Energy Market Company

# Notice of Market Rules Modification

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| **Paper No.:** | EMC/RCP/139/2024/RC386 |
| **Rule Reference:** | Appendix 6D, Sec A, B, C & D; Appendix 6E, Sec E.1A; Appendix 6G, Sec G.3; Chap 8 |
| **Proposer:** | EMC, Market Admin |
| **Date Received by EMC:** | 7 February 2024 |
| **Category Allocated:** | 2 |
| **Status:** | Supported by RCP |
| **Effective Date:** | NA |

This paper details EMC's proposed mechanism to incorporate State-of-Charge (SoC) data in the Market Clearing Engine (MCE), which acts as a constraint that improves the deliverability of scheduled quantities for Energy Storage Systems (ESS).

Rule modifications are proposed to:

a) adopt Option 2 as described in Section 3.2, where SoC data is provided by PSO to the EMC via the Network Status File before each dispatch period, and

b) model SoC in the MCE as described in Section 4 and Annex 1.

The RCP discussed these proposals at its 139th meeting and the panel **unanimously supported** the proposed recommendations to incorporate SoC data in the MCE.

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| **Date considered by Rules Change Panel:** | 13 March 2024 |
| **Date considered by EMC Board:** | |
| **Date considered by Energy Market Authority:** | |
| **Proposed rule modification:** | See attached paper |

**Reasons for rejection/referral back to Rules Change Panel (if applicable):**

| | | |
|---|---|---|
| PAPER NO. | : | **EMC/BD/xx/2024/xx** |
| RCP PAPER NO. | : | **EMC/RCP/139/2024/RC386** |
| SUBJECT | : | **INCORPORATION OF STATE-OF-CHARGE IN MCE MODELLING OF ESS**<br>**(ARISING FROM RC383: MODELLING OF ENERGY STORAGE SYSTEMS)** |
| FOR | : | **DECISION** |
| PREPARED BY | : | **LIM CHERN YUEN**<br>**SENIOR ECONOMIST** |
| REVIEWED BY | : | **POA TIONG SIAW**<br>**SVP, MARKET ADMINISTRATION** |
| DATE OF MEETING | : | **13 MAR 2024** |

## Executive Summary


This paper details EMC's proposed mechanism to incorporate State-of-Charge (SoC) data in the Market Clearing Engine (MCE), which acts as a constraint that improves the deliverability of scheduled quantities for Energy Storage Systems (ESS).

Rule modifications are proposed to:

a) adopt Option 2 as described in Section 3.2, where SoC data is provided by PSO to the EMC via the Network Status File before each dispatch period, and

b) model SoC in the MCE as described in Section 4 and Annex 1.

At the 139th RCP meeting held on 13th March 2024, the RCP **unanimously supported** EMC's recommendations.

The RCP recommends that the EMC Board:

a) **adopt** the proposed modifications to the Market Rules as set out in Annex 1; and

b) **seek the EMA's approval** of the proposed modifications to the Market Rules as set out in Annex 1.

## 1. Introduction

This paper details how State-of-Charge (SoC) data can be incorporated in the Market Clearing Engine (MCE), which acts as a constraint that improves the deliverability of scheduled quantities for Energy Storage Systems (ESS).

## 2. Background

At the 133rd Rules Change Panel (RCP) meeting in March 2023, paper RC383 proposed amending the MCE to more accurately model ESS, thus allowing dispatch schedules that better reflect the physical capabilities of ESS facilities.

At the meeting, EMC proposed to rely on MPs' self-commitment to implicitly manage SoC. However, the RCP had the following concerns if SoC is not incorporated into market clearing:

- The proposed modelling of ESS would not accurately reflect ESS' physical capability
- ESS operators would face difficulties in making offers reflective of ESS' capabilities within gate closure

As a follow-up, the RCP tasked the Technical Working Group (TWG) to examine:

(a) The feasibility of incorporating SoC in the MCE, the impact of doing so on the implementation timeline, and the system changes required

(b) The feasibility of alternative solutions (e.g., allow gate closure breach for ESS operators) to maintain self-commitment and allow for accurate MCE modelling of ESS

Items (a) and (b) are discussed in Sections 3 and 4.

## 3. Should SoC data be incorporated in the MCE?

At a high level, there are three options related to SoC, to ultimately facilitate accurate MCE modelling, elaborated upon in Sections 3.1 to 3.3 below.

At the 32nd TWG meeting on 24 Jan 2024, the TWG unanimously supported EMC's recommendation to adopt Option 2 as it is most likely to:

- increase ESS asset utilisation (relative to Option 1)[1],
- minimise manual effort and potential for human error from ESS operators and MAU (relative to Option 1), and
- incur lower costs for system changes (relative to Option 3)[2].

### *3.1 Option 1: Status quo with enhanced compliance checks*

Accurate MCE modelling of ESS require ESS offers that reflect physical capability. In the absence of SoC modelling in the MCE, this would then require compliance mechanisms that ensure ESS operators submit offers that already account for SoC limitations.

The status quo already incentivises such offer behaviour, for e.g.,

- Automatic Financial Penalty Scheme for deviations in energy
- No payment for non-delivery of ancillary services

[1] Further elaborated upon in Section 5.

[2] Effort estimates for each option are provided in Section 7.

- Downgrading of Reserve Provider Group if there are sufficient instances of reserve non-delivery

However, SoC may change significantly over the course of 65 minutes (between gate closure and start of trading period), depending on scheduled energy and ancillary service activation across the 65 minutes. The RCP noted that under the status quo, ESS operators may have to offer very conservatively, or frequently breach gate closure to ensure compliance with dispatch.

### 3.1.1 What should enhanced compliance mechanisms aim to achieve?

As such, compliance mechanisms specific to ESS facilities should have two main (arguably competing) aims:

1. To strengthen market confidence in dispatch schedules – ESS operators should be incentivised to offer responsibly (i.e., as far as they can tell, ESS should be able to fulfil offers whenever scheduled).
2. To encourage ESS utilisation – Compliance mechanisms should not be overly restrictive to ESS operations.

### 3.1.2 How should these compliance checks be conducted?

To achieve the aims stated in Section 3.1.1, the proposed workflow for Option 1 is as follows:

1. On a regular basis (e.g., monthly), based on batch SoC data provided by PSO, MAU checks for all periods, for all ESS Generation Registered Facilities (GRFs), that both (a) and (b) below are true.

    (a) SoC as of 5 minutes before the start of period T is sufficiently high to fulfill the remaining 5 minutes of energy schedule for period T-1, as well as the sum of offers for energy discharging, reserves (assuming activation) and regulation (assuming full up-regulation) for period T[3]:

$$
\begin{aligned}
& SoC_{T-5} - \frac{PriorScheduledDischarging \times \frac{1}{12}h}{MaxCapacity \times DischargingEfficiency} \\
& + \frac{PriorScheduledCharging \times \frac{1}{12}h \times ChargingEfficiency}{MaxCapacity} \\
& - \frac{Sum\ of\ EnergyDischarging\ Offers \times \frac{1}{2}h}{MaxCapacity \times DischargingEfficiency} \\
& - \frac{Sum\ of\ PriRes\ Offers \times \frac{1}{6}h + Sum\ of\ ConRes\ Offers \times \frac{1}{3}h}{MaxCapacity \times DischargingEfficiency} \\
& - \frac{Sum\ of\ Reg\ Offers \times \frac{1}{2}h}{MaxCapacity \times DischargingEfficiency} \geq MinSoC
\end{aligned}
$$

    (b) SoC as of 5 minutes before the start of the period is sufficiently low to fulfill the remaining 5 minutes of energy schedule for period T-1, as well as the sum of offers

[3] These inequalities are similar to those in Sections 4.1 and 4.2 below.

for energy charging and regulation (assuming full down-regulation and no reserve activation) for period T[4]:

$$SoC_{T-5} - \frac{PriorScheduledDischarging \times \frac{1}{12}h}{MaxCapacity \times DischargingEfficiency} + \frac{PriorScheduledCharging \times \frac{1}{12}h \times ChargingEfficiency}{MaxCapacity} + \frac{Sum\ of\ Energy\ Charging\ Offers \times \frac{1}{2}h \times ChargingEfficiency}{MaxCapacity} + \frac{Sum\ of\ Reg\ Offers \times \frac{1}{2}h \times ChargingEfficiency}{MaxCapacity} \leq MaxSoC$$

2. When an ESS GRF breaches gate closure, it will be reported by MAU to the MSCP for investigation. Additional gate closure exemptions[5] shall be required for ESS facilities when there are "unexpected events", i.e.,

   (a) when PSO issues a Dispatch Notice to charge/discharge, provide reserves or regulation, resulting in inability to fulfil offers (if scheduled) for the relevant period and subsequent periods that fall within gate closure, due to SoC limitations; or

   (b) when reserves and/or regulation are activated, resulting in inability to fulfil offers (if scheduled) for subsequent periods.

   ESS operators shall not be penalised by the MSCP for breaching gate closure, if the MSCP deems that either of (a) or (b) above applies. For avoidance of doubt, existing gate closure exemptions in Market Rules Chapter 6 Section 10.4.1.1 (e.g., due to forced outages) continue to apply to ESS GRFs.

Option 1, as detailed above, is not recommended as it relies heavily on ESS operators submitting offer variations in response to (potentially rapidly) changing SoC, which may result in human error and/or overly conservative offer behaviour. Furthermore, there is significant effort required for MAU compliance checks.

### 3.2 Option 2: SoC data provided by PSO

The proposed workflow for Option 2 is as follows:

- As per the status quo, ESS provide SoC data to PSO via the Remote Terminal Unit (RTU) every few seconds.
- PSO compiles this SoC data and provides to EMC via the Network Status File, 10 minutes before each period.
- System changes will be required for EMC to incorporate SoC in the MCE formulation.

EMC's recommendation is Option 2 as it is most likely to:

- increase ESS asset utilisation (relative to Option 1)[6],

[4] These inequalities are similar to those in Sections 4.1 and 4.2 below.

[5] Market Rules Chapter 6 Section 10.4.1.1

[6] Further elaborated upon in Section 5.

- minimise manual effort and potential for human error from ESS operators and MAU (relative to Option 1), and
- incur lower costs for system changes (relative to Option 3)[7].

## 3.3 Option 3: SoC data provided by ESS operators

The proposed workflow for Option 3 is as follows:

- ~6 minutes before each period, ESS operators will automatically transmit SoC data to EMC via a new web service, separate from the existing offer module.
- System changes will be required for EMC and each ESS operator to facilitate this SoC data transmission.
- System changes will be required for EMC to incorporate SoC in the MCE.
- On a regular (e.g., monthly) basis, PSO to provide batch data on SoC for all ESS GRFs, as of 6 minutes before each period – this will be based on RTU readings of SoC for each ESS.
- Post hoc compliance checks by MAU will be required, as detailed below:
    - MAU to check for all periods, for all ESS GRFs, that the SoC data submitted by ESS operators in real time are in line with SoC data provided by PSO ex-post.
    - The allowed difference in SoC (in percentage points) shall be equivalent to ±5 minutes at full charge/discharge:
        - E.g., for a 200MW/200MWh ESS, 5 minutes of full charge/discharge will result in a change in SoC of ±8.3pp.
    - The MSCP may impose penalties should the difference in SoC exceed the above threshold for any period.

Option 3, as detailed above, is not recommended as it involves significantly higher costs relative to Option 2[8], with the only benefit being that SoC data is received by EMC slightly closer to the start of each period (i.e., ~6 minutes beforehand under Option 3 vs 10 minutes beforehand under Option 2).

## 3.4 Technical Working Group's Recommendation

At the 32nd TWG meeting on 24 Jan 2024, the TWG unanimously supported EMC's recommendation to adopt Option 2 as it is most likely to:

- increase ESS asset utilisation (relative to Option 1)[9],
- minimise manual effort and potential for human error from ESS operators and MAU (relative to Option 1), and
- incur lower costs for system changes (relative to Option 3)[10].

[7] Effort estimates for each option are provided in Section 7.

[8] Effort estimates for each option are provided in Section 7.

[9] Further elaborated upon in Section 5.

[10] Effort estimates for each option are provided in Section 7.

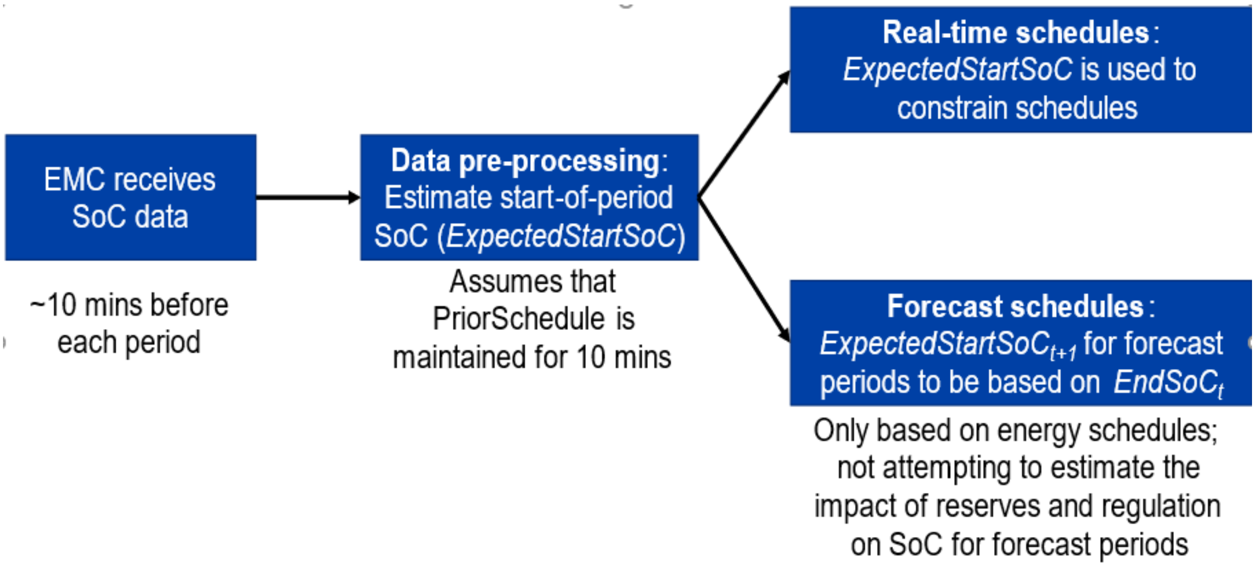
4. **How should SoC be modelled in the MCE?**

Should either Option 2 or 3 be implemented (i.e., EMC regularly receives SoC data before every period), the SoC data have to then be modelled in the MCE, ultimately to constrain ESS dispatch schedules generated by the MCE.

MCE modelling of SoC is the same under Options 2 and 3, except that Option 3 may involve EMC receiving SoC data a few minutes closer to the start of period (i.e., T-10 minutes for Option 2, T-6 minutes for Option 3).

An overview of proposed SoC modelling in the MCE is shown in Figure 1 below, further elaborated in Sections 4.1 to 4.3.

**Figure 1: Overview of SoC modelling in the MCE (applicable to Options 2 and 3)**[11]




## *4.1 Data pre-processing*

This step involves estimating *ExpectedStartSoC* at the beginning of the period, based on *StartSoC* data received 10 minutes prior.

At a high level, proposed formulae are illustrated below.

- If the ESS is discharging (*PriorScheduledGeneration* ≥ 0):

$$ExpectedStartSoC = StartSoC - \frac{PriorScheduledGeneration \times \frac{1}{6}h}{MaxCapacity \times DischargingEfficiency}$$

- If the ESS is charging (*PriorScheduledGeneration* < 0):

$$ExpectedStartSoC = StartSoC - \frac{PriorScheduledGeneration \times \frac{1}{6}h \times ChargingEfficiency}{MaxCapacity}$$

- *ExpectedStartSoC* will be further capped within the ESS's operating range *[MinSoC, MaxSoC]*, as provided by the ESS operator and approved by the PSO.

[11] For simplicity, within Figure 1, we assume Option 2 is implemented. Between Options 2 and 3, modelling of SoC in the MCE is the same, except that Option 3 involves EMC receiving SoC data a few minutes closer to the start of period (i.e., T-10 minutes for Option 2, T-6 minutes for Option 3).

### Worked example (1): calculation of *ExpectedStartSoC*

For all scenarios (1) to (4) in the table below, we assume the same inputs and parameters:

*StartSoC* = 20%

*ChargingEfficiency* = 99%

*DischargingEfficiency* = 99%

*MaxCapacity* = 10MWh

*MinSoC* = 10%

*MaxSoC* = 90%

**TABLE 1: Worked example for calculation of *ExpectedStartSoC***

| *PriorSchedule* | *ExpectedStartSoC* | Comment |
|---|---|---|
| - 6MW (charging) | $20\% - \frac{(-6\text{MW}) \times \frac{1}{6}\text{h} \times 99\%}{10\text{MWh}} = 29.90\%$ | |
| - 3MW (charging) | $20\% - \frac{(-3\text{MW}) \times \frac{1}{6}\text{h} \times 99\%}{10\text{MWh}} = 24.95\%$ | |
| + 3MW (discharging) | $20\% - \frac{3\text{MW} \times \frac{1}{6}\text{h}}{10\text{MWh} \times 99\%} = 14.95\%$ | |
| + 6MW (discharging) | $20\% - \frac{6\text{MW} \times \frac{1}{6}\text{h}}{10\text{MWh} \times 99\%} = 9.90\%$ | As 9.90% < 10% (*MinSoC*), *ExpectedStartSoC* is capped/adjusted to be 10% |

With *ExpectedStartSoC* calculated above, EMC will further calculate the energy limit (in MWh) that the ESS is able to charge and discharge, represented by *SoCChargeLimitMWh* and *SoCDishargeLimitMWh* respectively, following the equations below:

- ***SoCDischargeLimitMWh*** = *(ExpectedStartSoC− MinSoC)* × *MaxCapacity*
- ***SoCChargeLimitMWh*** = *(MaxSoC − ExpectedStartSoC)* × *MaxCapacity*

### 4.1.1 Can StartSoC be transmitted closer to the start of each period?

The TWG queried whether *StartSoC* can be transmitted from PSO to EMC closer to the start of the period (e.g., T-6 minutes). If the MCE is able to obtain *StartSoC* data a few minutes closer to the start of the period, it may result in more accurate estimates for *ExpectedStartSoC*.

However, EMC notes that to enable this one benefit will require significant system changes for both PSO and EMC – either for PSO to send the Network Status File at T-6 minutes, or for PSO to send a separate file only containing *StartSoC* at T-6 minutes. Both potential solutions incur significant costs and are not included in PSO's recent Energy Management System upgrade. Furthermore, availability of SoC data closer to the start of each period does not entirely eliminate the estimation error for *ExpectedStartSoC*.

At this point in time, EMC does not recommend the transmission of *StartSoC* data from PSO to EMC at T-6 minutes, due to the significant costs to be incurred, and limited benefits.

#### 4.1.2 Fallback mechanism for StartSoC

There may be cases where the *StartSoC* value is not provided to EMC for a particular period (e.g., Network Status File is unavailable). In such cases, *ExpectedStartSoC* shall be the *EndSoC* value calculated for the prior period (see Section 4.3 below for calculation of *EndSoC*).

### 4.2 Proposed SoC related MCE Constraints

Given *the discharge/charge limit* (in MWh*)* calculated in the previous section 4.1, it can then be used within new MCE constraints to limit real time energy, regulation and reserve schedules for ESS.

In particular, it is assumed

- in order to fulfil energy obligation, the ESS shall remain charging/discharging for 30 minutes following its energy schedule;
- in order to fulfil regulation obligation, the ESS shall be able to provide both regulation up and regulation down continuously for 30 minutes following regulation schedule;
- in order to fulfil primary reserve obligation, the ESS should minimally be able to provide 10 minutes of primary reserve from the beginning of the dispatch period;
- in order to fulfil contingency reserve obligation, the ESS should minimally be able to a) provide 30 minutes of contingency reserve; and b) provide 20 minutes of contingency reserve after 10 minutes of primary reserve activation.

The MCE will need to ensure that scheduled energy[12], reserve and regulation quantities will not result in the ESS' SoC going beyond *the discharge/charge limit* throughout the period.

#### 4.2.1 Minimum SoC Constraints

Three new constraints, as detailed below, are proposed to ensure the scheduled energy, reserve and regulation quantities will not result in the ESS' SoC going below MinSoC.

*Constraint 1: Combined Reserves Energy Regulation Minimum SoC Constraint*

Firstly, we considered the scenario where ESS need to provide the following services

a) sustained *energy* discharging/charging for *30 minutes*;

b) sustained *regulation* (up) provision for 30 *minutes*;

c) sustained primary *reserve* provision for *10 minutes*; and

d) sustained *contingency reserve* provision for remaining *20 minutes*

This means the total amount of energy consumed for the above services should not exceed its *discharge limit*, as illustrated in the constraint below.

$$\frac{EnergyStorageDischarging \times \frac{1}{2}h + Regulation \times \frac{1}{2}h + PrimaryReserve \times \frac{1}{6}h + ContingencyReserve \times \frac{1}{3}h}{DischargingEfficiency}$$

$$-EnergyStorageCharging \times ChargingEfficientcy \times \frac{1}{2}h$$

$$\leq SoCDischargeLimitMWh$$

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[12] Scheduled energy quantities are represented by *EnergyStorageDischarging* and *EnergyStorageCharging* within the proposed formulae changes facilitating ESS modelling.

Illustrative example:

Assuming a 100MWh ESS offers to discharge 10MW of energy, while also offering to provide 10MW of regulation, 30 MW of primary reserve and 60 MW of contingency reserve. In order to be scheduled for all of the above, the MCE will require its SoC to be sufficiently high, to potentially provide:

- 10MW for 30 minutes (1/2 h) to fulfil its energy obligation (i.e., 5MWh),
- 10MW for 30 minutes (1/2 h) to fulfil its regulation (up) obligation (i.e., 5MWh),
- 30MW for 10 minutes (1/6 h) to fulfil its primary reserve obligation (i.e., 5MWh), and
- 60MW for 20 minutes (1/3 h) to fulfill its contingency reserve obligation (i.e., 20MWh).

Therefore, the ESS would need to be capable of discharging 35MWh within the period.

For an ESS with a discharging efficiency of 99% and maximum capacity of 100MWh, discharging of 35MWh will require a drop of stored energy by 35.35MWh (35MWh / 99%). Assuming its *MinSoC* is 10%, the ESS's *ExpectedStartSoC* should be at least 45.35% in order to have discharge limit of 35.35MWh.

*Constraint 2: Combined Primary Reserve Energy Regulation Minimum SoC Constraint*

Secondly, we considered the scenario where ESS needs to provide the following services within the first 10minutes of a dispatch period.

a) sustained *energy discharging/charging* for *10 minutes*;

b) sustained *regulation (up)* provision for *10 minutes*; and

c) sustained *primary reserve* provision for *10 minutes*;

This means the total amount of energy consumed for the above services within 10 minutes, should not exceed its discharge limit, as illustrated in the constraint below.

$$\frac{EnergyStorageDischarging \times \frac{1}{6}h + Regulation \times \frac{1}{6}h + PrimaryReserve \times \frac{1}{6}h}{DischargingEfficiency}$$

$$-EnergyStorageCharging \times ChargingEfficientcy \times \frac{1}{6}h$$

$$\leq SoCDischargeLimitMWh$$

This constraint is necessary in the event the ESS is scheduled excessively for primary reserve while being scheduled to charge at the same time. This will ensure the ESS's stored energy plus the energy has been charged in the first 10 minutes is sufficient to meet its primary reserve and regulation obligation.

Illustrative example:

Assuming a 100MWh ESS offers to *charge* 10MW of energy, while also offering to provide 60 MW of primary reserve. In order to be scheduled for all of the above, based on Constraint 1 above alone, the ESS only need to have a discharge limit of 5MWh (i.e. charge 5MWh for energy and discharge 10MWh for primary reserve).

However, if the ESS is activated to provide primary reserve from the beginning of the period, by T+10minutes, the amount of energy needs to be discharged will be at 8.3 MWh (60MW x 1/6hr – 10MW x 1/6hr) to fulfil both primary reserve and energy (charging) obligation.

Constraint 2 is thus introduced to require its SoC to be sufficiently high, to potentially:

- provide 60MW for **10 minutes** (1/6 h) to fulfil its primary reserve obligation (i.e., 10MWh),
- charge 10MW for **10 minutes** (1/6 h) to fulfil its energy obligation (i.e. -1.66 MWh)

by T+10 min, to ensure the allowable discharge limit is no less than 8.3MWh.

*Constraint 3: Combined Contingency Reserve Energy Regulation Minimum SoC Constraint*

Lastly, we considered the scenario where ESS need to provide the following services.

a) sustained *energy discharging/charging* for *30 minutes*;

b) sustained *regulation (up)* provision for *30 minutes*; and

c) sustained ***contingency reserve*** provision for ***30 minutes***;

This means the total amount of energy consumed for the above services within the 30 minutes dispatch period, should not exceed its discharge limit, as illustrated in the constraint below.

$$\frac{EnergyStorageDischarging \times \frac{1}{2}h + Regulation \times \frac{1}{2}h + ContingencyReserve \times \frac{1}{2}h}{DischargingEfficiency}$$

$$-EnergyStorageCharging \times ChargingEfficientcy \times \frac{1}{2}h$$

$$\leq SoCDischargeLimitMWh$$

This constraint is necessary in the event the ESS starts to provide for contingency reserve from beginning of the dispatch period and sustain for 30 minutes. This will ensure the ESS's stored energy is sufficient to provide its energy, contingency reserve and regulation continuously for 30 minutes.

<u>Illustrative example:</u>

Assuming a 100MWh ESS offers to discharge 10MW of energy, while also offering to provide 10MW of regulation, 30 MW of primary reserve and 60 MW of contingency reserve.

To fulfil Constraint 1 alone, the Minimum ExpectedStartSoC needs to be at 45.35% as illustrated above.

However, if the ESS is activated to provide contingency reserve from the beginning of the dispatch period, the total energy required to be discharged would be:

- 10MW for 30 minutes (1/2 h) to fulfil its energy obligation (i.e., 5MWh),
- 10MW for 30 minutes (1/2 h) to fulfil its regulation (up) obligation (i.e., 5MWh), and
- 60MW for <u>30 minutes</u> (1/2 h) to fulfill its <u>contingency reserve</u> obligation (i.e., 30MWh).

Therefore, the ESS would need to be capable of discharging 40MWh within the period.

For an ESS with a discharging efficiency of 99% and maximum capacity of 100MWh, discharging of 40MWh will require a drop of stored energy by 40.4MWh (40MWh / 99%). Assuming its *MinSoC* is 10%, the ESS's *ExpectedStartSoC* should be at least 50.4% in order to have discharge limit of 40.4MWh.

### *4.2.2 Maximum SoC Constraint*

Maximum SoC Constraint is introduced such that the scheduled energy and regulation (down) quantities will not result in the ESS' SoC going above MaxSoC.

*Constraint 4: Combined Energy Regulation Maximum SoC Constraint*

This constraint is to ensure that the StartSoC is low enough to allow ESS to charge to cover its energy and/or meet its regulation (down) obligations, assuming no reserve activation[13], as illustrated in the constraint below:

$$(EnergyStorageCharging \times \frac{1}{2}h + Regulation \times \frac{1}{2}h) \times ChargingEffcientcy$$

$$- \frac{EnergyStorageDischarging \times \frac{1}{2}h}{DischargingEfficiency}$$

$$\leq SoCChargeLimitMWh$$

Illustrative example:

Assuming a 100MWh ESS offers to charge 10MW of energy and provide 10MW of regulation (it may also offer to provide reserve, but those quantities are irrelevant in this example), In order to be scheduled for its offered energy and regulation quantity, the MCE will require its SoC to be sufficiently low, such that its charge limit is sufficient to provide 10MW regulation (down) and energy charge of 10MW for 30 minutes (i.e., 10 MWh in total).

For an ESS with a charging efficiency of 99% and maximum capacity of 100MWh, this will result in an SoC increase of 9.9% (10MWh x 99% /100MWh)). Assuming its *MaxSoC* is at 90%, the ESS's *ExpectedStartSoC* should not exceed 80.1% in order to be scheduled such energy and regulation quantity.

### 4.3 Forecast schedules

In order for forecast schedules to correctly reflect the SoC change due to prior energy schedules, ExpectedStartSoC will have to be forecasted for each ESS, for each period within all forecast runs (i.e., Look Ahead Run, Day Ahead Run, Week Ahead Run) as well.

It is proposed for $ExpectedStartSoC_{t+1}$ for forecast periods to be based on $EndSoC_t$, where:

- If the ESS is discharging ($EnergyStorageDischarging_t > 0$),

$$EndSoC_t = ExpectedStartSoC_t - \frac{EnergyStorageDischarging_t \times \frac{1}{2}h}{MaxCapacity \times DischargingEfficiency}$$

- If the ESS is charging ($EnergyStorageCharging_t > 0$),

$$EndSoC_t = ExpectedStartSoC_t + \frac{EnergyStorageCharging_t \times \frac{1}{2}h \times ChargingEfficiency}{MaxCapacity}$$

[13] Reserve schedules are not considered in the *MaxSoC* constraint, as reserve activation lowers SoC. For the *MaxSoC* constraint, it has to consider the most extreme scenario of the ESS scheduled to charge but not activated for reserves, resulting in the maximum potential increase in SoC.

### Worked example (2): Calculation of *EndSoC*

For all periods (1) to (3) in the table below, we assume the same inputs and parameters:

*EnergyStorageTransfer* = +3MW (scheduled to discharge the same energy output each period)

*ChargingEfficiency* = 99%

*DischargingEfficiency* = 99%

*MaxCapacity* = 10MWh

*MinSoC* = 10%

*MaxSoC* = 90%

**TABLE 2: Worked example for calculation of *EndSoC***

| Period | *ExpectedStartSoC* | *EndSoC* |
|---|---|---|
| 1 | 60% | $60\% - \frac{3\text{MW} \times \frac{1}{2}\text{h} \div 99\%}{10\text{MWh}} = 44.85\%$ |
| 2 | 44.85% | $44.85\% - \frac{3\text{MW} \times \frac{1}{2}\text{h} \div 99\%}{10\text{MWh}} = 29.70\%$ |
| 3 | 29.70% | $29.70\% - \frac{3\text{MW} \times \frac{1}{2}\text{h} \div 99\%}{10\text{MWh}} = 14.5\%$ |

The above formulae do not attempt to estimate the impact of reserves and regulation on SoC for forecast periods.

## 5. What are the benefits of incorporating SoC in the MCE?

Incorporating SoC in the MCE[14] gives at least four types of beneficial impacts to ESS operations and the wholesale market, as elaborated on in the subsequent sections.

Pertaining to the benefits illustrated in Sections 5.2, 5.3 and 5.4, EMC could only draw up illustrative examples, based on simplified assumptions and dummy data. EMC did not conduct analysis based on actual historical data because:

- Actual historical data pertaining to SoC levels, ESS offers and ESS schedules are commercially sensitive.
- Even with historical data (where SoC is not incorporated in the MCE), it is not realistic to compare against a hypothetical counterfactual scenario (where SoC is incorporated in the MCE), which would logically have materially changed ESS offer patterns.

The purpose of the illustrative examples in Sections 5.2-5.4 is not to quantitatively predict how large the benefits of incorporating SoC in the MCE are, but to provide a qualitative description of potentially significant benefits of incorporating SoC in the MCE.

[14] The comparisons within this Section 5 are between Option 1 (without incorporation of SoC in the MCE, but with allowances to breach gate closure) vs Option 2 (with incorporation of SoC in the MCE, where ESS scheduling is constrained by SoC limitations).

### 5.1 *Greater assurance that ESS can actually deliver when activated for ancillary services*

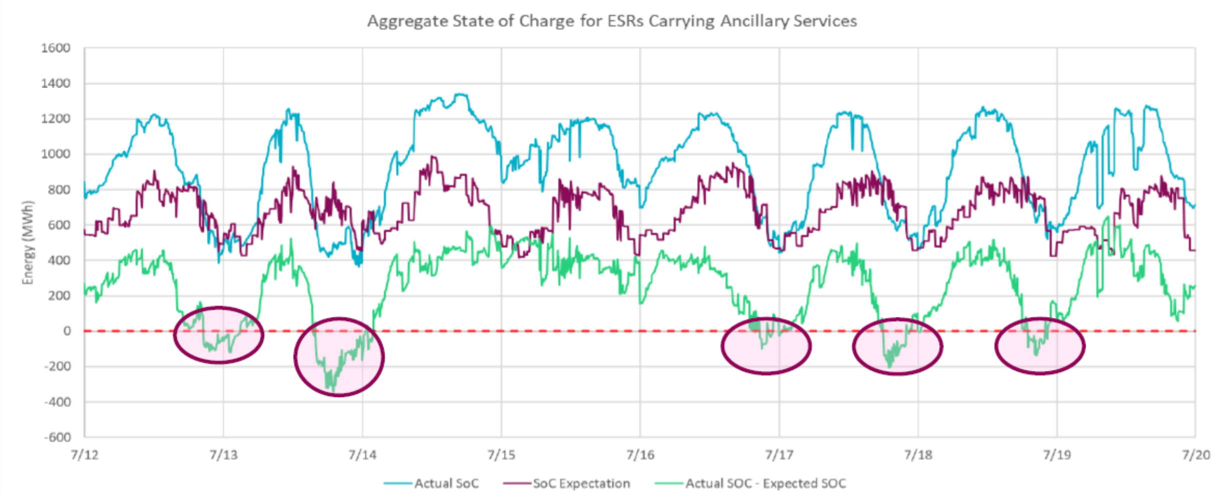
As noted earlier in Section 2, in the absence of incorporating SoC in the MCE, the RCP raised concerns that the modelling of ESS would not accurately reflect ESS' physical capability.

For both conventional generators and ESS, scheduling of ancillary services is constrained such that the combined MW schedule for energy, reserves and regulation cannot exceed the facility's maximum rated MW capacity[15]. This reflects the physical limitation of both conventional generators and ESS – these facilities cannot have a MW output that exceeds their rated MW capacity.

However, for ESS, there is an additional pertinent physical limitation that does not apply to conventional generators – ESS facilities cannot charge above their maximum rated MWh storage capacity, and cannot discharge below their minimum rated MWh storage capacity. As such, it is prudent for this MWh limitation to be modelled in the MCE as well.

In particular, there is the concern that ESS may be scheduled for ancillary services (i.e., to be on "standby"), but not actually be able to deliver if activated. This is borne out by the experience of ERCOT (which did not have SoC-related scheduling constraints for ESS as of April 2022) when scheduling ESS to provide ancillary services[16]. As illustrated in the figure below, within a particular week, there were five instances (of multiple periods each) where ESS facilities were unable to fulfil their "up ancillary service"[17] obligations, due to physical SoC constraints.

**Figure 2: ESS being unable to fulfil up ancillary service obligations in Texas[18]**




Currently, ESS market revenues are reduced if there is non-performance for ancillary services (e.g., downgrading of Reserve Provider Group, non-payment for non-provision of ancillary service). However, it seems prudent within the SWEM for SoC limitations to be modelled in the MCE, to provide further assurance to MPs that ESS will be able to deliver when activated for ancillary services.

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[15] For conventional generators, this refers to the Reserve Generation Max Constraint in Market Rules Appendix 6D, Section D.17.2.4. For ESS, this refers to the proposed analogous Energy Storage Reserve Max Constraint in RC383 (new Section D.17.2.4A).

[16] https://www.esig.energy/download/ercots-operational-experience-with-battery-energy-storage-nitika-mago/?wpdmdl=10068&refresh=642d6539ac3b01680696633

[17] This includes up-regulation and reserve obligations.

[18] Source: https://www.esig.energy/download/ercots-operational-experience-with-battery-energy-storage-nitika-mago/?wpdmdl=10068&refresh=642d6539ac3b01680696633

### 5.2 ESS operators will not need to adjust their offers as frequently

Without incorporating SoC in the MCE (i.e., as per Option 1 in Section 3.1 earlier), there are broadly two situations where the ESS operator needs to adjust offers due to SoC limitations:

(a) ESS is activated for reserve and/or regulation, resulting in an unexpected change in SoC → offers need to be adjusted, allowable within gate closure[19].

(b) ESS is scheduled for energy, resulting in a change in SoC → offers need to be adjusted beyond gate closure[20].

While it is difficult to estimate the impact of (a) above, it is possible to illustrate the impact of (b) above, as shown below.

**Illustration: Reducing the need to adjust offers due to scheduled energy affecting SoC[21]**

To illustrate the impact of (b), we assume an ESS with the following simplified characteristics:

- Max output = ±6MW
- *MaxCapacity* = 6MWh
- *MinSoC* = 0%
- *MaxSoC* = 100%
- *ChargingEfficiency* = *Discharging Efficiency* = 100%

In order to determine a reasonable charging/discharging pattern for the ESS across periods, we use actual USEP across the month of October 2023, and assume that for each period:

- The ESS is scheduled to charge 2MW (1MWh) if USEP < $200/MWh[22] and the ESS submitted an energy charging offer.
- The ESS is scheduled to discharge 2MW (1MWh) if USEP > $210/MWh and the ESS submitted an energy discharging offer.
- The ESS is idle (neither charging nor discharging) otherwise.
- The ESS operator is extremely responsible and conservative, removing offers if there is any chance that current SoC may not be able to fulfil the next 3 periods' schedule, and resubmitting offers that current SoC is definitely able to fulfil.

Without incorporation of SoC in the MCE, the ESS operator would have to consider removing/resubmitting energy charging/discharging offers 3 periods ahead[23], given the risk of SoC going beyond [*MinSoC*, *MaxSoC*] 3 periods later. Given the above illustrative setup, the ESS operator needs to remove/resubmit offers ~10% of the time throughout the month[24], as shown in the table below.

| | Remove offer | Resubmit offer |
|---|---|---|
| **No. of periods** | 73 | 72 |

[19] As per gate closure exemptions provided for under Option 1 (Section 3.1 above)

[20] Not covered by gate closure exemptions provided for under Option 1 (Section 3.1 above)

[21] Based on a Microsoft Excel simulation.

[22] In practice, MCE scheduling of ESS will depend on various factors such as nodal prices, transmission constraints, co-optimisation, etc. (but does not consider USEP). However, we simplify the scheduling decision in this illustration to provide a reasonable charging/discharging pattern for the ESS across periods.

[23] In order to comply with the 65-minute gate closure requirement. For example, offers for period 4 need to be removed/resubmitted by the end of period 1.

[24] Total number of periods in the testing month of October 2023 was 1488.

In contrast, with incorporation of SoC in the MCE, the ESS operator never has to amend energy offers. If SoC is at risk of going beyond [*MinSoC*, *MaxSoC*], MCE constraints will ensure that the ESS is not scheduled for energy charging/discharging.

Besides the reduced burden on ESS operators to submit offer variations, reduced offer variations due to both (a) and (b) will also result in reduced potential for human error and improved forecast run accuracy, providing greater dispatch certainty to all generators and demand response providers.

## 5.3 ESS will likely be scheduled more frequently

Building on Section 5.1 earlier, with incorporation of SoC in the MCE, energy offers no longer need to be removed due to SoC limitations. As such, it is likely that the ESS will be scheduled more frequently for energy.

Based on the same illustrative setup from Section 5.1[25], the ESS would be scheduled to charge/discharge ~13%[26] more often, if SoC is incorporated in the MCE.

| No. of periods | Without incorporation of SoC | With incorporation of SoC |
|---|---|---|
| **Scheduled to charge** | 192 | 217 |
| **Scheduled to discharge** | 186 | 211 |
| *Total* | *378* | *428* |

Besides greater asset utilisation of ESS, this increased supply of energy by ESS assets helps defer costly investment in generation (especially peaking) capacity to meet overall energy demand.

## 5.4 ESS operators can offer in higher quantities for energy

Without incorporation of SoC in the MCE, ESS' standing energy offer quantities can only sum to a maximum of one third of the maximum MWh storage of a BESS.

- E.g., for a 6MWh ESS, it can offer up to +4MW of energy discharge per period, potentially discharging 2MWh for three consecutive periods.

With incorporation of SoC in the MCE, ESS operators can offer in higher quantities for energy – ESS' standing energy offer quantities can sum to the maximum MWh storage of the BESS (limited by maximum MW output). In subsequent periods, the ESS will be constrained off by the MCE.

- E.g., for a 6MWh ESS, it can offer up to +12MW of energy discharge per period (limited by maximum MW output), potentially discharging 6MWh for one period.

Based on a similar illustrative setup from Section 5.1, the ESS would charge/discharge ~52%[27] more in terms of MWh, if SoC is incorporated in the MCE and the ESS is allowed to offer in energy quantities of ±6MW[28].

[25] Based on the same Microsoft Excel simulation.

[26] (428-378) / 378 = 13.2%

[27] (576-378) / 378 = 52.4%

[28] The simulation is based on the scenario of a 6MWh/6MW BESS.

| | Without incorporation of SoC, offer quantity = ±2MW | With incorporation of SoC, offer quantity = ±6MW |
|---|---|---|
| **MWh charged** | 192 | 291 |
| **MWh discharged** | 186 | 285 |
| *Total* | *378* | 576 |

The overall benefits are similar to those in Section 5.2 – besides greater asset utilisation of ESS assets, this increased supply of energy by ESS assets helps defer costly investment in generation (especially peaking) capacity to meet overall energy demand.

## 6. Rule Modifications Required

In addition to the proposed rule modifications in RC383 facilitating the modelling of ESS within the MCE, Table 3 below provides a summary of additional proposed rule modifications facilitating the modelling of SoC in particular within the MCE. Detailed modifications are set out in Annex 1.

**TABLE 3: Summary of Proposed Modifications**

| S/N | Chapter/ Section | Proposed Modifications | Reasons for Modifications |
|---|---|---|---|
| 1 | Appendix 6D, Section A: Definitions | Introduce new parameters and variables | To facilitate the changes made in Appendix 6D (Sections D.12A, D.15, D.19A and D.25) |
| 2 | Appendix 6D, Section D.12A | Introduce a new section, to include calculations for ExpectedStartSoC, including fallback values for ExpectedStartSoC | Start-of-period SoC has to be estimated based on SoC data received 10 minutes before each period.<br>Fallback values are required in case SoC data is not received from PSO on time. |
| 3 | Appendix 6D, Section D.15 | Amend constraints to differentiate between charging and discharging | Discharging schedules cannot exceed discharging offers; charging schedules cannot exceed charging offers. |
| 4 | Appendix 6D, Section D.19A | Introduce a new section, to include SoC related constraints introduced in Section 4 of this paper. | ESS schedules should reflect SoC limitations. |
| 5 | Appendix 6D, Section D.21 | Inclusion of SoC constraint violations. | Added SoC constraint violations to total constraint violations |
| 6 | Appendix 6D, Section D.25 | Introduce a new section for the MCE to produce EndSoC for each period which will be used as ExpectedStartSoC for forecast periods. | Forecast periods have to include ESS schedules, which should also reflect SoC limitations. |

| S/N | Chapter/ Section | Proposed Modifications | Reasons for Modifications |
|---|---|---|---|
| 7 | Appendix 6E, Section E.1A | Augment the list of standing capability data required for ESS facilities. | Physical capabilities related to SoC should be included as well for ESS. |
| 8 | Appendix 6G, Section G.3 | Inclusion of SoC within data that PSO is to provide to EMC. | To include SoC data within the Network Status File that PSO provides to EMC before each half hour period. |
| 9 | Chapter 8 | Introduce new definitions pertaining to SoC. | To define new terms used. |

## 7. Consultation

The proposed modifications were published for consultation on 7 February 2024, and we have received comments from EMC Markets and Operations, as well as Senoko Energy.

A summary of industry comments, as well as EMC's responses are provided below in Table 4.

**TABLE 4: Summary of Industry Comments**

| S/N | Comment | EMC's Response |
|---|---|---|
| **Comments received from: EMC Markets and Operations** | | |
| **1** | As the market operator, EMC Markets and Operations team supports the incorporation of SoC into MCE modelling of ESS. Furthermore, we also recommend including the rule change work plan prioritisation on *"Enhancements to the StartGeneration used in the real time schedule (RTS), and the first dispatch period of the short term schedule (STS) and pre-dispatch schedule (PDS)"* to be concurrently implemented with this rule change.<br><br>Besides the implementation synergy between these two rule change initiatives, the recommendation also offers the following two other benefits of implementing them in one go:<br><br>1. Enhanced modelling accuracy and scheduling resiliency: The StartGeneration of ESS is a critical input for ESS modelling. A robust and reliable fallback mechanism for it is essential. By aligning the fallback mechanisms for both StartGeneration and ExpectedStartSoC, it will not only ensure coherence in processing logics but also further enhances MCE's scheduling resilience. This alignment will minimize key service disruptions to PSO and MPs. | EMC notes the benefits of implementing this rule change proposal, and the synergy between the two MCE modelling related initiatives. EMC will seek RCP's support to implement these two projects concurrently. |

| S/N | Comment | EMC's Response |
|---|---|---|
| | 2. Cost-efficiency in implementation: The system changes required for the StartGeneration enhancement are specifically related to the MCE. Implementing this rule change in conjunction with the SoC incorporation will avoid additional implementation costs if done separately.<br><br>Below describes the StartGeneration enhancement which encompasses two key modifications aimed at enhancing dispatch schedule accuracy and resiliency:<br><br>1. For StartGeneration in the real time schedule (RTS) or the first dispatch period of the short term schedule (STS): currently, in the absence of the immediate preceding RTS Generation data, the system defaults it to zero, as per Market Rules. The proposed enhancement enhances this fallback mechanism to utilize the Generation from the immediate preceding period in the latest released STS using the normal load forecast. In the absence of such STS, it can further fall back to utilize the respective values in the latest released pre-dispatch schedule (PDS). This change addresses the issue of not scheduling regulation due to zero StartGeneration, ensuring a more feasible dispatch schedule which is more reflective of the physical conditions of the generating units.<br><br>2. For StartGeneration in the first dispatch period of the pre-dispatch schedule (PDS): The current method for calculating StartGeneration for the PDS involves deriving dispatch schedules for periods between the period with the most recent RTS and the first dispatch period of the PDS. As PDS runs every two hours, there are four such additional periods that requires calculation for each PDS. The proposed enhancement aligns this process with the same treatment for RTS and STS by adopting the Generation from the immediately preceding period in the latest STS using the normal load forecast. Similarly, in the absence of such STS, it can further fall back to utilize the respective values in the latest released PDS. This adjustment not only removes the PDS's dependency on the RTS, thereby bolstering its robustness for MPs and the PSO, but also streamlines the scheduling process by eliminating the need for additional period calculations, making it significantly more efficient. | |

| S/N | Comment | EMC's Response |
|---|---|---|
| **Comments received from: Senoko Energy** | | |
| **2** | While we agree that option 2 lowers the costs for system changes, we should aim to reduce the lag-time (i.e., data to be sent as close to the next period as possible) in anticipation of higher BESS penetration in the SWEM.<br><br>A 10-min lag time is about 17% of a 1-hour battery, providing the best information we have at hand as close to real-time as possible will improve market signals. | EMC appreciates that receiving StartSoC data as close to the start-of-period as possible may improve estimation accuracy for ExpectedStartSoC.<br><br>However, significant system changes will be required for both PSO and EMC, to enable this one benefit. Also, PSO provision of SoC data to EMC a few minutes closer to the start of period does not entirely eliminate the estimation error.<br><br>At this point in time, EMC does not recommend the transmission of StartSoC data from PSO to EMC at T-6 minutes, due to the significant costs to be incurred, and limited benefits. |
| **3** | <u>Ref: Page 7, 4.1 Data Pre-processing (Worked Example – 6MW Discharging)</u><br><br>PriorSchedule = P1<br>ExpectedStartSoC = P2<br><br>ExpectedStartSoC is less than min SoC of 10%, which should not be allowed to happen in the first place for P1. It is expected that the MCE should have constrained the discharge in P1 to 5.94MW to end up with an ExpectedStartSoC of 10%. | For the +6MW (discharging) example provided in Table 1, it should only be applicable on rare occasions, illustrating scenarios where:<br><br>• The P1 schedule was deemed feasible by the MCE (i.e., based on P1 schedule of energy, reserves and regulation, ESS SoC would not go below MinSoC at the end of P1).<br><br>• Due to PSO issuing a Dispatch Notice, activation of reserves and/or regulation beyond schedule, or any other unexpected scenario or technical issue, P2's unadjusted ExpectedStartSoC goes below MinSoC. |
| **4** | <u>Ref: Page 12, Forecast Schedules (The above formulae do not attempt to estimate the impact of reserves and regulation on SoC for forecast periods.)</u><br><br>It's agreed that the inclusion or attempt to include reserves / regulation provision for forecast periods is a huge undertaking, and taking a conservative approach of assuming that all products would be scheduled for actual dispatch would result in the BESS' SoC at MinSoC for the future periods. | EMC appreciates the comment, but at this point in time, does not recommend the inclusion of auxiliary load requirements within the estimation of ExpectedStartSoC and EndSoC for both real-time and forecast schedules, due to the following reasons:<br><br>• ESS auxiliary load requirements are typically only a small percentage |

| S/N | Comment | EMC's Response |
|---|---|---|
| | However, we would like to check what is the auxiliary load requirements for BESS systems. i.e., to power its cooling / IT systems, etc.<br><br>Once this has been determined, the auxiliary load requirements should be factored into the forecast schedules, StartSoC, EndSoC. | compared with its maximum capacity. Hence, the impact of including auxiliary load is small.<br><br>• Auxiliary load tends to differ from period to period. Hence, it would be difficult to accurately estimate beforehand.<br><br>• Some ESS auxiliary load draw power from the ESS (thus reducing ESS SoC), while some ESS auxiliary load draw power directly from the grid (without reducing ESS SoC).<br><br>When we have gathered sufficient data and experience on ESS operations, further enhancements can be explored in future. |

## 8. Implementation Effort Estimate

A summary of implementation time estimates, depending on choice between the three different options, is provided in Table 5 below. Option 1 pertains to ESS modelling without SoC, while Options 2 and 3 pertain to ESS modelling with SoC.

**TABLE 5: Implementation Time Estimate (in Weeks)**

| S/N | Work Item | Option 1 (EMC) | Option 2 (EMC) | Option 3 (EMC) | Option 3 (each ESS operator[29]) |
|---|---|---|---|---|---|
| 0 | Vendor Selection / Preparation | 8 | 12 | 12 | NA |
| 1 | Change Requirement Scoping and Analysis | 5 | 6 | 6 | NA |
| 2 | System Development / Testing / Project Management | 18 | 29 | 39 | NA |
| 3 | User Acceptance Testing (UAT) | 6 | 6 | 6 | NA |
| 4 | Security Testing | 2 | 2 | 2 | NA |
| 5 | Audit (overlapping with UAT for two weeks) | 6 | 6 | 6 | NA |
| | **Total Elapsed Time in Weeks** | **43** | **59** | **69** | **8 months / ~34 weeks** |

[29] Estimates provided by Sembcorp Cogen, which have not been verified by EMC (i.e., taken at face value).

A summary of implementation cost estimates, depending on choice between the three different options, is provided in Table 6 below. Similarly, Option 1 pertains to ESS modelling without SoC, while Options 2 and 3 pertain to ESS modelling with SoC.

**TABLE 6: Implementation Cost Estimate**

| S/N | Cost Item | Option 1 (EMC) | Option 2 (EMC) | Option 3 (EMC) | Option 3 (each ESS operator[30]) |
|---|---|---|---|---|---|
| 1 | Internal EMC Manpower (inc. Backfill) | $156,589 | $221,665 | $257,233 | NA |
| 2 | External Resource to Support (Vendor) | $220,629 | $322,910 | $417,678 | NA |
| 3 | Audit | $60,000 | $60,000 | $60,000 | NA |
| | **Total One-Off Cost** | **$437,218** | **$604,575** | **$734,910** | **$850,000** |
| 4 | Annual Operating Expenditure | $0 | $48,412 | $64,220 | NA |
| | **Total Recurring Cost** | **$0** | **$48,412** | **$64,220** | **$205,000** |

## 9. Conclusion

By incorporating SoC in the MCE, there would be greater assurance that ESS can deliver when activated for ancillary services and results in higher utilisation of ESS assets.

Rule modifications are proposed to:

a) adopt Option 2 as described in Section 3.2, where SoC data is provided by PSO to the EMC via the Network Status File before each dispatch period, and

b) model SoC in the MCE as described in Section 4 and Annex 1.

At the 33rd TWG meeting on 29 Feb 2024, the TWG unanimously endorsed the proposed mechanism to incorporate SoC in the MCE, and the associated rule modifications.

## 10. RCP's Decision at the 139th RCP Meeting

At the 139th meeting, the RCP **unanimously supported** the proposed modifications as set out in Annex 1.

## 11. Recommendation

The RCP recommends that the EMC Board:

a) **adopt** the proposed modifications to the Market Rules as set out in Annex 1; and

b) **seek the EMA's approval** of the proposed modifications to the Market Rules as set out in Annex 1.

[30] Estimates provided by Sembcorp Cogen, which have not been verified by EMC (i.e., taken at face value).

## ANNEX 1: Proposed Modifications to Market Rules[31]

<table>
<tr><th>Proposed Rule Changes<br><br>(deletions represented by strikethrough text and additions represented by double underlined text)</th><th>Reasons for Modification</th></tr>
<tr><td>APPENDIX 6D – MARKET CLEARING FORMULATION</td><td></td></tr>
<tr><td>SECTION A: DEFINITIONS</td><td></td></tr>
<tr><td>D.2 SET
<table>
<tr><td>RESERVECLASS</td><td>the set of reserve classes refenced by c, comprising primary reserve class (indexed by primary) and contingency reserve class (indexed by contingency).</td></tr>
</table></td><td>To include “primary” and “contingency” as a reference index of respective reserve class.</td></tr>
<tr><td>D.3 PARAMETERS</td><td></td></tr>
<tr><td>
<table>
<tr><td>$ChargingEfficiency_{es}$</td><td>The factor representing the expected increase in energy stored (in MWh) due to charging of the energy storage facility associated with energy storage offer es at 1MW for one hour, divided by 1MWh. Set from the standing capability data referred to in Appendix 6E section E.1A.1.15.</td></tr>
<tr><td>ConResSustainTime</td><td>The required sustain time for contingency reserve class, in seconds. Set in accordance with Appendix 5A section A.2.4</td></tr>
<tr><td>$DischargingEfficiency_{es}$</td><td>The factor representing 1MWh divided by the expected decrease in energy stored (in MWh) due to discharging of the energy storage facility associated with energy storage offer es at 1MW for one hour. Set from the standing capability data referred to in Appendix 6E section E.1A.1.14.</td></tr>
</table></td><td>To include new parameters that are used in the new constraints introduced in Appendix 6D (Sections D.12A, D.13A and D.19A)</td></tr>
</table>

[31] The proposed modification to the Market Rules is being legally reviewed. The modification is proposed assuming RC383 is approved.

| Proposed Rule Changes<br>(deletions represented by strikethrough text and additions represented by double underlined text) | | | Reasons for Modification |
|---|---|---|---|
| ExpectedStartSoC$_{es}$ | The forecast *SoC* level at the beginning of a given *dispatch period* of an *energy storage facility* associated with *energy storage offer es* for that *dispatch period*, which shall be determined in accordance with sections D.12A.1 to D.12A.4. | | |
| MaxSoC$_{es}$ | The maximum *SoC* acceptable to the *energy storage facility* associated with *energy storage offer es*. Set from the *standing capability data* referred to in Appendix 6E section E.1A.1.12. | | |
| MaxCapacity$_{es}$ | The maximum *energy* storage capacity, in MWh, of the *energy storage facility* associated with *energy storage offer es*. Set from the *standing capability data* referred to in Appendix 6E section E.1A.1.11. | | |
| MinSoC$_{es}$ | The minimum *SoC* acceptable to the *energy storage facility* associated with *energy storage offer es*. Set from the *standing capability data* referred to in Appendix 6E section E.1A.1.13. | | |
| PriorScheduledGeneration$_{es}$ | In respect of an *energy storage facility* associated with an *energy storage offer es* for a given *dispatch period*, either:<br>(a) the scheduled *energy* in the *real-time dispatch schedule* for that *energy storage facility* for the prior *dispatch period*, or<br>(b) in the event that such *real-time dispatch schedule* is not available, that *energy storage facility*'s StartGeneration$_{es}$. | | |
| PriResSustainTime | The required sustain time for primary *reserve class*, in seconds. Set in accordance with Appendix 5A section A.2.2 | | |

| Proposed Rule Changes<br>(deletions represented by strikethrough text and additions represented by double underlined text) | Reasons for Modification |
|---|---|
| <table><tr><td>StartSoC$_{es}$</td><td>The *SoC* level of an *energy storage facility* associated with *energy storage offer es* for that *dispatch period*, as received from the *PSO* in accordance with section G.3.4 of Appendix 6G.</td></tr><tr><td>SoCDischargeLimitMWh$_{es}$</td><td>The MWh limit on *energy* discharging for the *energy storage facility* associated with *energy storage offer es.*<br><br>This limit is applied in order to ensure *energy storage facility* associated with *energy storage offer es* operates above MinSoC$_{es}$ given ExpectedStartSoC$_{es}$. Calculated in accordance with section D.12A.5.</td></tr><tr><td>SoCChargeLimitMWh$_{es}$</td><td>The MWh limit on *energy* charging for the *energy storage facility* associated with *energy storage offer es.*<br><br>This limit is applied in order to ensure *energy storage facility* associated with *energy storage offer es* operates below MaxSoC$_{es}$ given ExpectedStartSoC$_{es}$. Calculated in accordance with section D.12A.6.</td></tr></table> | |
| **D.4 VARIABLES**<br><table><tr><td>EnergyStorageCharging$_{es}$</td><td>The charging MW amount scheduled for *energy storage offer es.*</td></tr><tr><td>EnergyStorageDischarging$_{es}$</td><td>The discharging MW amount scheduled for energy storage offer *es*.</td></tr><tr><td>ExcessDischarging$_{es}$</td><td>The MW amount by which the constraint giving the combined limit for the *reserves*, *energy* and *regulation* schedules for *energy storage facility* associated with *energy storage offer es* is exceeded.</td></tr></table> | To include new variables that are required in the new constraints introduced in section D.15 and D.19A of Appendix 6E. |

| Proposed Rule Changes (deletions represented by strikethrough text and additions represented by double underlined text) | Reasons for Modification |
|---|---|
| <table><tr><td>ExcessPrimaryDischarging$_{es}$</td><td>The MW amount by which the constraint giving the combined limit for the primary *reserve*, *energy* and *regulation* schedules for *energy storage facility* associated with *energy storage offer es* is exceeded.</td></tr><tr><td>ExcessContingencyDischarging$_{es}$</td><td>The MW amount by which the constraint giving the combined limit for the contingency *reserve*, *energy* and *regulation* schedules for *energy storage facility* associated with *energy storage offer es* is exceeded.</td></tr><tr><td>ExcessCharging$_{es}$</td><td>The MW amount by which the constraint giving the combined limit for the *energy* and *regulation* schedules for *energy storage facility* associated with *energy storage offer es* is exceeded.</td></tr><tr><td>FacilitySoCViolation$_{es}$</td><td>The total MW violation of the *SoC* constraints associated with the *energy storage facility* that *energy storage offer es* is for.</td></tr></table> | |
| **SECTION B: PRE-PROCESSING** | |
| **D.12A STATE-OF-CHARGE CONSTRAINTS**<br><br>D.12A.1 In the case where a *real-time dispatch schedule* is being produced, or where the *dispatch period* is the first *dispatch period* of the multiple *dispatch periods* involved in the calculation of a *short-term schedule*, provided that a value of StartSoC$_{es}$ is updated by the *PSO* or provided to the *EMC* during the *dispatch period* for the time being when the calculation of the *real-time dispatch schedule* or the first *dispatch period* of the multiple *dispatch periods* involved in the calculation of a *short-term schedule* commences, the ExpectedStartSoC$_{es}$ of | To set out the process for the determination of ExpectedStartSoC used for real-time dispatch schedule and 1st period of short-term schedule. Order of preference is as below: |

| | |
|---|---|
| an *energy storage facility* associated with an *energy storage offer* es shall be determined in accordance with the following table:<br><br>When the *energy storage facility* is discharging (i.e., $PriorScheduledGeneration_{es} > 0$),<br>$$ExpectedStartSoC_{es} = StartSoC_{es} - \frac{PriorScheduledGeneration_{es} \times \frac{RampingTime}{60}}{DischargingEfficiency_{es} \times MaxCapacity_{es}}$$<br>$ExpectedStartSoC_{es}$ shall be further capped within the range [$MinSoC_{es}$, $MaxSoC_{es}$].<br><br>When the *energy storage facility* is charging or idle (i.e., $PriorScheduledGeneration_{es} \leq 0$),<br>$$ExpectedStartSoC_{es} = StartSoC_{es} - \frac{PriorScheduledGeneration_{es} \times \frac{RampingTime}{60} \times ChargingEfficiency_{es}}{MaxCapacity_{es}}$$<br>$ExpectedStartSoC_{es}$ shall be further capped within the range [$MinSoC_{es}$, $MaxSoC_{es}$].<br><br>D.12A.1.1 In the event that a value of $StartSoC_{es}$ is not updated by the *PSO* or provided to the *EMC* during the *dispatch period* for the time being when the calculation of the *real-time dispatch schedule* or the first *dispatch period* of the multiple *dispatch periods* involved in the calculation of a *short-term schedule* commences, the values of $ExpectedStartSoC_{es}$ for each *energy storage facility* shall be the same as the corresponding value of $EndSoC_{es}$ for the same *energy storage facility* in the *real-time dispatch schedule* for the *dispatch period* with respect to the time when the calculation of the *real-time dispatch schedule* commences.<br><br>D.12A.1.2 In the event that no such *real-time dispatch schedule* is available, the values of $ExpectedStartSoC_{es}$ for each *energy storage facility* shall be the same as the corresponding value of $EndSoC_{es}$ for the same *energy storage facility* in the *short-term schedule* (based on normal *load* forecast) for the *dispatch period* with respect to the time when the calculation of the *short-term schedule* commences. | 1) Estimated based on SoC data received 10 minutes before each period<br>2) *EndSoC* for period t-1 in real-time dispatch schedule<br>3) *EndSoC* for period t-1 in short-term schedule<br>4) *EndSoC* for period t-1 in pre-dispatch schedule<br>*5) MinSoC* |

| Proposed Rule Changes<br>(deletions represented by strikethrough text and additions represented by double underlined text) | Reasons for Modification |
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| D.12A.1.3 In the event that no such *short-term schedule* is available, the values of ExpectedStartSoC$_{es}$ for each *energy storage facility* shall be the same as the corresponding value of EndSoC$_{es}$ for the same *energy storage facility* in the *pre-dispatch schedule* for the *dispatch period* with respect to the time when the calculation of the *pre-dispatch schedule* commences.<br><br>D.12A.1.4 In the event that no such *pre-dispatch schedule* is available, then the values of ExpectedStartSoC$_{es}$ for each *energy storage facility* shall equal to MinSoC$_{es}$. | |
| D.12A.2 In the case where the *dispatch period* is the first *dispatch period* of the multiple *dispatch periods* involved in the calculation of the *pre-dispatch schedule*, then the values of ExpectedStartSoC$_{es}$ for each *energy storage facility* shall be the corresponding values of EndSoC$_{es}$ in the *short-term schedule* (based on normal *load* forecast) for the *dispatch period* current at the time when the calculation of the *pre-dispatch schedule* commences<br><br>D.12A.2.1 In the event that no such *short-term schedule* is available, then the values of ExpectedStartSoC$_{es}$ for each *energy storage facility* shall be the same as the corresponding value of EndSoC$_{es}$ for the same *energy storage facility* in the *pre-dispatch schedule* for the *dispatch period* | To set out the process for the determination of ExpectedStartSoC used for 1st period of pre-dispatch schedule, order of preference is as below:<br>1) *EndSoC* for period t-1 in short-term schedule (normal load)<br>2) *EndSoC* for period t-1 in pre-dispatch schedule<br>3) *MinSoC* |

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| immediately preceding that which is current at the time when the calculation of the *pre-dispatch schedule* commences.<br><br>D.12A.2.2 In the event that no such *pre-dispatch schedule* is available, then the values of $ExpectedStartSoC_{es}$ for each *energy storage facility* shall equal to $MinSoC_{es}$. | |
| D.12A.3 In the case where the *dispatch period* is the first *dispatch period* of the multiple *dispatch periods* involved in the calculation of the *market outlook scenario*, the values of $ExpectedStartSoC_{es}$ for each *energy storage facility* shall be the same as the corresponding values of $EndSoC_{es}$ for the same *energy storage facility* in the most recently released *pre-dispatch schedule* with a *nodal load forecast* corresponding to the *market outlook scenario* being calculated, and shall be taken from the *dispatch period* in such *pre-dispatch schedule* immediately preceding the first *dispatch period* required in the calculation of the *market outlook scenario*, provided that such *pre-dispatch schedule* contains the appropriate *dispatch period*.<br><br>D.12A.3.1 If such *pre-dispatch schedule* does not contain the appropriate *dispatch period*, then the values of $ExpectedStartSoC_{es}$ for such *energy storage facility* shall equal to $MinSoC_{es}$. | To set out the process for the determination of ExpectedStartSoC used for 1$^{st}$ period of market outlook scenario. Order of preference is as below:<br>1) *EndSoC* for period t-1 in pre-dispatch schedule<br>*2) MinSoC* |
| D.12A.4 In the case where the *dispatch period* is involved in the calculation of a *short-term schedule*, a *pre-dispatch schedule* or a *market outlook scenario*, and is not the *first dispatch period* of the multiple *dispatch periods* involved in the calculation of the *short-term schedule*, *pre-dispatch schedule* or a *market outlook scenario*, the values of $ExpectedStartSoC_{es}$ for each *energy storage facility* shall be the corresponding values of $EndSoC_{es}$ for the immediately preceding *dispatch period* in the *short-term schedule*, *pre-dispatch schedule* or *market outlook scenario* respectively. | To set out the process for the determination of ExpectedStartSoC used for subsequent periods within the short-term schedule / pre-dispatch schedule / market outlook schedule. The value is to be based on *EndSoC* for period t-1 |

| Proposed Rule Changes<br>(deletions represented by strikethrough text and additions represented by double underlined text) | Reasons for Modification |
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| D.12A.5 SoCDischargeLimitMWh$_{es}$ = (ExpectedStartSoCes − MinSoCes) × MaxCapacityes<br>$\{es \in ENERGYSTORAGEOFFERS\}$<br>D.12A.6 SoCChargeLimitMWh$_{es}$ = (MaxSoC$_{es}$ − ExpectedStartSoC$_{es}$) × MaxCapacity$_{es}$<br>$\{es \in ENERGYSTORAGEOFFERS\}$ | in the corresponding schedule.<br><br>To set out the formulae for the calculation of Discharge/charge limits. |
| **D.15 CONSTRAINTS ON ENERGY GENERATION AND PURCHASES**<br>D.15.4.3 Energy Storage Discharging Constraint<br>$$\text{EnergyStorageDischarging}_{es} = \sum_{j \in ENERGYSTORAGEOFFERBLOCKS_{es} \mid EnergyStorageBlockLimit_{es,j} \geq 0} \text{EnergyStorageBlock}_{es,j}$$<br>$\{es \in ENERGYSTORAGEOFFERS\}$<br>D.15.4.4 Energy Storage Charging Constraint<br>$$\text{EnergyStorageCharging}_{es} = -\sum_{j \in ENERGYSTORAGEOFFERBLOCKS_{es} \mid EnergyStorageBlockLimit_{es,j} < 0} \text{EnergyStorageBlock}_{es,j}$$<br>$\{es \in ENERGYSTORAGEOFFERS\}$ | To include discharging constraint and charging constraints such that discharging schedules cannot exceed discharging offers, and charging schedules cannot exceed charging offers. |

| Proposed Rule Changes (deletions represented by strikethrough text and additions represented by double underlined text) | Reasons for Modification |
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| D.15.4.5 Energy Storage Summation Constraint<br>~~$EnergyStorageTransfer_{es} = \sum_{j \in ENERGYSTORAGEOFFERBLOCKS} EnergyStorageBlock_{es,j}$~~<br>$EnergyStorageTransfer_{es} = EnergyStorageDischarging_{es} - EnergyStorageCharging_{es}$<br>$\{es \in ENERGYSTORAGEOFFERS\}$ | |
| **SECTION C: LINEAR PROGRAM** | |
| **D.19A STATE-OF-CHARGE**<br>D.19A.1 Combined Reserves Energy Regulation Minimum SoC Constraint:<br>$\frac{EnergyStorageDischarging_{es} + Regulation_{es} + RawReserve_{r(es,Primary)} \times \frac{PriResSustainTime}{DispatchPeriod} + RawReserve_{r(es,Contingency)} \times \frac{DispatchPeriod - PriResSustainTime}{DispatchPeriod}}{DischargingEfficiency_{es}}$<br>$-EnergyStorageCharging_{es} \times ChargingEfficiency_{es}$<br>$-ExcessDischarging_{es}$<br>$\leq \frac{SoCDischargeLimitMWh_{es}}{DispatchPeriod/3600}$<br>$\{es \in ENERGYSTORAGEOFFERS\}$ | To include SoC related constraints for ESS such that the schedules would reflect SoC limitations. |

| Proposed Rule Changes (deletions represented by strikethrough text and additions represented by double underlined text) | Reasons for Modification |
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| D.19A.2 Combined Primary Reserve Energy Regulation Minimum SoC Constraint:<br><br>$$\frac{\text{EnergyStorageDischarging}_{es} + \text{Regulation}_{es} + \text{RawReserve}_{r(es,Primary)}}{\text{DischargingEfficiency}_{es}} - \text{EnergyStorageCharging}_{es} \times \text{ChargingEfficiency}_{es} - \text{ExcessPrimaryDischarging}_{es} \leq \frac{\text{SoCDischargeLimitMWh}_{es}}{\text{PriResSustainTime}/3600}$$<br><br>$\{es \in \text{ENERGYSTORAGEOFFERS}\}$<br><br>D.19A.3 Combined Contingency Reserve Energy Regulation Minimum SoC Constraint:<br><br>$$\frac{\text{EnergyStorageDischarging}_{es} + \text{Regulation}_{es} + \text{RawReserve}_{r(es,Contingency)}}{\text{DischargingEfficiency}_{es}} - \text{EnergyStorageCharging}_{es} \times \text{ChargingEfficiency}_{es} - \text{ExcessContingencyDischarging}_{es} \leq \frac{\text{SoCDischargeLimitMWh}_{es}}{\text{ConResSustainTime}/3600}$$<br><br>$\{es \in \text{ENERGYSTORAGEOFFERS}\}$ | |

| Proposed Rule Changes (deletions represented by strikethrough text and additions represented by double underlined text) | Reasons for Modification |
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| D.19A.4 Combined Energy Regulation Maximum SoC Constraint: $$(\text{EnergyStorageCharging}_{es} + \text{Regulation}_{es}) \times \text{ChargingEfficiency}_{es} - \frac{\text{EnergyStorageDischarging}_{es}}{\text{DischargingEfficiency}_{es}} - \text{ExcessCharging}_{es} \leq \frac{\text{SoCChargeLimitMWh}_{es}}{\text{DispatchPeriod}/3600}$$ $\{es \in \text{ENERGYSTORAGEOFFERS}\}$ | |
| **D.21 VIOLATION GROUP CONSTRAINTS**<br>D.21.5 Facility Constraint: $$\sum_{j \in \text{VIOLATIONGROUPBLOCKSFAC}_{y(es)}} \text{ViolationGroupBlock}_{y(es),j} \geq \text{FacilityReserveViolation}_{es} + \text{FacilityRegulationViolation}_{es} + \text{FacilityRampViolation}_{es} + \text{FacilitySoCViolation}_{es}$$ $\{es \in \text{ENERGYSTORAGEOFFERS}\}$<br>D.21.5.6 Energy Storage Facility State-of-Charge Constraint: $$\text{FacilitySoCViolation}_{es} = \text{ExcessDischarging}_{es} + \text{ExcessPrimaryDischarging}_{es} + \text{ExcessContingencyDischarging}_{es} + \text{ExcessCharging}_{es}$$ | To include SoC constraint violations to total constraint violations |

| Proposed Rule Changes<br>(deletions represented by strikethrough text and additions represented by double underlined text) | Reasons for Modification |
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| $\{es \in ENERGYSTORAGEOFFERS\}$ | |
| **SECTION D: POST-PROCESSING** | |
| **D.25** **ADDITIONAL OUTPUTS**<br>D.25.1.14 the estimated end-of-period SoC in accordance with the following formulae:<br>$EndSoC_{es} = ExpectedStartSoC_{es} - \frac{EnergyStorageDischarging_{es}}{DischargingEfficiency_{es} \times MaxCapacity_{es}} + \frac{EnergyStorageCharging_{es} \times ChargingEfficiency_{es}}{MaxCapacity_{es}}$<br>$\{es \in ENERGYSTORAGEOFFERS\}$ | To calculate and include EndSoC as additional output. |
| **APPENDIX 6E – STANDING CAPABILITY DATA** | |
| **E.1A** **ENERGY STORAGE FACILITY DATA**<br>E.1A.1.12 the maximum *State-of-Charge* of the *energy storage facility*;<br>E.1A.1.13 the minimum *State-of-Charge* of the *energy storage facility*;<br>E.1A.1.14 the discharging efficiency of the *energy storage facility*;<br>E.1A.1.15 the charging efficiency of the *energy storage facility*; | To include physical capabilities related to SoC for ESS in the standing capability data. |

| Proposed Rule Changes<br>(deletions represented by strikethrough text and additions represented by double underlined text) | Reasons for Modification |
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| **APPENDIX 6G – DISPATCH RELATED DATA** | |
| **G.3 GENERATOR DATA**<br><br>G.3.4 The *SoC* of each *generation registered facility* that is an *energy storage facility* captured by the *PSO* before the upcoming *dispatch period.* | To include SoC data as part of the dispatch related data that PSO provides to EMC before each dispatch period. |
| **CHAPTER 8 DEFINITIONS** | |
| 1.1.xxx *SoC* or *State-of-Charge* refers to the remaining percentage of stored *energy* in an *energy storage facility*. Unless otherwise stated, this is a factor which represents the amount of stored *energy* in the *energy storage facility* as a fraction of the maximum *energy* storage capacity of the *energy storage facility.* | To define State-of-Charge as a new term. |