Explanatory Note
Reserve Mode

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A LER Reserve Proving Unit (RPU) or Reserve Providing Group (RPG) shall ensure that it is always in a State of Charge (SoC) to be able to continuously react on frequency deviations, by applying an active reservoir management. Only when Synchronous Area CE enters into alert state or emergency state and the LER RPU is close to the upper or lower limit of its energy reservoir it is obliged to switch to the reserve mode, as the remaining capacity is sufficient to maintain a proper response on short-term frequency deviations. The energy of FCR provision during the transition from normal to reserve mode is included in LER energy reservoir taking into account the minimum activation period.

Therefore, it shall switch from Normal Mode, during which it reacts to the normal frequency deviation, to the Reserve Mode, during which it reacts to a zero-mean frequency deviation. After coming back from alert state or emergency state to normal state, the LER RPU shall switch back to normal mode.

The transition from Normal to Reserve Mode is initiated once the following SoC thresholds are reached or exceeded, when we are in alert or emergency state. These thresholds are defined by the amount of energy necessary to provide FCR for a time interval equal to the local full activation time of aFRR. When the full activation time is harmonized (in 2025) that has to be changed to no more than 5 minutes by the BSPs of the LER units.

$$\mathrm{SoC}_{min} = \mathrm{t_{FAT}} * \frac{\mathrm{P}}{\mathrm{C}} \tag{1}$$

$$\mathrm{SoC}_{max} = 1 - \mathrm{SoC}_{min} \tag{2}$$

Where:

$\mathrm{t_{FAT}}$ is the full activation time of aFRR in h;

P is the provided FCR power corresponding to a frequency deviation ±200 mHz in MW; and

C is the energy capacity of the battery in MWh

The transition from Normal to Reserve Mode is therefore initiated at time $\mathrm{t_{start}} = \mathrm{t(SoC} <= \mathrm{SoC_{min}}$ or $\mathrm{SoC} >= \mathrm{SoC_{max}}$) and lasts $\mathrm{t_{FAT}}$.

During Normal Mode the unit shall react to the normal frequency deviation $\mathrm{Df(t)}$ while in Reserve Mode the unit shall only react to short-term frequency deviations by following the zero-mean frequency:

$$\mathrm{DF_{zero-mean}(t)} = \mathrm{Df(t)} - \frac{1}{\mathrm{t_{FAT}}} \sum_{\mathrm{i=0}}^{\mathrm{t_{FAT}}-1} \mathrm{D}f(\mathrm{t-i}) \tag{3}$$

During the transition from Normal Mode to Reserve Mode (from $\mathrm{t_{start}}$ to $\mathrm{t_{start}} + \mathrm{t_{FAT}}$), the unit shall react to the combination $\mathrm{Df_{reaction}(t)}$ of normal frequency deviation and short-term frequency deviation:

$$\mathrm{Df_{reaction}(t)} = \mathrm{DF_{zero-mean}(t)} \cdot \mathrm{T} + (1-\mathrm{T}) \cdot \mathrm{Df(t)} \tag{4}$$

Where T is the weighting function defined as follows:

$$T = \begin{cases} 0 & \mathrm{t} < \mathrm{t_{start}} \\ \dfrac{\mathrm{t} - \mathrm{t_{start}}}{\mathrm{t_{\Delta FAT}}} & \mathrm{t_{start}} \le \mathrm{t} < \mathrm{t_{start}} + \mathrm{t_{\Delta FAT}} \\ 1 & \mathrm{t} \ge \mathrm{t_{start}} + \mathrm{t_{\Delta FAT}} \end{cases} \tag{5}$$

By the time the SoC is restored ($\mathrm{SoC_{min}} < \mathrm{SoC} < \mathrm{SoC_{max}}$) and the systems enters normal state, the unit shall switch again to the Normal Mode. The transition to Normal Mode is similar to the transition to Reserve Mode. It is initialized at $\mathrm{t_{restore}}$ and lasts $\mathrm{t_{FAT}}$. During the transition from Reserve to Normal

Mode the unit must react to the $\mathrm{Df_{reaction}}(\mathrm{t})$ (Equation (4)). The weighting function in this case is defined as follows:

$$\mathrm{T} = \begin{cases} 1 & \mathrm{t} < \mathrm{t_{restore}} \\ \frac{\mathrm{t_{restore-t}}}{\mathrm{t_{\Delta FAT}}} + 1 & \mathrm{t_{restore}} \leq \mathrm{t} < \mathrm{t_{restore}} + \mathrm{t_{\Delta FAT}} \\ 0 & \mathrm{t} \geq \mathrm{t_{restore}} + \mathrm{t_{\Delta FAT}} \end{cases} \quad (6)$$

It should be noted that the minimum activation time of a LER-unit must be always guaranteed irrespective of the implementation of the Reserve Mode.

ANNEX Exemplary Cases

To facilitate the understanding of the definition and implementation of Reserve Mode we simulated two reference cases.

CASE I

This Case is based on the frequency measurements of Swissgrid for the 07.06.2019 and made the following assumptions:

LER-RPU: One single battery;

$\mathrm{t_{FAT}}$: 5 min (300 sec);

P: 1 MW; and

E : 1 MWh

The minimum and maximum SoC-values, below or above which we switch from Normal to Reserve Mode are calculated as follows:

$\mathrm{SoC}_{min} = 0.083;\ and$

$\mathrm{SoC}_{max} = 0.917$

The SoC-values that we use in our reference case are calculated based on the relative change of the actual (normal) frequency deviation. The SoC-value at the beginning of the simulation is assumed to be 0.25.

Figure 1 illustrates the transition from the Normal to the Reserve Mode. The X-axis corresponds to the frequency deviation. The black curve represents the actual (normal) frequency deviation Df, whereas the red curve represents the zero-mean frequency deviation $\mathrm{DF_{zero-mean}}$. This is calculated as the difference between the actual (normal) frequency deviation (black curve) and the moving average (green curve) (see Equation (3)). The Y-axis (on the right) corresponds to the transition function (Equation (5)), which is used as a weighting factor for the calculation of the frequency deviation $\mathrm{Df_{reaction}}$ that should be followed during the Transition Mode (see Equation (4)). At the moment when the transition from Normal to Reserve Mode is initiated (at $t = t_{start}$), the $\mathrm{Df_{reaction}}$ equals the normal frequency deviation Df (the blue curve coincides with the black curve). From the moment the battery exits the Transition Mode and enters the Reserve Mode (at $t = t_{start} + t_{FAT}$), the $\mathrm{Df_{reaction}}$ equals the zero-mean frequency deviation $\mathrm{DF_{zero-mean}}$ (the blue curve coincides with the red curve).

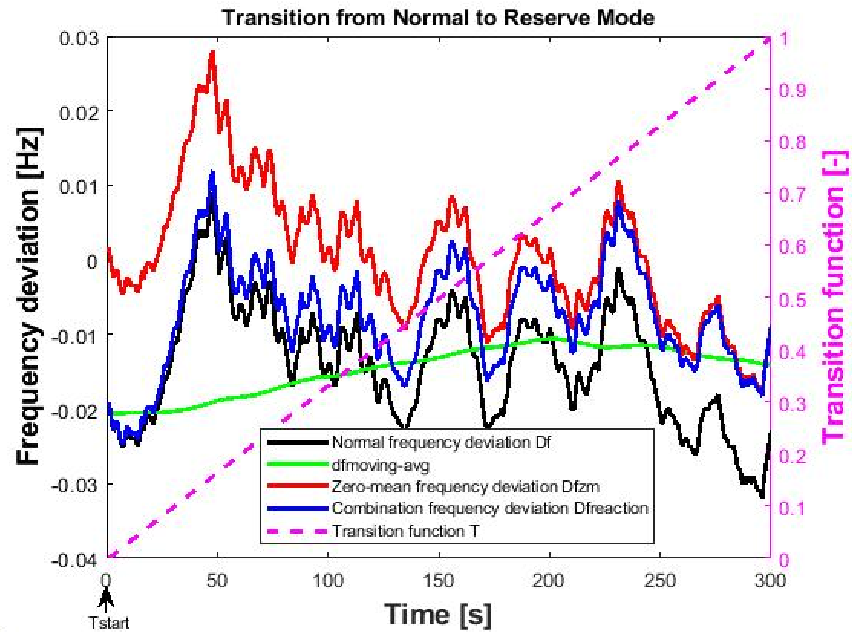

Figure 1: Transition from Normal to Reserve Mode

The impact of the Reserve Mode to the SoC is illustrated in Figure 2. The magenta curve represents the SoC that would have resulted if the battery had followed the actual (normal) frequency deviation Df (black curve). The dotted magenta curve shows the SoC if the battery applies the Reserve Mode. By the time the SoC falls under the SoC_{min} the battery enters the Transition Mode (grey area on the left) and follows the $\mathrm{Df}_{\mathrm{reaction}}$ (blue curve). After $\mathrm{t}_{\mathrm{FAT}}$ and given that the SoC continues to be lower than the SoC_{min}, the battery enters the Reserve Mode (grey area on the right) and follows the zero-mean frequency deviation $\mathrm{DF}_{\mathrm{zero-mean}}$ (red curve). The battery exits the Reserve Mode with a linear transition once the SoC becomes greater than the SoC_{min} and the system enters normal state.

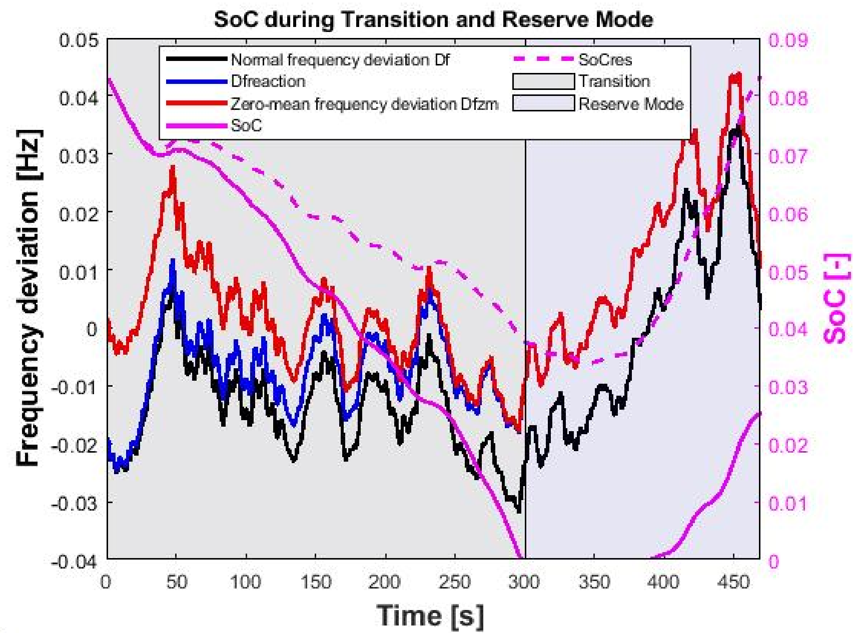

Figure 2: Impact of the Reserve Mode on the SoC

The effect of following the $\mathrm{Df}_{\mathrm{reaction}}$ during the transition Mode and the $\mathrm{DF}_{\mathrm{zero-mean}}$ during the Reserve Mode, as described in Figure 2, on the provided FCR is shown in Figure 3. One can observe the difference between the FCR provided without applying the Reserve Mode (black curve) and the FCR provided if we apply the Reserve Mode (blue curve).

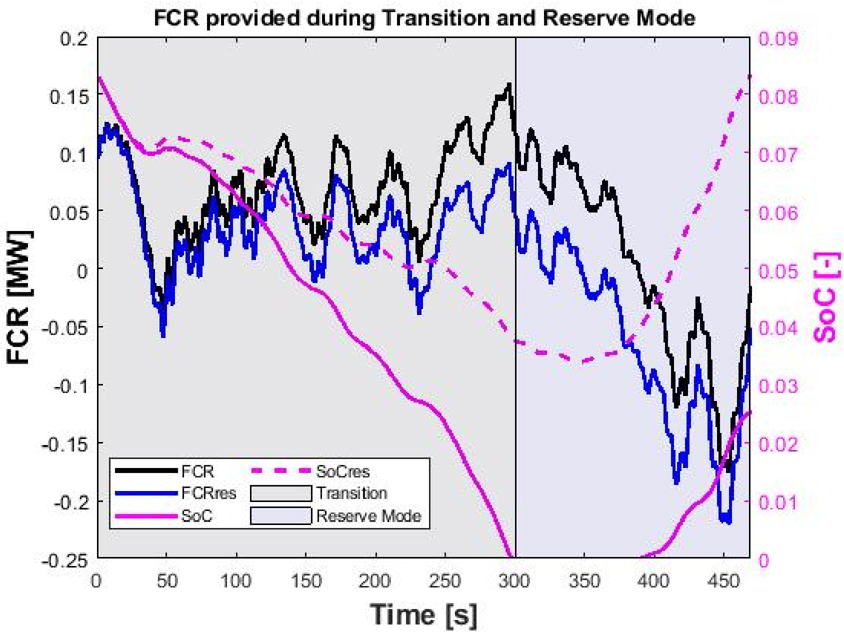

Figure 3: Impact of the Reserve Mode on the FCR provided

At last, we plot the FCR provided (X-axis) with respect to the frequency deviation (Y-axis on the right). We compare the FCR that would have been provided (black curve) if the battery had followed the Df (black dotted curve) with the FCR that is provided (blue curve) if the battery applies the Reserve Mode (following frequency deviation of the blue dotted line within the Transition Mode and of the red dotted line within the Reserve Mode).

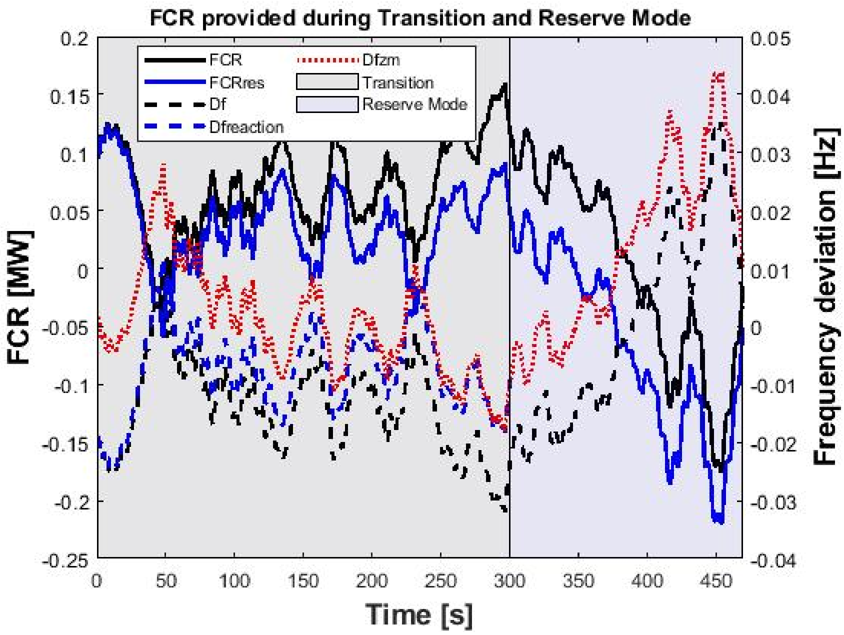

Figure 4: FCR provided In Reserve Mode vs Frequency deviation

CASE II

Short Term Over frequency

Case 2 represents the scenario of a short term over frequency. The SoC-value at the beginning of the simulation is assumed to be 0.50. We picked a frequency series and manipulated it by adding a signal in the form of a trapezoid with a maximum height of 200 mHz.

Once the state of charge reaches the upper limit the LER switch from normal mode to reserve mode by using the transition. Thereby the reserve mode prevents from reaching physical limits and FCR base on the zero mean frequency can be provided continuously. Without the reserve mode the LER would stop providing FCR when the physical limit of their reservoir are reached. That is exactly what happens when the FCR in normal Mode skips to 0.

By switching to reserve mode the LER provide FCR differently to non LER FCR units. To ensure that there are no leaps in the FCR provision the analysis shows the delta between FCR provision in normal and reserve mode for this case.

- Observation period: 18.10.2020, 08-09 a.m.
- Frequency manipulation:
  Additive frequency signal in the form of a trapezoid
  Maximum height: 200 mHz

Outcome:

- Switches to reserve mode using the transition
- Reserve mode prevents from reaching physical limits
- FCR (based on zero-mean frequency) can be provided continuously

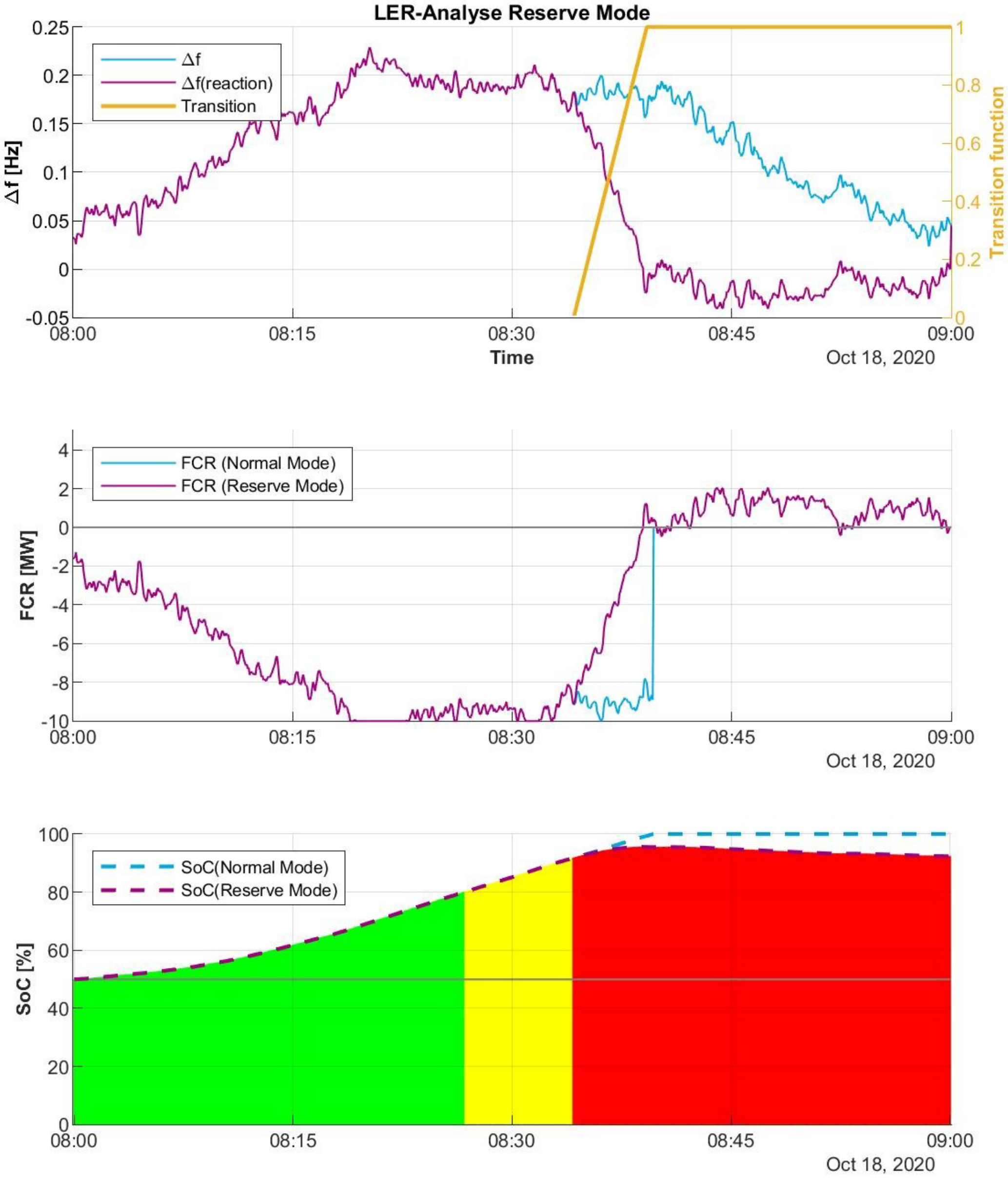

Figure 5 Case II LER Analysis Reserve Mode

It can be seen in Figure 5, that without the Reserve Mode, the LER reaches its energy reservoir maximum at approximately 8:40 a.m.. With the Reserve Mode however, the LER units or groups can still provide FCR.

CASE III

The following example shows the reserve mode with a synthetic frequency, as it was proposed by SG SF.

The synthetic frequency is calculated by adding an artificial offset to a real frequency timeseries. The offset is designed as follows:

- 10 minutes: zero
- 5 minutes: ramp up/down to offset of +/- 100mHz
- 120 minutes: offset of +/- 100mHz
- 5 minutes: ramp down to zero
- 10 minutes: zero

The positive offset was added to the frequency from 25.01.2021, starting at 05:05:25, see figure 6. The negative offset is added to the real frequency of 28.01.2021, starting at 19:27:46, see figure 7. The reason for choosing these specific timeslots is, that they contain moderate DFDs in the direction of the respective offset.

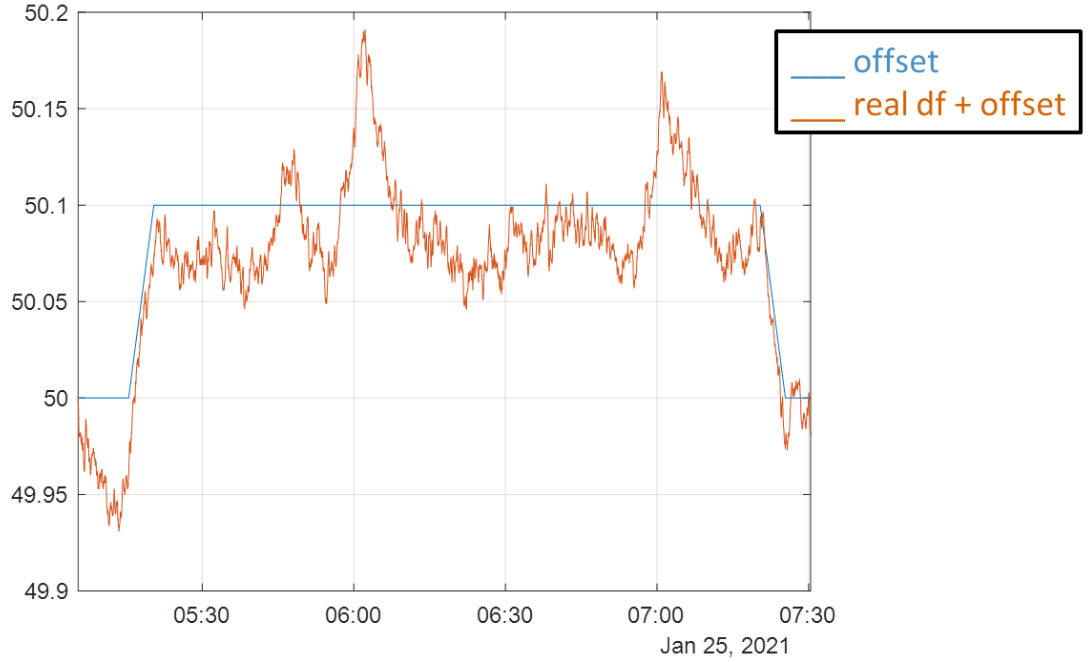

Figure 6 Case III synthetic profile with positive offset

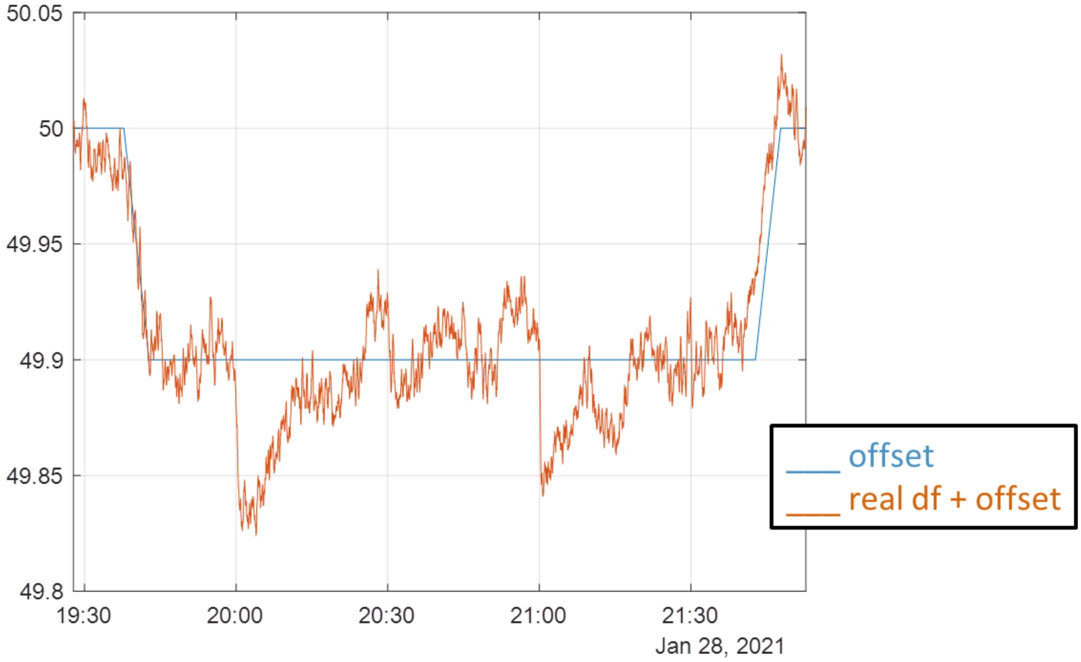

Figure 7 Case III synthetic profile with negative offset

The configuration of the battery that was used for the example:

- $P_{awarded} = 1\ MW$
- $E_{max} =\ 1{,}25\ MWh$
- $t_{FAT}\ =\ 5\ min$
- $SoC_{min} = \frac{P_{awarded} \cdot t_{FAT}}{E_{max}} = 6{,}67\%$
- $SoC_{max} = 1 - \frac{P_{awarded} \cdot t_{FAT}}{E_{max}} = 93{,}3\%$
- $SoC_{start}\ = 50\%$

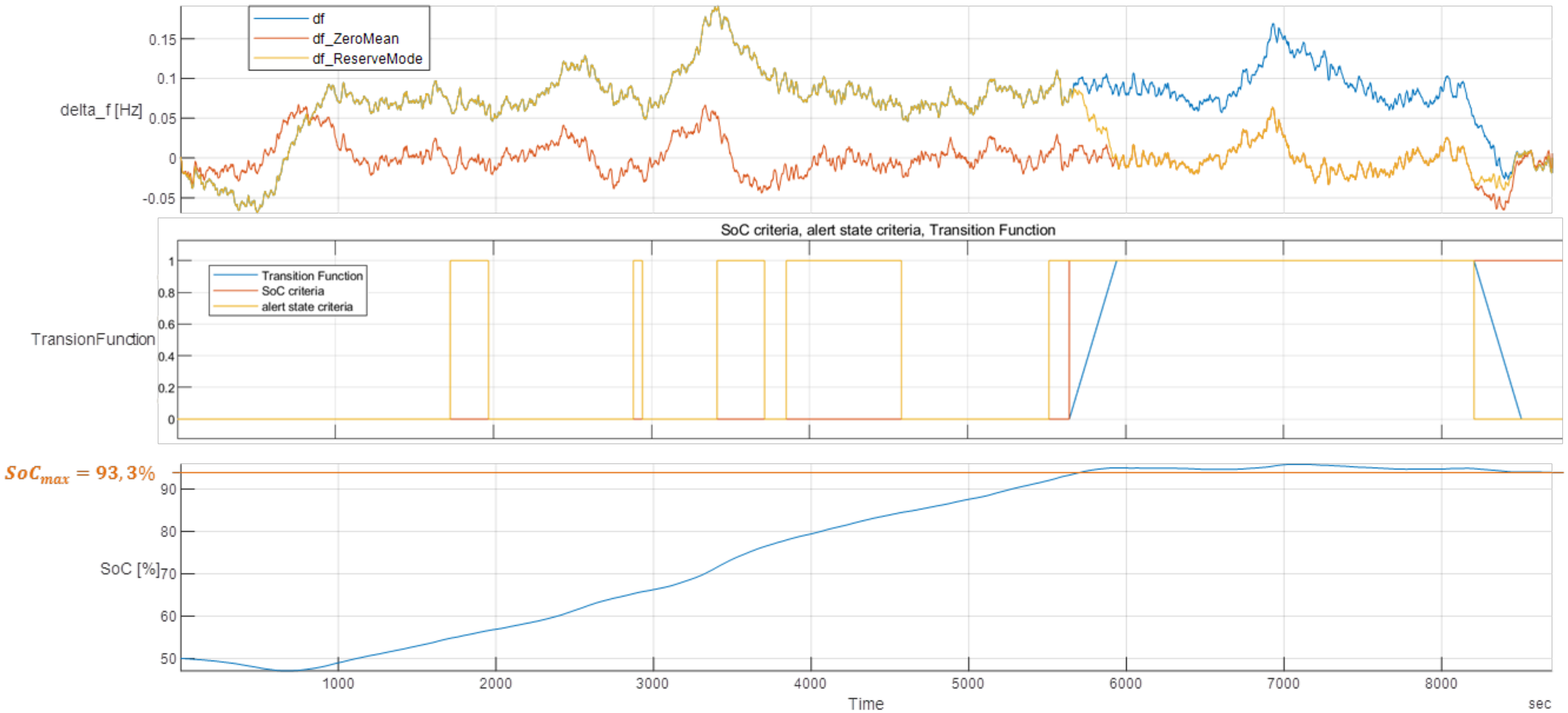

Figure 8 Case III behaviour of battery with positive offset

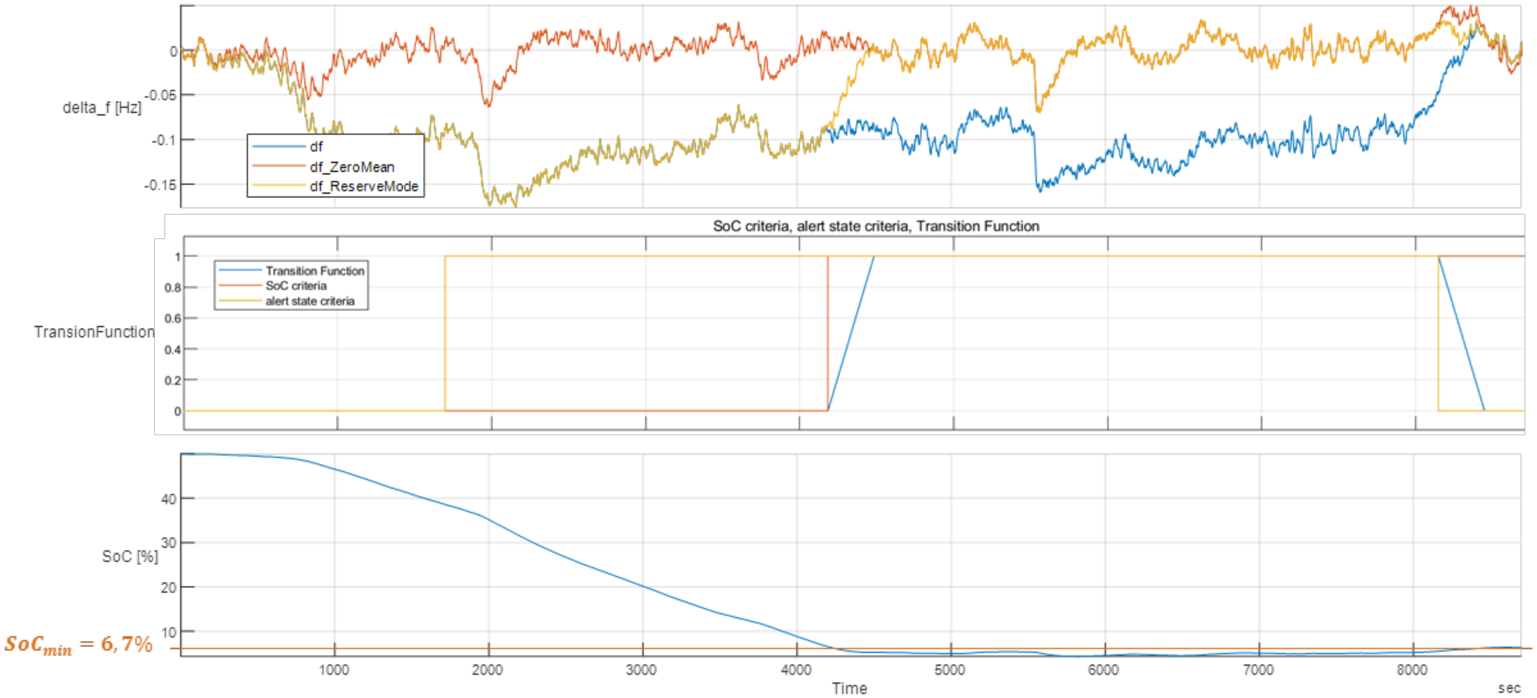

Figure 9 Case III behaviour of battery with negative offset