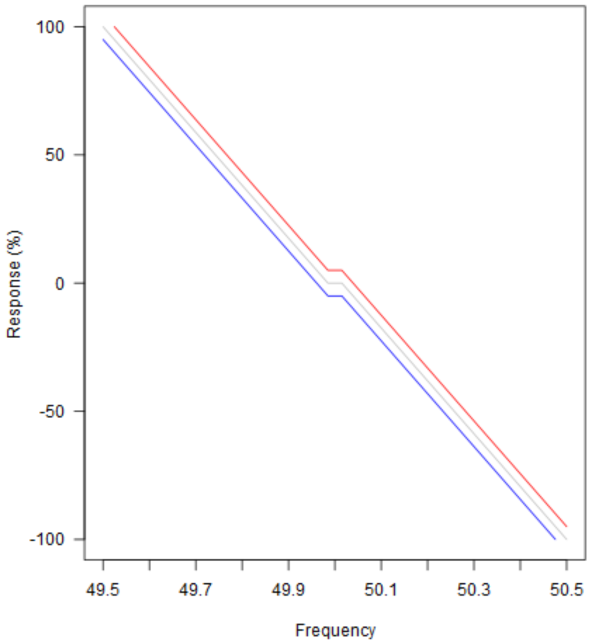

Figure 2 Proposed response envelopes: Type C showing 5% over-delivery in red or 5% under-delivery in blue at all frequency deviations.

METHODOLOGY

The Type A, B and C envelopes have been implemented into our models and three tests have then been performed in order to evaluate the impact of the envelopes on:

1. The state of charge of the battery providing response
2. System frequency following an event
3. Primary and Secondary response holding requirements

TEST ONE: THE IMPACT OF THE RESPONSE ENVELOPES ON THE SOC OF THE BATTERY OVER ONE MONTH

The SoC of the battery asset is sampled over a one month time period providing response. This analysis assumes a 200 MW battery with 2 hour capacity providing response 24/7 with a target SoC of 50%. The charging efficiency of the battery has been modelled at both 80% and 90% efficiency.

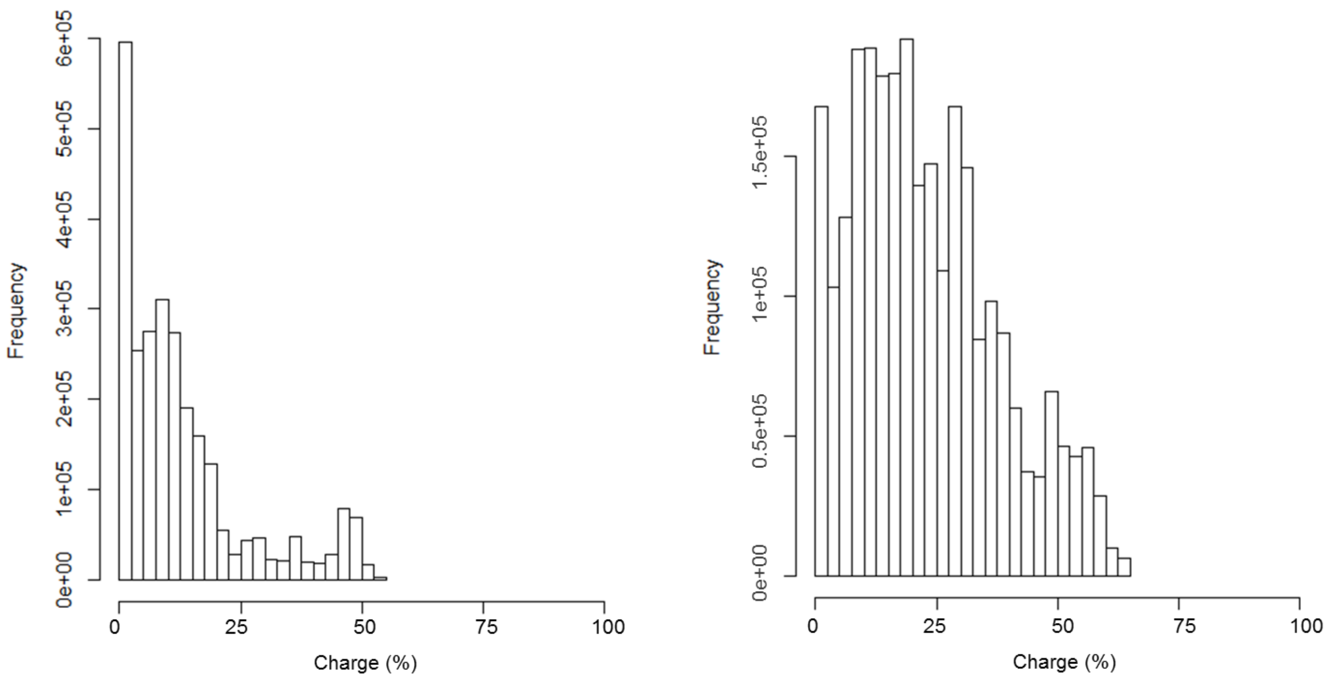

Figure 3 Occurrence of a battery's SoC (%) for a standard FFR delivery profile with no SoC management over one month (Left: 80% charging efficiency and Right: 90% charging efficiency)

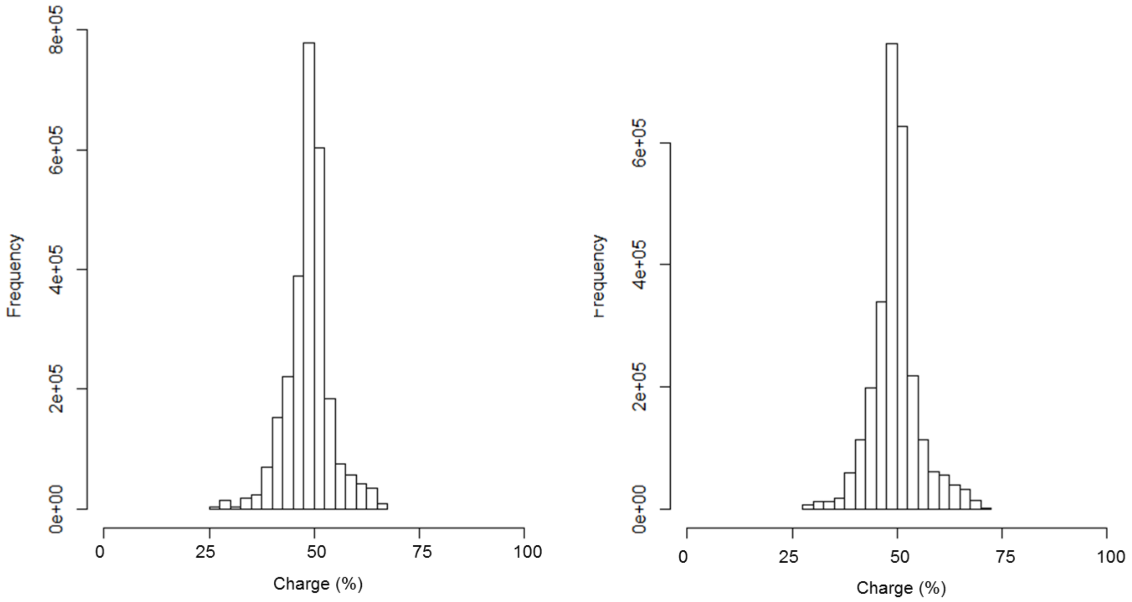

Figure 4 Occurrence of a battery's SoC (%) for Type B FFR envelope (Left: 80% charging efficiency and Right: 90% charging efficiency)

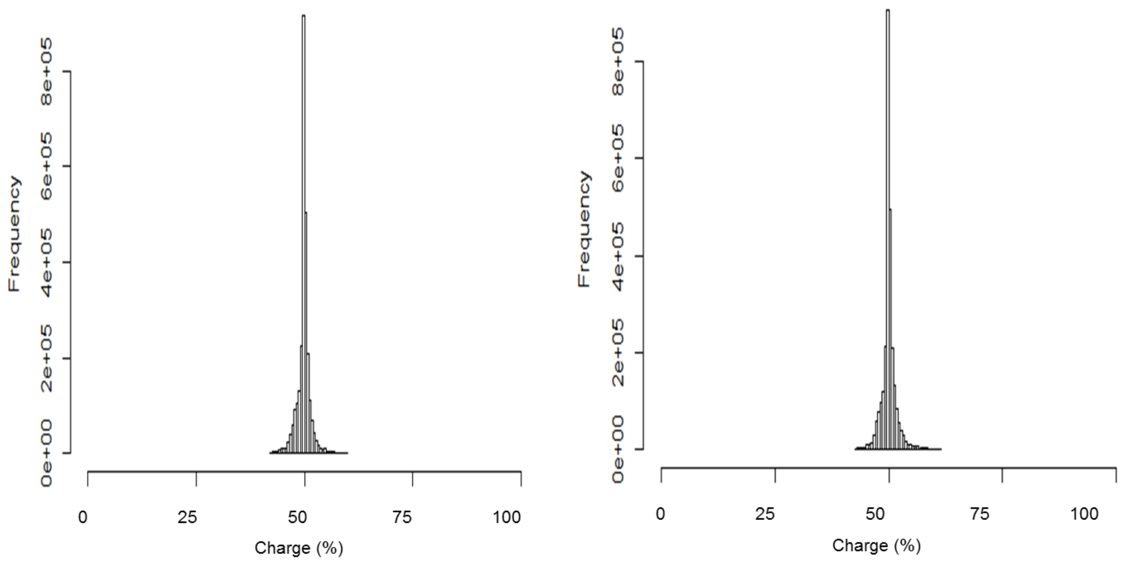

Figure 5 Occurrence of a battery's SoC (%) Type C FFR envelope over one month (Left: 80% charging efficiency and Right: 90% charging efficiency)

This analysis shows that a battery will often become depleted and therefore not be able to provide response for a large proportion of the month if there is no state of charge management in place (Figure 3). However if Type A, B or C is implemented these methods are effective in managing SOC (Type A is not shown here as results are similar to Type B).

Test one conclusion: Envelope Type A, B and C is an effective way of managing a battery asset's SoC.

TEST TWO: THE IMPACT OF THE RESPONSE ENVELOPES ON SYSTEM FREQUENCY FOLLOWING AN EVENT

The system frequency following a 100 MW generation loss, when system frequency is ~ 49.9 Hz is simulated. The difference in frequency recovery with a standard FFR delivery profile compared to the response from a Type B envelope is compared in Figure 6. The standard FFR delivery profile results in the loss of frequency to be quickly recovered and within a few seconds a stable frequency returns. This scenario is shown on the left of Figure 6. However with a Type B envelope as shown on the right, oscillations occur long after the event. These oscillations are likely to be due to sharp edges and lag times in the response envelope so that frequency is not able to settle and become stable. The frequency oscillations caused by Type A are not shown here but are more pronounced due to the fact that over delivery is not capped at 20%.

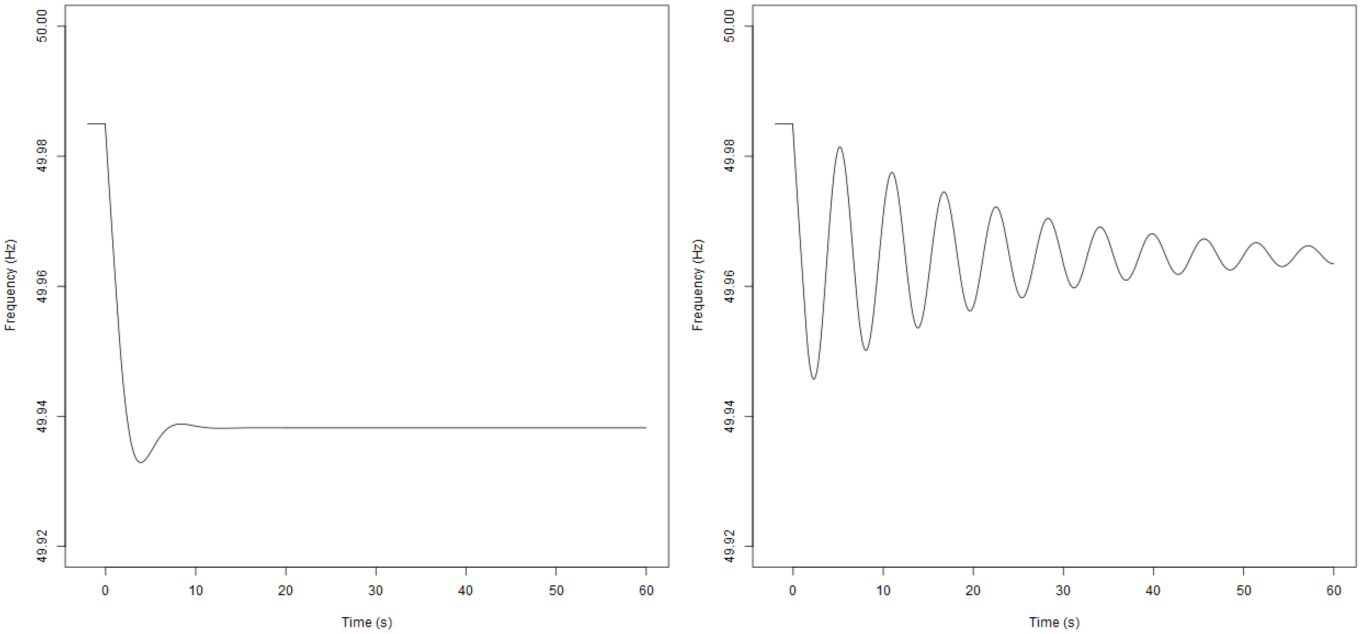

Figure 6: Frequency following a generation loss event. Left: event with standard FFR response, right: event with response at 20% over-delivery at Type B envelope

Test two conclusion: Type A and B response envelopes can cause frequency to become unstable after a generation loss event.

TEST THREE: THE IMPACT OF THE RESPONSE ENVELOPES ON RESPONSE HOLDINGS

The minimum response requirements for any given system conditions are defined far ahead of real time. Simulations of events such as the one outlined in this test are performed in order to define these minimum response requirements. In each simulation the minimum or 'worst-case' level of response delivery has been assumed. The 'worst-case' for these envelopes in this event are that both providers are managing their SoC at the time of the fault, therefore Type B has eroded 20% of its maximum available response and Type C will under-deliver response by 5% at all frequencies.

Table 1 and 2 show for a range of system conditions; inertias, demand and loss sizes the required volume of Primary, Secondary and High response holdings (assuming max delivery at 0.5 Hz). To produce these results, a generation loss on the system is assumed to occur when system frequency is at 49.9 Hz. The results are shown in Table 1 where 'FFR standard' refers to all response coming from a standard FFR delivery profile, and 'FFR Type B/C' refers to 500 MW of response from a Type B or C envelope alongside standard FFR providers. 'Delta' is the difference in holdings between the two.

Table 1 shows that for Scenario 1, an extra 437 MW of Primary would need to be procured as a result of 500 MW of Type B response and an extra 147 MW of Secondary. This is due to the fact that the maximum amount of response available as been eroded at the time of the fault on the system. Similar results are found for response envelopes Type A.

Scenario	Inertia (GVA.s)	Demand (GW)	Loss size (MW)	Primary FFR standard (MW)	Primary FFR Type B (MW)	Secondary FFR standard (MW)	Secondary FFR Type B (MW)	Primary Delta (MW)	Secondary Delta (MW)
1	200	20	-1000	1153	1590	570	717	437	147
2	300	30	-1000	414	566	423	570	153	147
3	400	40	-1000	214	378	276	423	164	147
Scenario	**Inertia (GVA.s)**	**Demand (GW)**	**Loss size (MW)**	**High FFR standard (MW)**	**High FFR Type B (MW)**	**NA**	**NA**	**High Delta (MW)**	**NA**
4	200	20	1000	1153	1590			437	
5	300	30	1000	384	517			133	

Table 1 The effect of response providers using Type B delivery envelope on required response holdings compared to standard FFR delivery.

Scenario	Inertia (GVA.s)	Demand (GW)	Loss size (MW)	Primary FFR standard (MW)	Primary FFR Type C (MW)	Secondary FFR standard (MW)	Secondary FFR Type C (MW)	Primary Delta (MW)	Secondary Delta (MW)
1	200	20	-1000	1153	1408	570	644	255	74
2	300	30	-1000	414	491	423	497	77	74
3	400	40	-1000	214	297	276	349	83	74
Scenario	Inertia (GVA.s)	Demand (GW)	Loss size (MW)	High FFR standard (MW)	High FFR Type C (MW)	NA	NA	High Delta (MW)	NA
4	200	20	1000	1153	1408			255	
5	300	30	1000	384	450			67	

Table 2 The effect of response providers using Type C delivery envelope on required response holdings compared to standard FFR delivery.

Table 2 shows that for Scenario 1, an extra 255 MW of Primary and an extra 74 MW of Secondary would need to be procured as a result of 500 MW of Type C response.

Test three conclusion: The effect of the Type B and C delivery envelopes is that more Primary, Secondary and High response will need to be procured in order to compensate for the possibility of erosion of the maximum response holdings and under-delivery. This will occur when providers with these envelopes are managing their SoC at the time of a generation loss event.

CONCLUSIONS

The outputs of this analysis show that introducing these envelopes could potentially:

1. Reduce the maximum amount of response available in the event of a fault on the system
2. Cause frequency disturbances following an event
3. Result in an overall increase in frequency response requirements

Therefore we suggest that the FFR envelope is not be altered to allow for SOC management. SoC management, however, will continue to be considered when designing the new response services as part of the Future of Balancing Services Product Roadmap.