Network Innovation Competition:

Enhanced Frequency Control Capability (NIC EFCC)

MATLAB Hybrid Model – Simulation Report

Modelled Solar PV - Battery Hybrid System – EFCC Control Scheme

BELECTRIC GmbH

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List of Abbreviations

CET	:	Central European Time
EFCC	:	Enhanced frequency control capability
GB	:	Great Britain
GCP	:	Grid connecting point
MPP	:	Maximum power point
PMU	:	Phasor Measurement Unit
PV	:	Photovoltaic
RoCoF	:	Rate of Change of Frequency
SCADA	:	Supervisory Control And Data Acquisition
SoC	:	State of Charge

1. Introduction

This document presents an overview on the mathematical EFCC solar PV-Battery – hybrid model which was developed by BELECTRIC to study and analyse the behaviour of the implemented control system in the PV-Battery Hybrid System at Willersey under the EFCC control scheme.

The document also illustrates the modelled output behaviour of the individual power source in the Hybrid System for some selective simulated and real frequency events which were observed by the phasor measurement unit (PMU) deployed at the grid connecting point of the BELECTRIC PV Resource at Willersey. To successfully execute the simulation, BELECTRIC used historical data of real and simulated frequency events measured by the PMU in the GB power network.

The transmission system parameters like regional frequency and rate of change of frequency (RoCoF) are given to the hybrid model. The model observes the parameters to detect the intensity and magnitude and nature of the frequency event. Further, the model sends a power request to the modelled EFCC solar PV-Battery hybrid resource according to the resource availability, nature and intensity of the frequency event.

The model simulates the individual dynamic behaviour of the two resources. The requested power is distributed amongst PV and Battery resources depending on numerous factors like time of the day, nature of the event and amount of power available.

2. System Overview

This section gives a system overview of the hybrid model and the implemented control design. The hybrid model is designed to simulate and study the behaviour of the PV-Battery Hybrid System for providing frequency response service under the (only) EFCC control scheme. The section explains the modelled event detection algorithm, modelled output behaviour of EFCC PV-Battery Power Resource and the Hybrid Response Strategies. Moreover, the section also mentions the essential data fields required for successful execution of the simulation.

Event Detection Algorithm: The EFCC PV-Battery Hybrid System Model simulates the behaviour of the GE Local Controller at an elementary level by observing the transmission line parameters from the Phasor Measurement Unit (PMU) installed at the grid connecting point of Rainbows PV plant at Willersey. The historical transmission line parameters are observed to detect a frequency event in the power network. The event detection algorithm in the EFCC PV-Battery Hybrid Model observes the frequency and the rate of change of frequency from the PMU installed on site (data granularity – 20 ms). In parallel the model uses the SMA PV inverter power in kW from an already existing SCADA system (data granularity – 1 s) used by BELECTRIC. The PV power is essential for resource calculation and for estimating the balancing power. The two sets of data are interpolated by the model to an interval of 10ms so that the reaction time of battery system which is 50ms (mentioned later in detail) can be simulated. The data sets with minimum granularity of 20 ms can only be used to simulate the reaction times in the multiple of 20.

The event detection algorithm compares the transmission line parameters with the configurable RoCoF triggering threshold and frequency values for event detection. These thresholds are explained in Figure 1 with additional information mentioned in Table 1 and Table 2 on page number 7.

The hybrid model simulation also handles and introduces the real time communication and processing latencies in the final results. The current implementation of the RoCoF event triggering threshold limit is set as ±0.04 Hz/s. Once the threshold limit is exceeded, the model triggers RoCoF flag after a delay of 20 ms. This 20 ms reaction delay is deliberately introduced by the model and is termed as *communication buffer time* which was observed in the EFCC scheme by the real hardware system of GE Local controller, this small communication buffer time is required by the EFCC control system to measure and process the real time data.

Once the RoCoF event is triggered, the model observes the frequency values, as the frequency deviates and goes beyond the limit of 49.7/50.2 Hz the model triggers event detection flag after adding another *communication buffer time* of 20ms.

As soon as the event is detected the PV-Battery Hybrid Model distinguishes between an actual frequency event and a local noise by observing the real-time frequency values as usually done by the local controller. If the frequency values continue to stay beyond the threshold limit for 420 ms the system observes it is a real event. Otherwise the system recognizes the disturbance as a noise or a fault in the transmission system. Once the frequency stays beyond the threshold limit for 420 ms the control sends the first power request to the modelled EFCC PV-Battery Power Resource. This power request corresponds to 20% of the system availability.

The control scheme doesn't provide continuous response and avoid following small frequency changes, this allows the model to work efficiently with noisy data. A sample releasing power request under the EFCC control scheme from the PV-Battery Hybrid Model is illustrated in Figure 1. If the frequency doesn't recover and continues to deviate further, the power request is increased every time the frequency crosses and stays beyond the next threshold for 420 ms. The frequency thresholds for a frequency event and it's corresponding power request increments are mentioned in the Table 1 and Table 2.

In total, the 'power request rise' and 'holding power' stays for 50 s followed by a 10 second ramp down power request at the end of EFCC response service. For higher frequency events the power request rise and holding time can go up to 80 s.

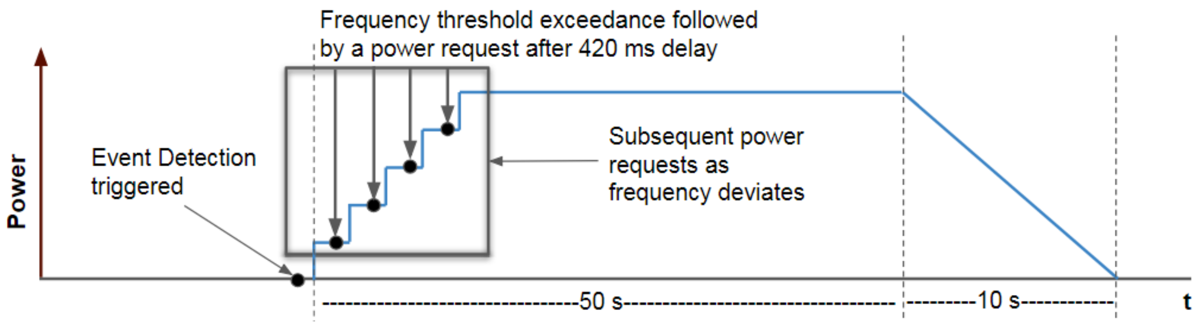

Figure 1: Simulated power request by the hybrid model

SNO	ROCOF LIMIT	FREQUENCY THRESHOLD	POWER REQUEST
1	+0.04 Hz/s	50.20 Hz	20% of negative power availability
2	+0.04 Hz/s	50.30 Hz	40% of negative power availability
3	+0.04 Hz/s	50.40 Hz	60% of negative power availability
4	+0.04 Hz/s	50.50 Hz	80% of negative power availability
5	+0.04 Hz/s	50.60 Hz	100% of negative power availability

Table 1: Frequency threshold for over frequency events.

SNO	ROCOF LIMIT	FREQUENCY THRESHOLD	POWER REQUEST
1	-0.04 Hz/s	49.70 Hz	20% of positive power availability
2	-0.04 Hz/s	49.50 Hz	40% of positive power availability
3	-0.04 Hz/s	49.30 Hz	60% of positive power availability
4	-0.04 Hz/s	49.10 Hz	80% of positive power availability
5	-0.04 Hz/s	48.80 Hz	100% of positive power availability

Table 2: Frequency thresholds for under frequency events.

Individual PV-Battery resource response: The model simulates the output behaviour of the battery and PV system individually. For battery response – the model simulates a ramp rate of 8000 kW/s with a response delay of 50 ms. This behaviour of the battery system is derived from the results of Enhanced Frequency Response (EFR) battery project by Belectric in Nevendon, UK. The parameters from the EFR project in Nevendon, UK were used for the purpose of study and control evaluation only, the real reaction time may vary in the actual scenario due to different communication setup and due to the distance between the battery container and hybrid controller located at the PV farm.

As the EFCC control scheme is a non-continuous service, frequency events with observed RoCoF of more than ±0.04 Hz/s and frequency nadir breaching 49.7/50.2 Hz (first power request thresholds) are very rare, therefore the model doesn't consider the situation where the battery state of charge (SoC) is out of its operational limits due multiple EFCC responses in a day. The maximum power request duration in the current set up 80 s – in case of the largest event with a frequency drop below/above 48.8/50.6 Hz - the maximum energy used by the battery will be below 2% of its capacity. The system therefore considers power availability from the battery system to be always constant at 800 kW for the whole duration of the power request by the EFCC local controller as the impact on the SoC is marginal.

During the EFCC PV stand-alone trials the response time of the PV inverter was found to be inconsistent and varying due to 1:N Modbus communication protocol. The inverter response was found to be of the rate of 750 ms for the first power request while the reaction time decreased to 200 ms for the consecutive second and third power requests as seen in Figure 1.

Note: To improve the overall PV reaction time the hybrid controller has been re-optimised as a result, with the current implementation the reaction time for the first power request in the PV system is down to 200 ms. This updated faster PV reaction time is not implemented in the simulation study.

The hybrid model simulates the output behaviour of the PV inverters with a non-linear ramp as shown in Figure 2. This was done to resemble the results from EFCC PV standalone trials. The PV inverter ramp at a rate of 300 kW/s, providing 80% of the power request, is followed by a slower ramp rate of 150 kW/s providing the rest of the power.

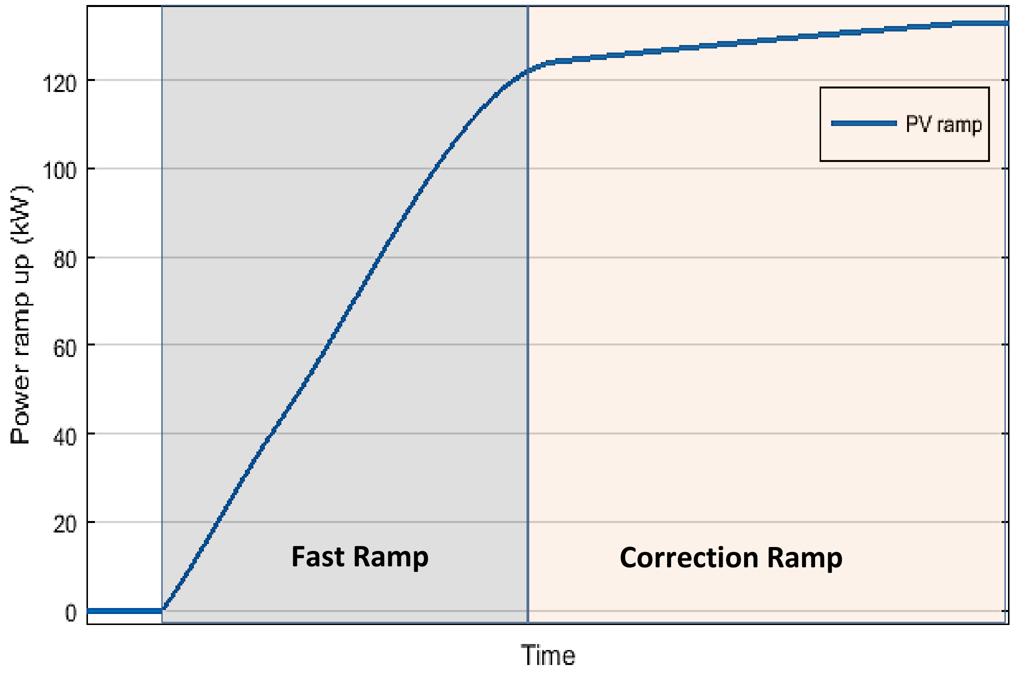

Figure 2: Modelled PV inverter ramp rate behaviour with fast ramp and correction ramp.

Response Strategy: The response strategy of the EFCC PV-Battery Hybrid Model is divided into two schemes which are as follows:-

- **Day**
  - The positive power availability of the system depends on the battery system. Due to the absence of SoC management system the positive power availability is constant 800 kW.
  - The negative power availability of the system depends on the forecasted *15-minute balance power* [1] by the PV inverter.
- **Night**
  - Due to the unavailability of the PV resource, the battery system provides both positive and negative power response. This allows for larger overall response. The response strategy depends on the nature of the frequency event as well as the time of the day. Table 3 shows the implemented response strategy in the EFCC PV-Battery Hybrid Model.

SNO	TIME OF THE DAY	RESPONSE STRATEGY FOR THE FREQUENCY EVENT		
1	Day	**Under frequency**	:	Response from battery system
2		**Over frequency**	:	Coordinative response from PV and battery
3	Night	**Under frequency**	:	Response from battery system
4		**Over frequency**	:	Response from battery system

Table 3: EFCC PV-Battery Hybrid System response strategy.

[1] More details on forecasting procedure and accuracy available in NIC EFCC WP2.3 Solar PV Report.

In the current implementation of the control system the decision upon the day and night is taken at a fixed local time i.e. 7 AM-7 PM. Under the actual EFCC scheme the energy buffer unit used during the PV-Battery hybrid system has a workable SoC interval between 20% and 100%. To provide the frequency response services during the night, when the PV is not available, the EBU reduces its SoC to 60% which is the mean value in the workable battery SoC interval, thus configuring the storage system to have an ability to provide frequency response services in both directions by charging or discharging. The decision for day and night occurrences is taken by observing the historical sunrise and sunset times at Willersey. This allows the control system to evaluate the start and the end of the day while considering the seasonal change. During the early morning the PV inverters are observed to be switching on and off due to low irradiance. To eliminate this situation of low irradiance levels the start of the day/night is adjusted 45 minutes after the sunrise and 45 minutes before the sunset at Willersey. Table 4 illustrates the overview on the energy storage SoC adjustments according to the day and night control scheme.

SNO	CONTROL SCHEME	TIME	SOC LEVEL
1	Day	Sunrise time + 45 minutes	90%
2	Night	Sunset time - 45 minutes	60%

Table 4: State of Charge levels of Battery Energy Storage System during the day and at night according to the implemented control strategy under the EFCC Hybrid Control scheme.

Under the EFCC control scheme implementation the hybrid controller adjusts the battery SoC level for maximum availability. As a result the SoC level of the energy storage system is increased to 90% in the morning. Additional 10% is kept free as buffer for the battery to absorb the power while enhancing the PV ramp during an over frequency events (explained in detail below). At night the battery reduces its SoC to 60% so that the system can provide frequency response services in both directions.

The inverter active power (kW) is not used to distinguish between the occurrences of day and night as this may unnecessarily trigger battery SoC adjustment multiple times during the day with low irradiance. This false triggering is illustrated in the Figure 3 where the controller may start to adjust the SoC during the day with low irradiance values.

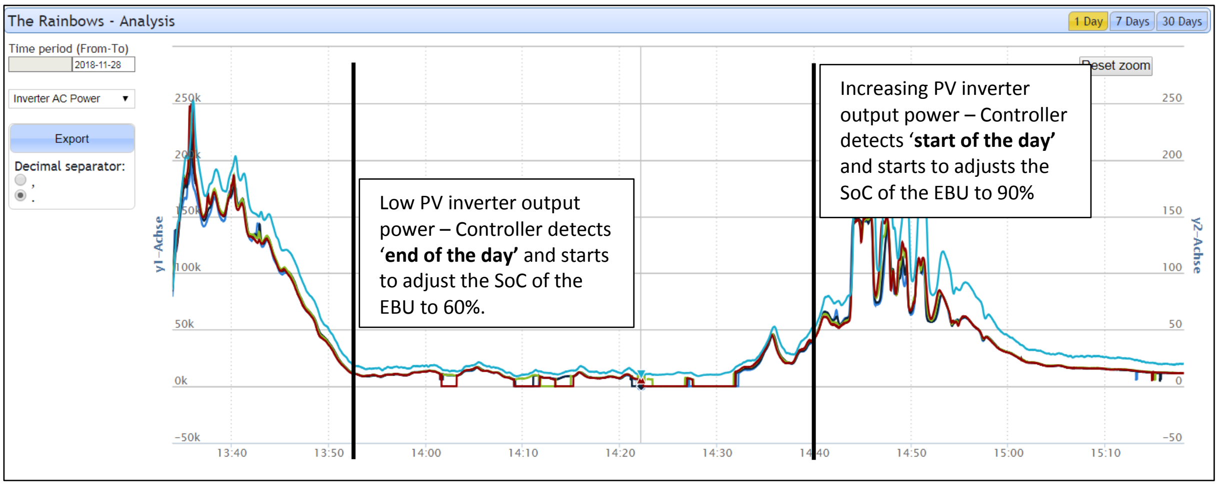

Figure 3: Illustration of scenario with extremely low irradiance recorded during the day time at Willersey – This event may be detected by the controller as sunset and then sunrise thus triggering of SoC adjustment functionality.

As per the current implementation in the PV-Battery Simulation Model –

- During day, when the PV resource is available,
  - When an under-frequency event occurs, the battery system provides the power response by injecting power into the grid while the PV inverter continues to run unaffectedly at its maximum power point.
  - When an over frequency event occurs, PV system provides the negative power by changing its working point for a small duration and reducing its power output below the maximum power point. Due to comparatively slower PV inverter response times and lower ramp rates (key learnings from EFCC PV standalone trials), the battery system provides the initial ramp support and therefore increases the overall performance of the system. The battery system with its high ramp rates and lower response time responds to the power request initially, only with a small communication induced latency, and once the PV inverter starts to respond the battery reduces its output power in a coordinative manner to maintain the power constant at the grid connecting point without exceeding the requested power request. This behaviour of PV and Battery system coordinative responding to a power request and increasing the total system performance is illustrated in Figure 4.

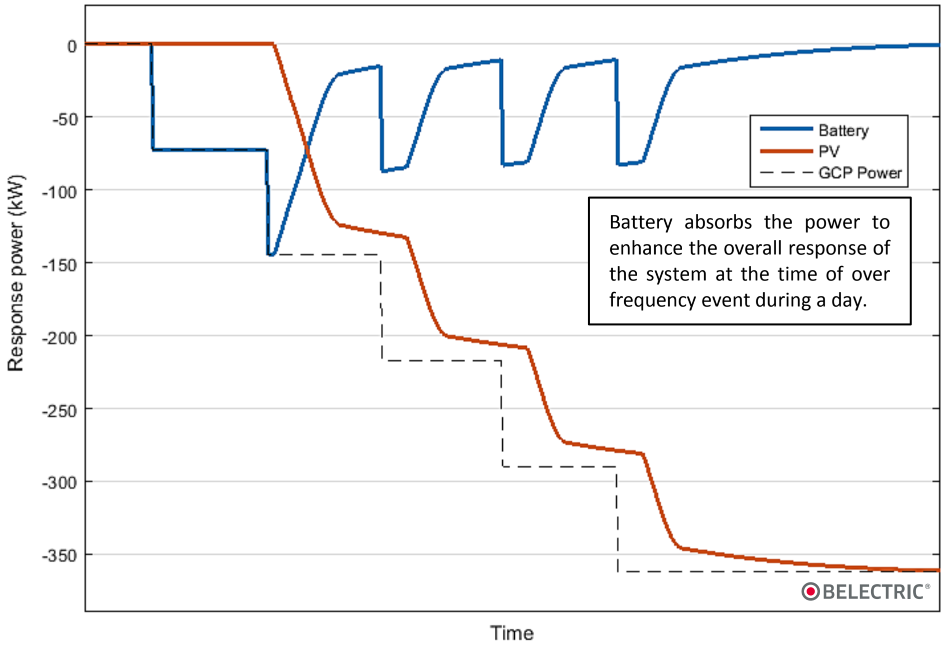

Figure 4: Initial ramp support by the battery system during an under-frequency event to follow the EFCC power request more precisely at the grid connection point (GCP).

Hybrid system response availability: Table 5 below shows the evaluation of power availability according to the deployed response strategy in the EFCC hybrid system.

SNO	TIME	FREQUENCY RESPONSE STRATEGY FOR THE EVENT		
1	Day	**Positive power response**	:	800 kW from the Energy Buffer Unit
2		**Negative power response**	:	15 minute forecasted power
3	Night	**Under frequency response**	:	800 kW from the Energy Buffer Unit
4		**Negative power response**	:	800 kW from the Energy Buffer Unit

Table 5: EFCC power availability evaluation under the hybrid simulations

Data import: For proper execution of the simulation program the hybrid model needs the following parameters. Below are mentioned the essential fields required for the execution of the model.

1. Date and Time stamp
2. Frequency values from the PMU
3. RoCoF values from the PMU
4. Inverter power (kW)

List of real time delays: The hybrid model introduces communication and processing latencies during real time simulation. The latencies used in the model are further divided in two sections which are mentioned below:

1. EFCC detection and signalling delays.

   a. GE Communication buffer time for RoCoF triggering – 20 ms
   b. GE Communication buffer time for frequency event triggering – 20 ms
   c. GE Power request buffer time – 420 ms
2. PV- battery hybrid resource delays.
   a. Observed battery response time – 50 ms
   b. Observed PV response time to the first power request – 750 ms
   c. Observed PV response time to second or higher power request – 200 ms

3. Simulation behaviour with simulated frequency event data

3.1 Simulated under frequency events

To test the behaviour of the PV-Battery hybrid model during the under frequency events, historical simulated under frequency event data with known RoCoF values and pre-defined frequency nadir were injected in the model. For executing the simulations the frequency event data of different magnitudes were injected to the model. The undermentioned steps illustrates the expected behaviour of the model during an under frequency event.

Step 1: The model observes the RoCoF values, once the RoCoF threshold of -0.04 Hz/s is exceeded the model triggers the RoCoF flag after a delay of 20 ms.

Step 2: If the RoCoF flag is triggered and the frequency continues to deviate, the event detection flag is triggered 20 ms after the frequency crosses the first threshold limit of 49.7 Hz in case of under frequency event.

Once the event is detected and the frequency stays below the threshold limit of 49.7 Hz for 420 ms, the model sends its first power request corresponding to 20% of positive power availability. If the frequency doesn't stay below the threshold limit for 420 ms the event is handled as a noise/fault in the power network and the EFCC frequency response service is not activated.

Step 3: Due to the nature of the frequency event (under frequency, day) the power request is only responded by the battery system, while the PV inverter's working point continues to remain at maximum power point (MPP). The battery system responds to the power request after a response delay of 50 ms with a ramp rate of 8000 kW/s.

Step 4: If the frequency doesn't recover and continues to deviate further, the power request is increased every time the frequency crosses and stays beyond the next threshold for 420 ms. The frequency thresholds for an under frequency events and corresponding power requests are mentioned in Table 2 on page number 7.

Step 5: The power request is sent for 50 seconds after the last frequency threshold followed by a 10 seconds ramp back to the initial state as observed in the simulations done during the PV stand-alone trials.

Note: This model does not respond to slow frequency events.[2]

[2] Frequency events due to gradual change in frequency for longer durations of time without reaching the RoCoF threshold.

1. Frequency Event 1 – Frequency nadir of 49.65 Hz & RoCoF of -0.15 Hz/s

The following section presents the behaviour of the EFCC hybrid model during a simulated under frequency event with predefined RoCoF value of -0.15 Hz/s and a frequency nadir of 49.65 Hz. The EFCC hybrid model observed the RoCoF and triggered the RoCoF flag 20 ms after the RoCoF exceeded the value of -0.04 Hz/s.

The event detection flag was triggered 20 ms after the frequency crossed the first under frequency threshold of 49.7 Hz and a 160 kW power request corresponding to 20% of battery power availability was sent by the EFCC Hybrid system model once the frequency stayed below the first under frequency threshold for more than 420 ms. In response, the battery system provided the frequency response with a delay time of 50 ms at a ramp rate of 8000 kW/s while the PV system continued to operate at maximum power point. The Hybrid model requested the power for 50 seconds followed by a 10 second power ramp down to initial condition.

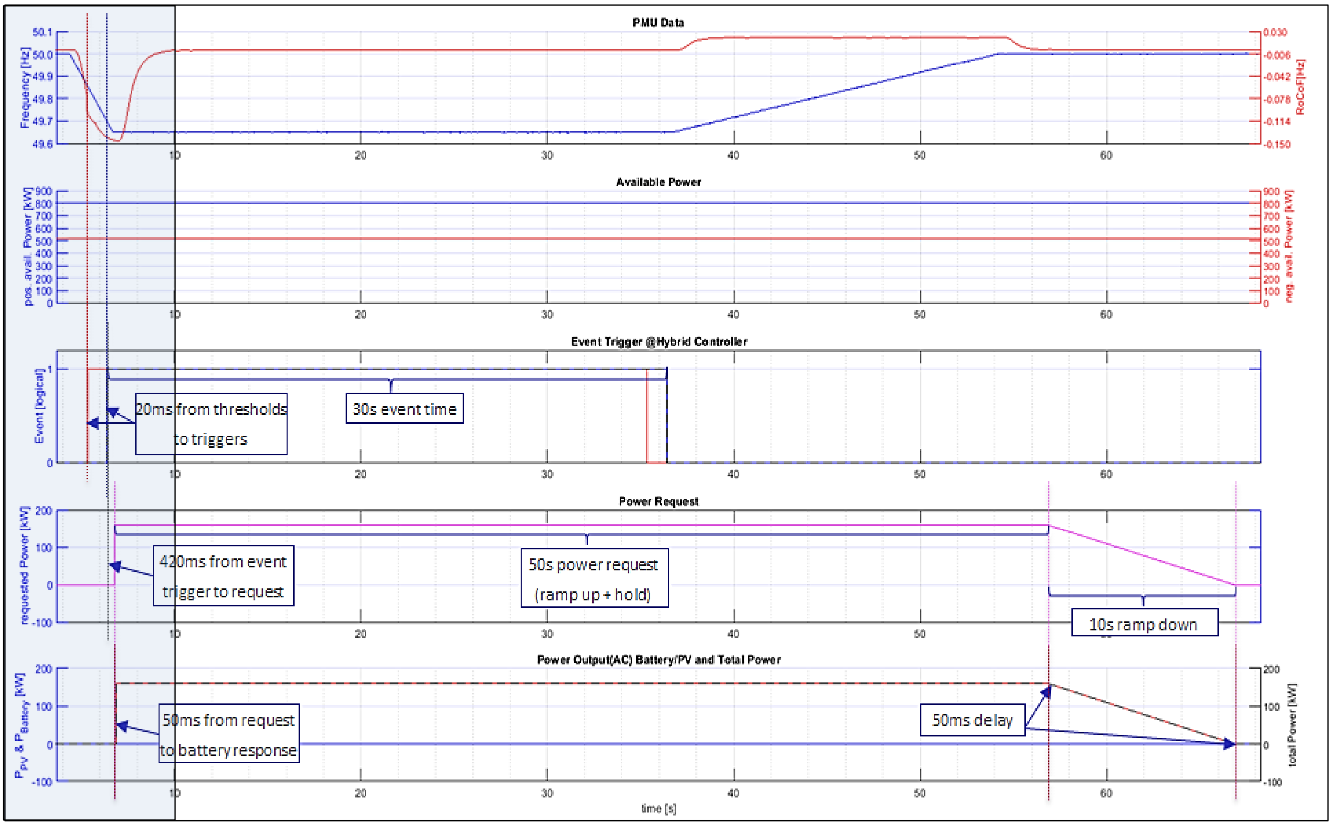

Figure 5(a): EFCC Hybrid model behaviour during simulated event (RoCoF -0.15 Hz/s, frequency nadir 49.65 Hz). Blue part in more detail in Figure 5(b).

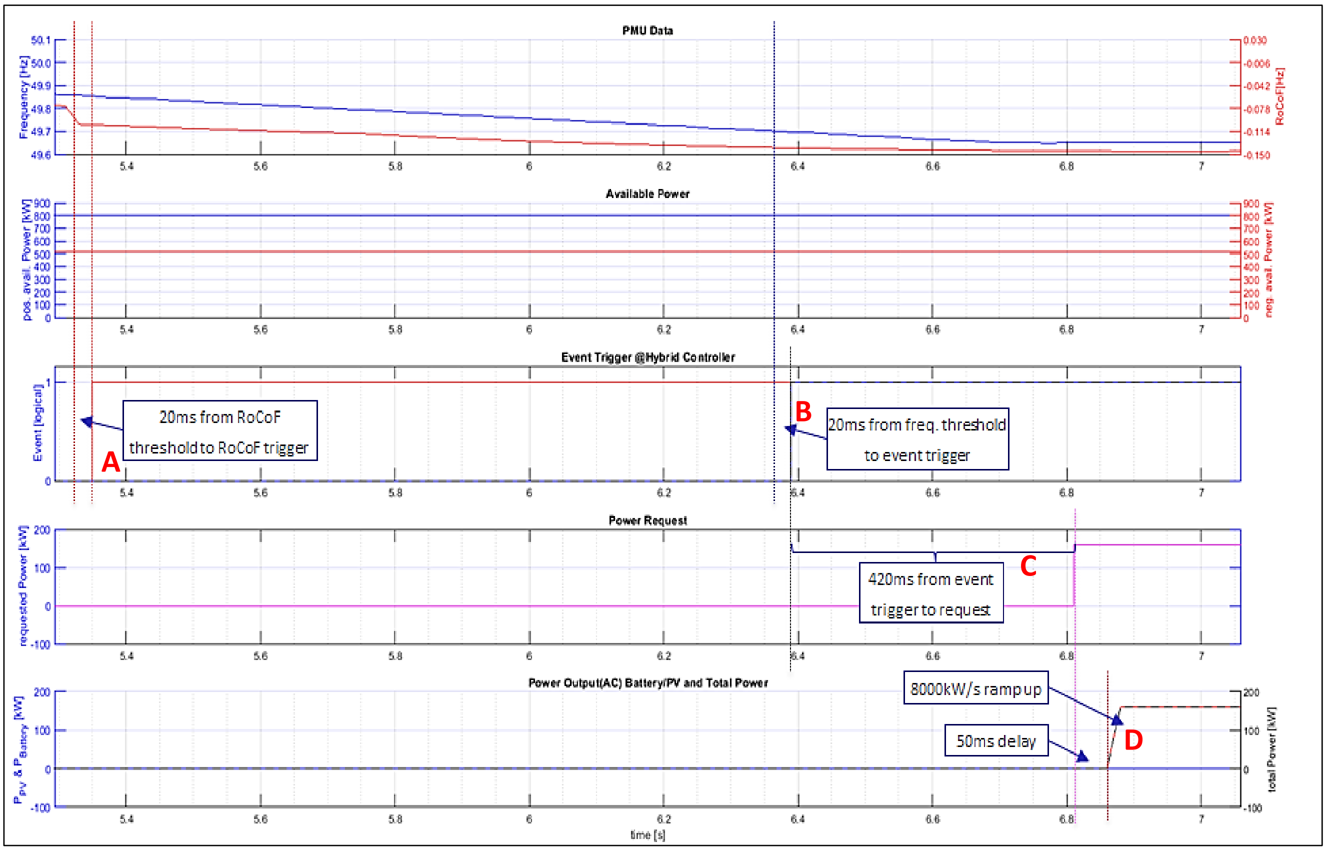

Figure 5(b): 20 ms delay during RoCoF triggering and event detection (A and B), 420 ms Power request hysteresis (C) Battery response to the power request (D).

2. Frequency Event 2 – Frequency nadir of 49.45 Hz & RoCoF of -0.15 Hz/s

The following section presents the behaviour of the EFCC Hybrid model during a simulated under frequency event with a predefined RoCoF value of -0.15 Hz/s and a frequency nadir of 49.45 Hz. The EFCC hybrid model observed the RoCoF and triggered the RoCoF flag 20ms after the RoCoF exceeded the value of -0.04 Hz/s.

The event detection flag was triggered 20 ms after the frequency crossed the first under frequency threshold of 49.7 Hz and a 160 kW power request ,which corresponds to 20% of battery power availability, was sent by the Hybrid model once the frequency stayed below the first under frequency threshold for 420 ms. As the frequency reached the second threshold limit of 49.5 Hz, stage 2 of the event was detected after a delay of 20 ms, and the power request was increased to 320 kW which corresponds to 40% of available positive power. In response to each power request the battery system provided a response with a 50 ms delay at a rate of 8000 kW/sec.

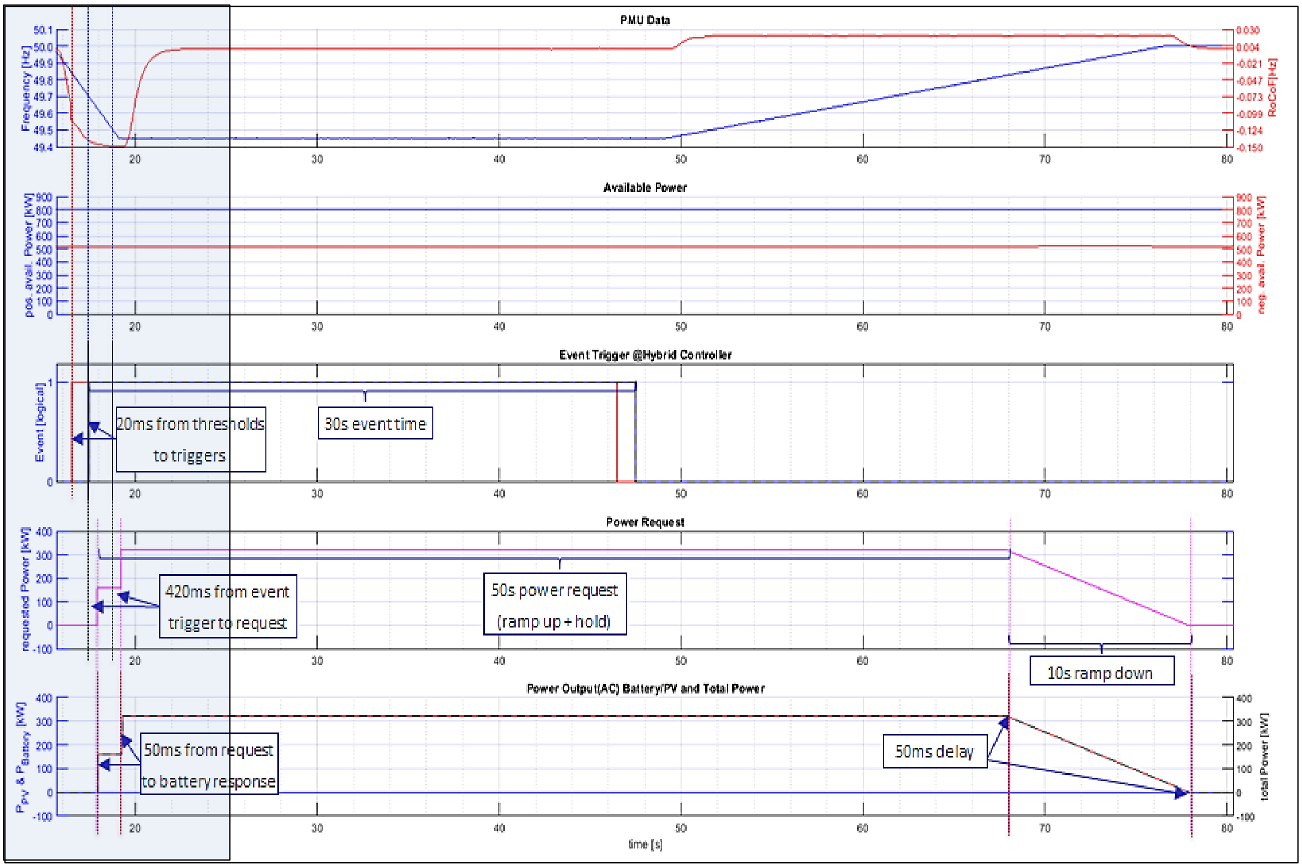

Figure 6(a): EFCC Hybrid model behaviour during simulated event (RoCoF -0.15Hz/s, frequency nadir 49.45 Hz). Blue part in more detail in Figure 6(b).

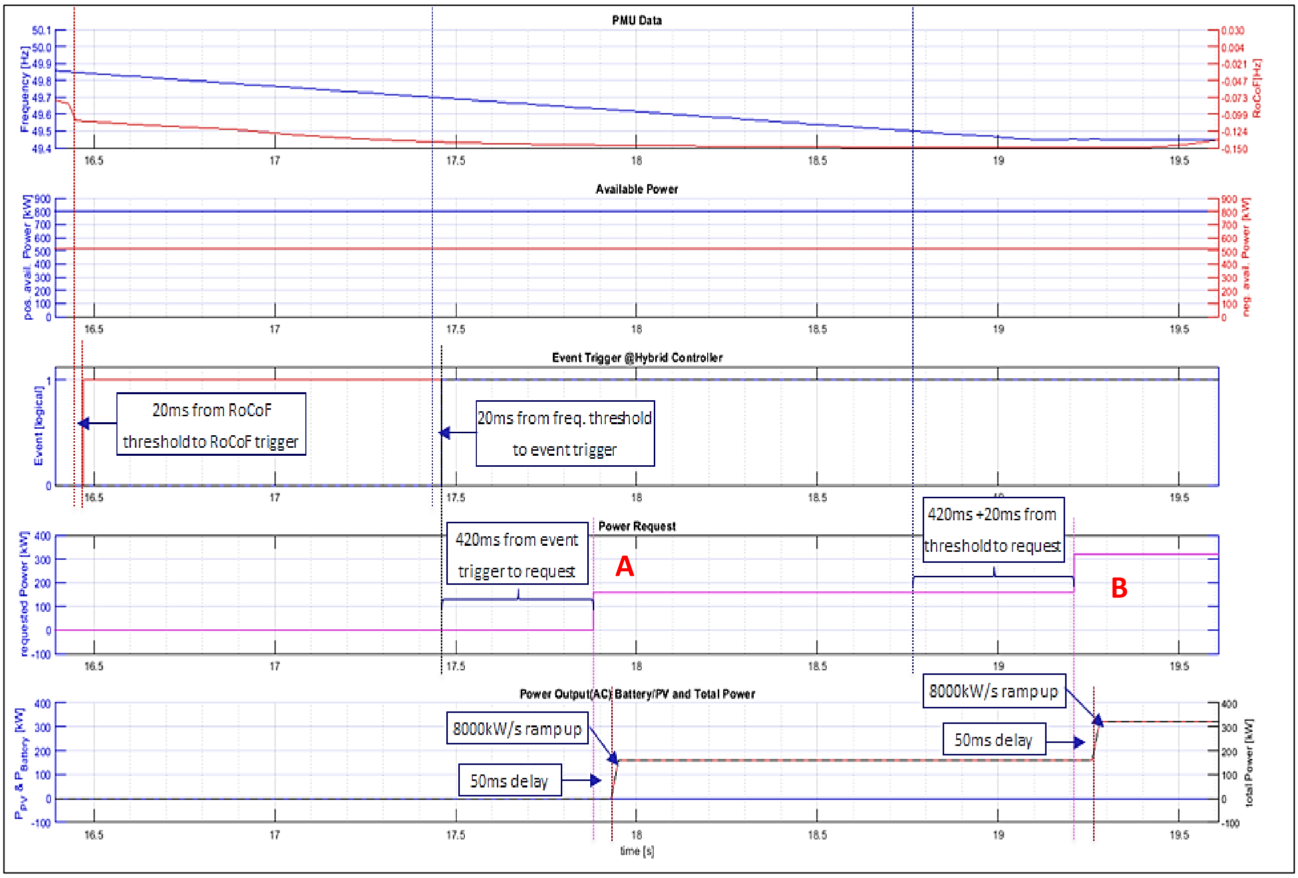

Figure 6(b): Stepped power request (A and B) with 420 ms event detection and 20 ms communication delay.

3. Frequency Event 3 – Frequency nadir of 49.25 Hz & RoCoF of -0.15 Hz/s

The following section presents the behaviour of the EFCC Hybrid model during a simulated under frequency event with predefined RoCoF value of -0.15 Hz/s and a frequency nadir of 49.25 Hz. The model triggered the RoCoF and event detection flag as expected. The model requested a three stage power request, which corresponded to 20%, 40% and 60% of positive power availability; in response to reach the power request the battery provided the response after a delay of 50 ms at a ramp rate of 8000 kW/s.

The model sent a 50 second (ramp up + hold) power request followed by a 10 second ramp down. The battery solely provided the whole power request and followed the ramp down request with a communication and internal processing latency of 50 ms due to hybrid controller.

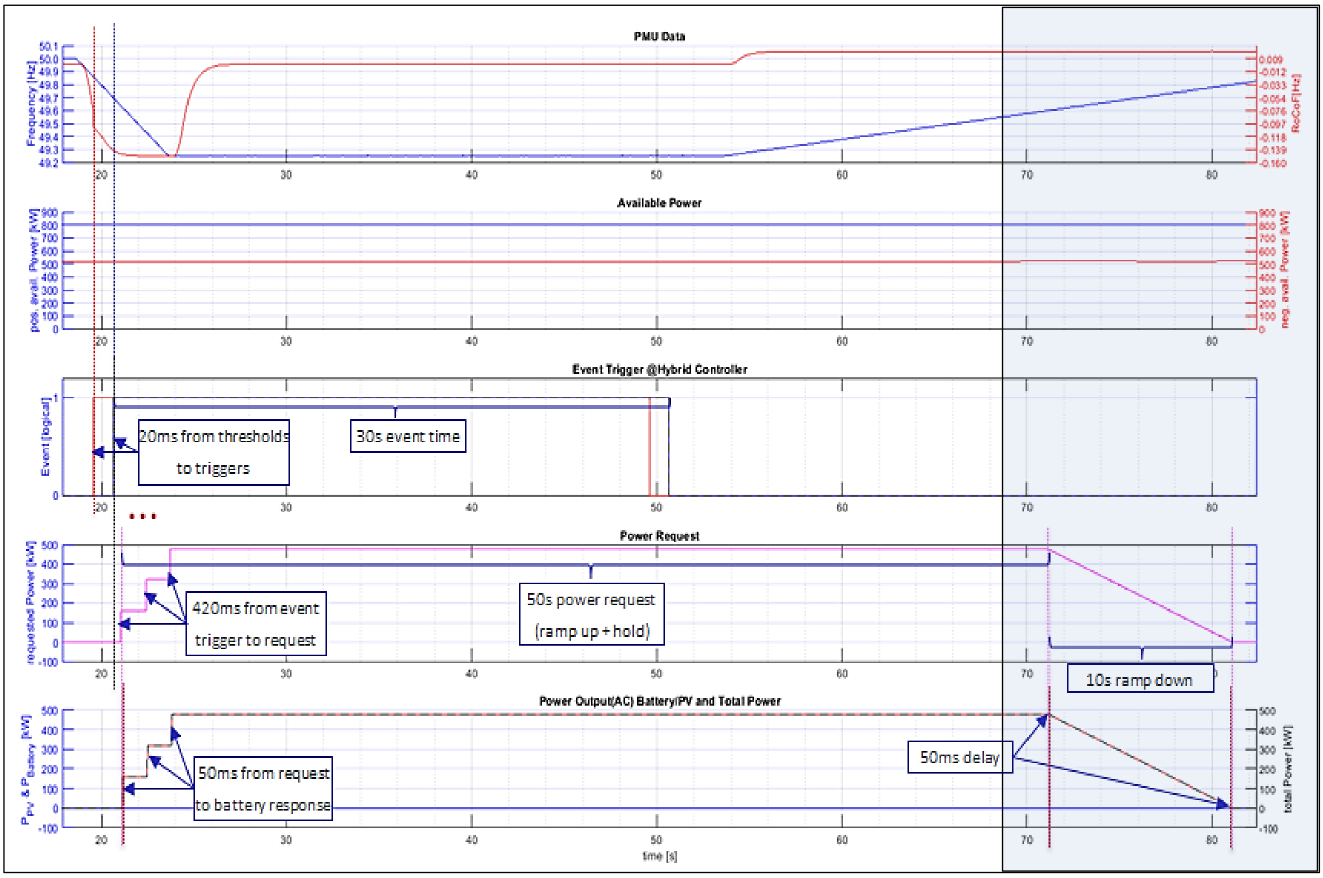

Figure 7(a): Hybrid model behaviour during simulated event (RoCoF -0.15 Hz/s, frequency nadir 49.25 Hz). Blue part in more detail in Figure 7(b).

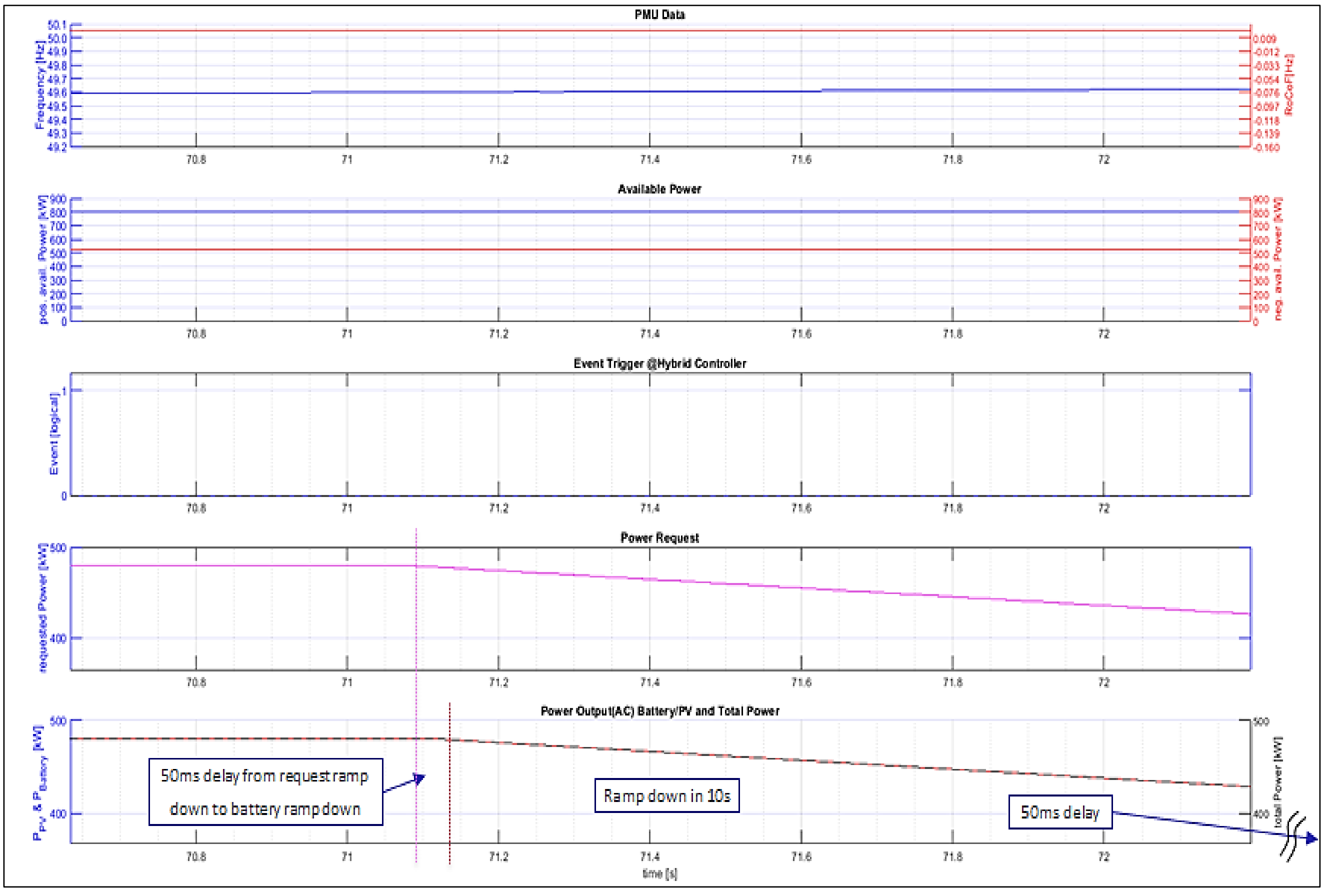

Figure 7(b): Ten second ramp down behaviour with 50 ms delay by battery storage system during under frequency event.

3.2 Simulated over frequency events

To test the behaviour of the PV-Battery hybrid model during the over frequency events, historical simulated over frequency event data with known RoCoF and pre-defined frequency nadir values were used. For executing the simulations the frequency events data of different magnitude were injected to the model. The undermentioned steps show the expected behaviour of the model during an over frequency event.

Step 1: The model observes the RoCoF values, once the RoCoF threshold of +0.04 Hz/s is exceeded the model triggers the RoCoF flag after a simulated local controller communication and measuring delay of 20 ms.

Step 2: If the RoCoF flag is triggered and the frequency continues to deviate, the event detection flag is triggered 20 ms after the frequency crosses the first threshold limit of 50.2 Hz in case of an over frequency event.

Once the event is detected and the frequency continues to stay above the threshold limit of 50.2 Hz for 420 ms, the model sends its first negative power request corresponding to 20% of PV negative power availability. If the frequency doesn’t stay above the threshold limit for 420 ms the event is handled as a noise/fault in the power network and the EFCC frequency response service is not activated.

Step 3: Due to the nature of the frequency event (over frequency) the power request is responded by PV inverter and the battery systems together as mentioned in Figure 2 on page 9.

Step 4: Every time the frequency crosses and stays below the next threshold for 420 ms, the model increases the negative power request. The currently configured frequency thresholds for an over frequency events and its corresponding negative power requests are listed in Table 1 on page 7.

Step 5: In total, the power request is sent for 50 seconds after the last threshold is reached and the power is ramped back to zero in the next 10 second.

Note: This model does not detect slow frequency events.

4. Frequency Event 4 – Frequency nadir of 50.2 Hz & RoCoF of +0.15 Hz/s

The following section presents the behaviour of the EFCC Hybrid model during a simulated over frequency event with predefined RoCoF value of +0.15 Hz/s and a frequency nadir of 50.20 Hz. The model triggered the RoCoF flag, 20ms after the RoCoF exceeded the threshold value of +0.04 Hz/s. The event was detected 20ms after the frequency crossed the first over frequency threshold of 50.2 Hz. The first negative power request of 102 kW, which corresponds to 20% of negative power availability (PV) was sent once the frequency stayed above the over frequency threshold of 50.2 Hz for 420 ms.

In response, the PV inverter provided a negative power response with a delay of 750 ms while the battery system enhanced the performance of the whole system by reducing the delay time and responding initially within 50 ms. The battery system co-ordinately reduced its output power as the PV response started.

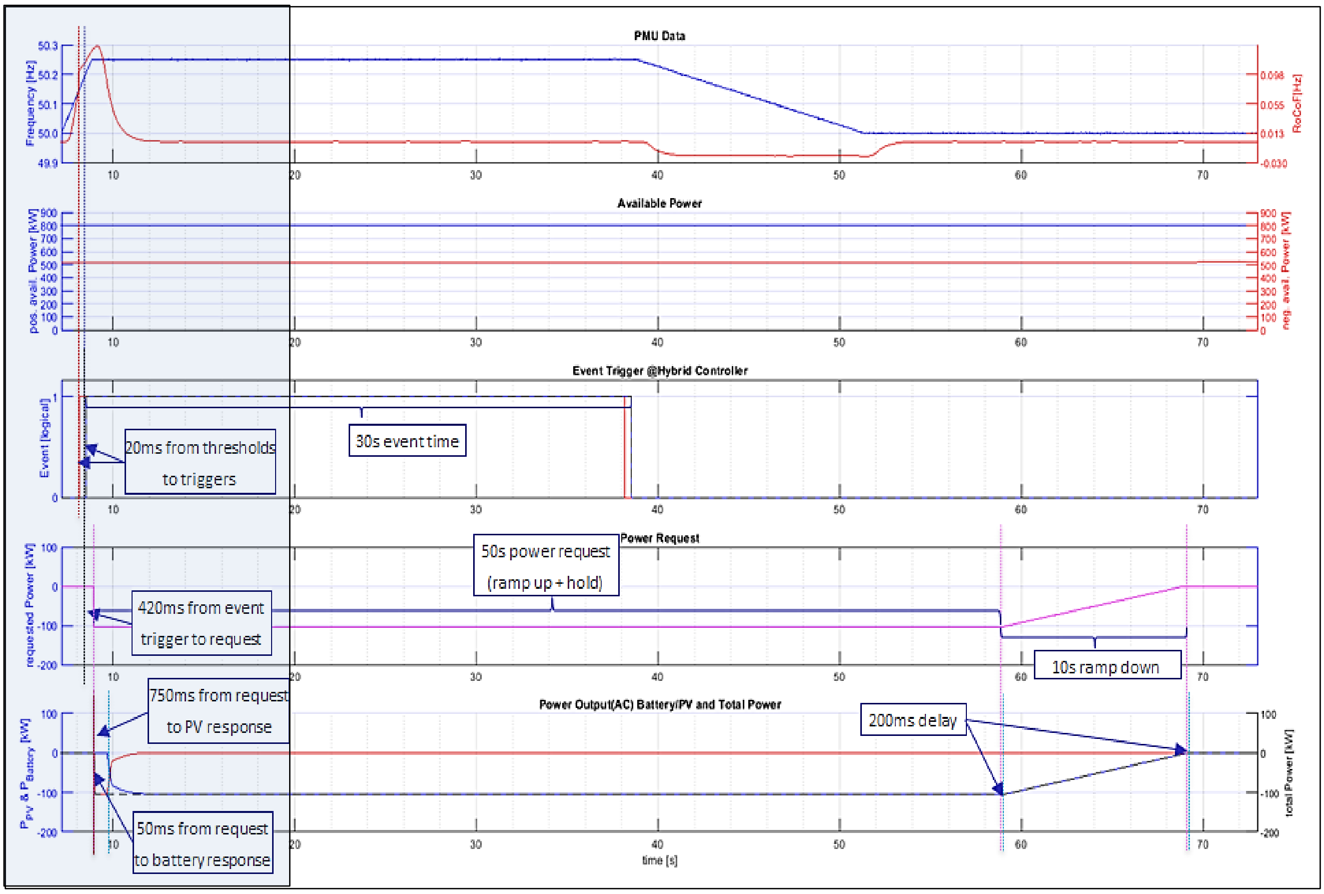

Figure 8(a): EFCC Hybrid model behaviour during simulated event (RoCoF +0.15 Hz/s, frequency nadir 50.2 Hz). Blue part in more detail in Figure 8(b).

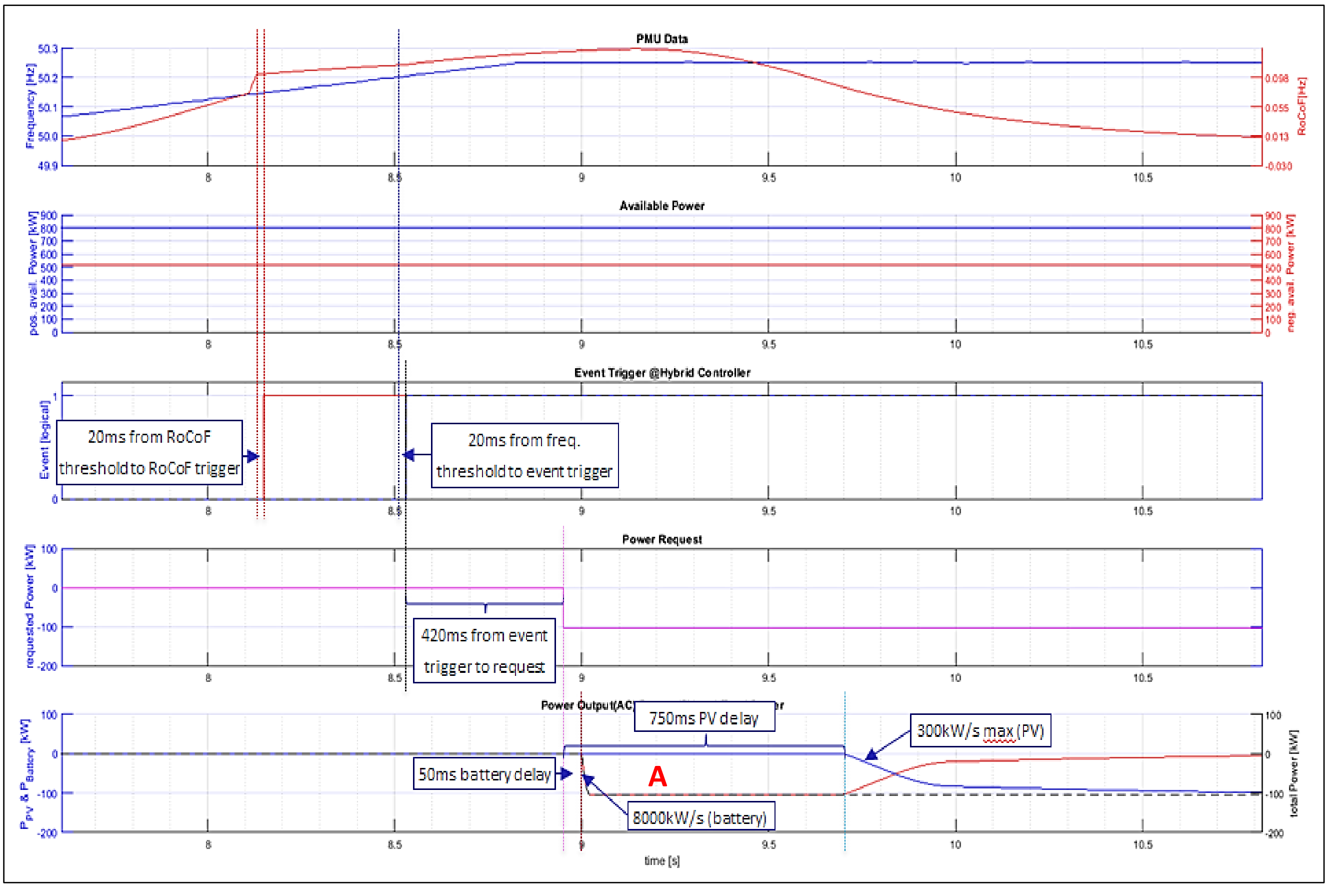

Figure 8(b): PV and battery coordinative response to provide ramp support and increase the overall system performance during an under frequency event (A).

5. Frequency Event 5 – Frequency nadir of 50.55 Hz & RoCoF of +0.15 Hz/s

The following section presents the behaviour of the EFCC Hybrid model during a simulated over frequency event with predefined RoCoF value of +0.15 Hz/s and a frequency nadir of 50.55 Hz. The model triggered a 4 stage power request during this event. For each request battery and PV system co-ordinately provided the response thus reducing the overall response time and increasing the system performance.

The PV system responded to the first request after 750 ms and reduced its response time to 200 ms for the higher power requests. The power request was maintained for 50 seconds followed by a 10 second ramp down. This ramp down was provided by PV with an overall delay of 200 ms.

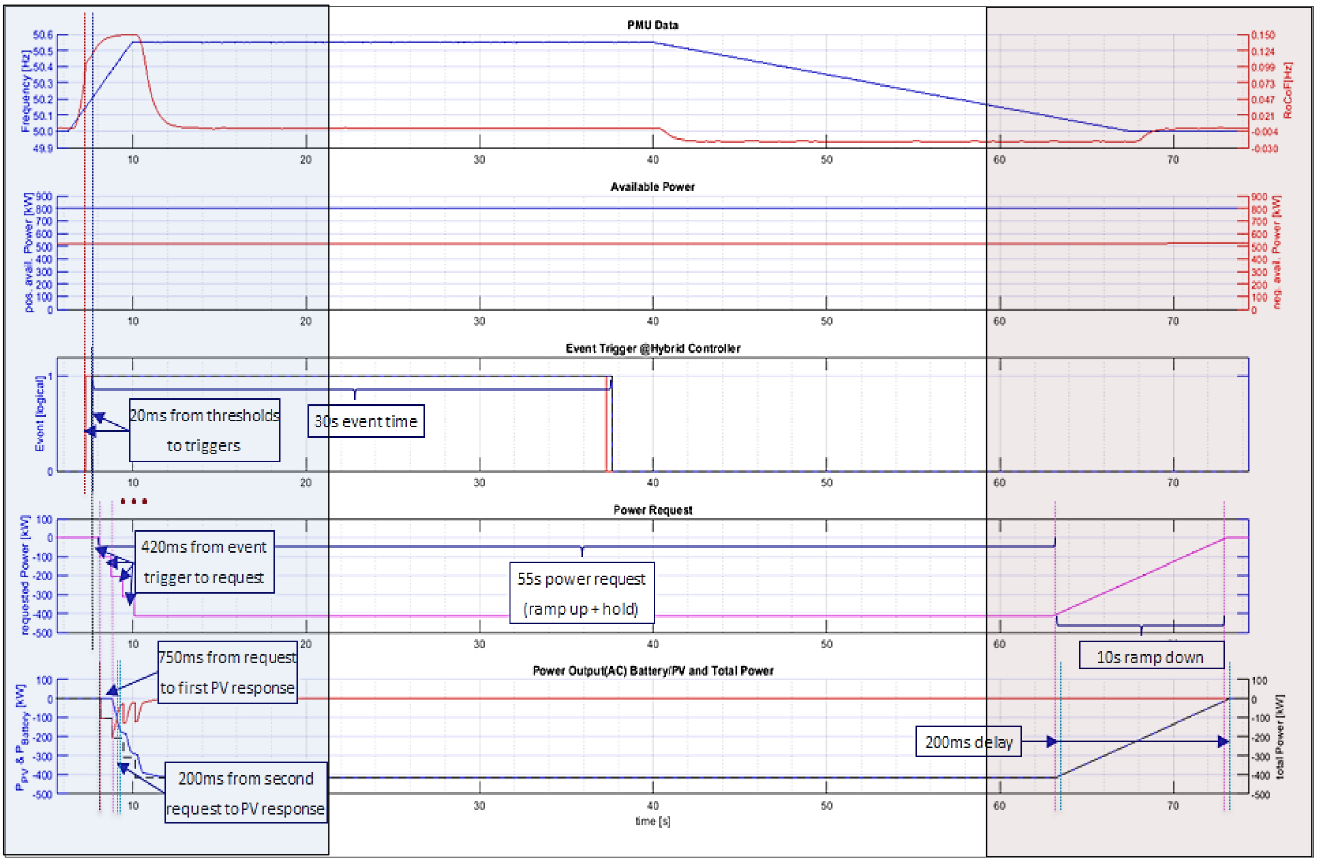

Figure 9(a): EFCC Hybrid model behaviour during simulated event (RoCoF +0.15Hz/sec, frequency nadir 50.55 Hz). Blue part in more detail in Figure 9(b), red part in Figure 9(c).

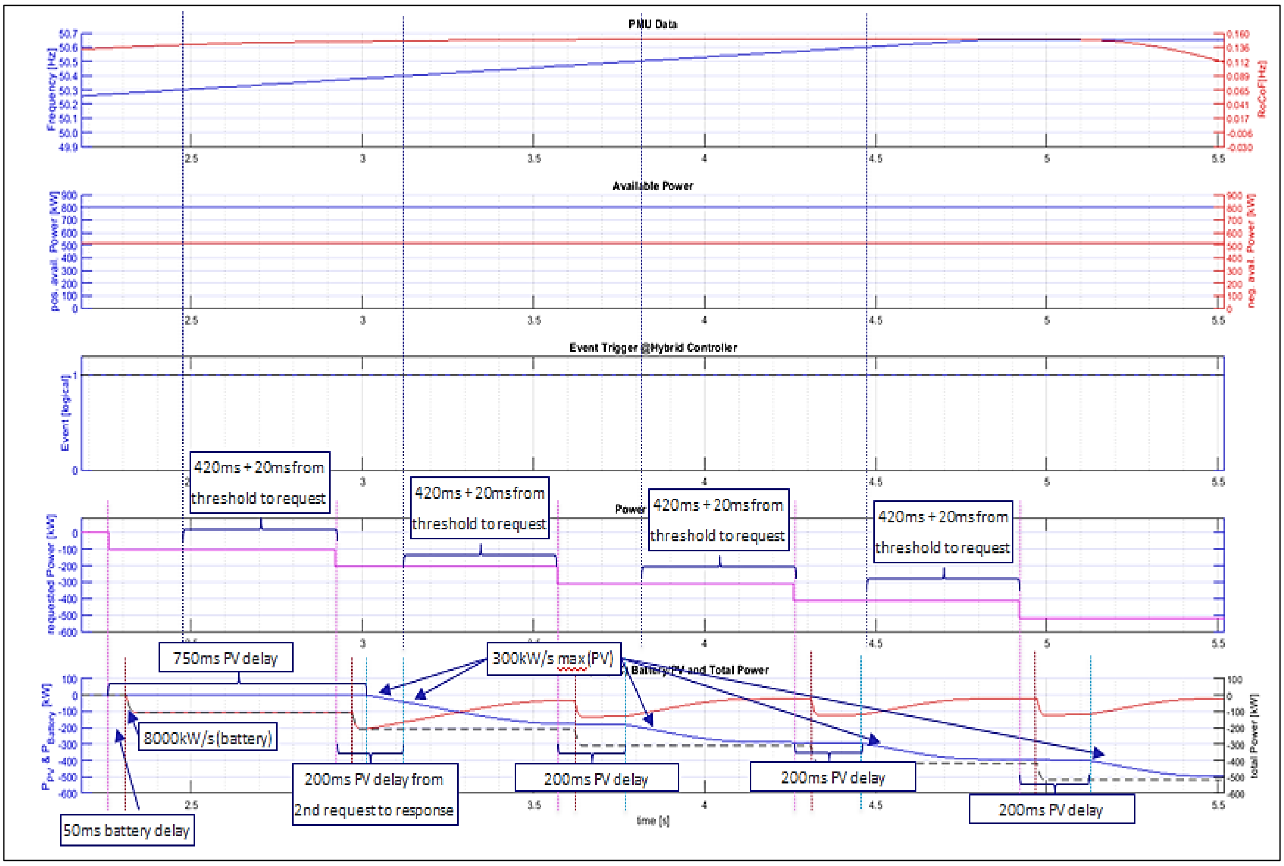

Figure 9(b): Multiple PV- battery coordinative response to provide ramp support for every new power request to increase the overall system performance during an over frequency event.

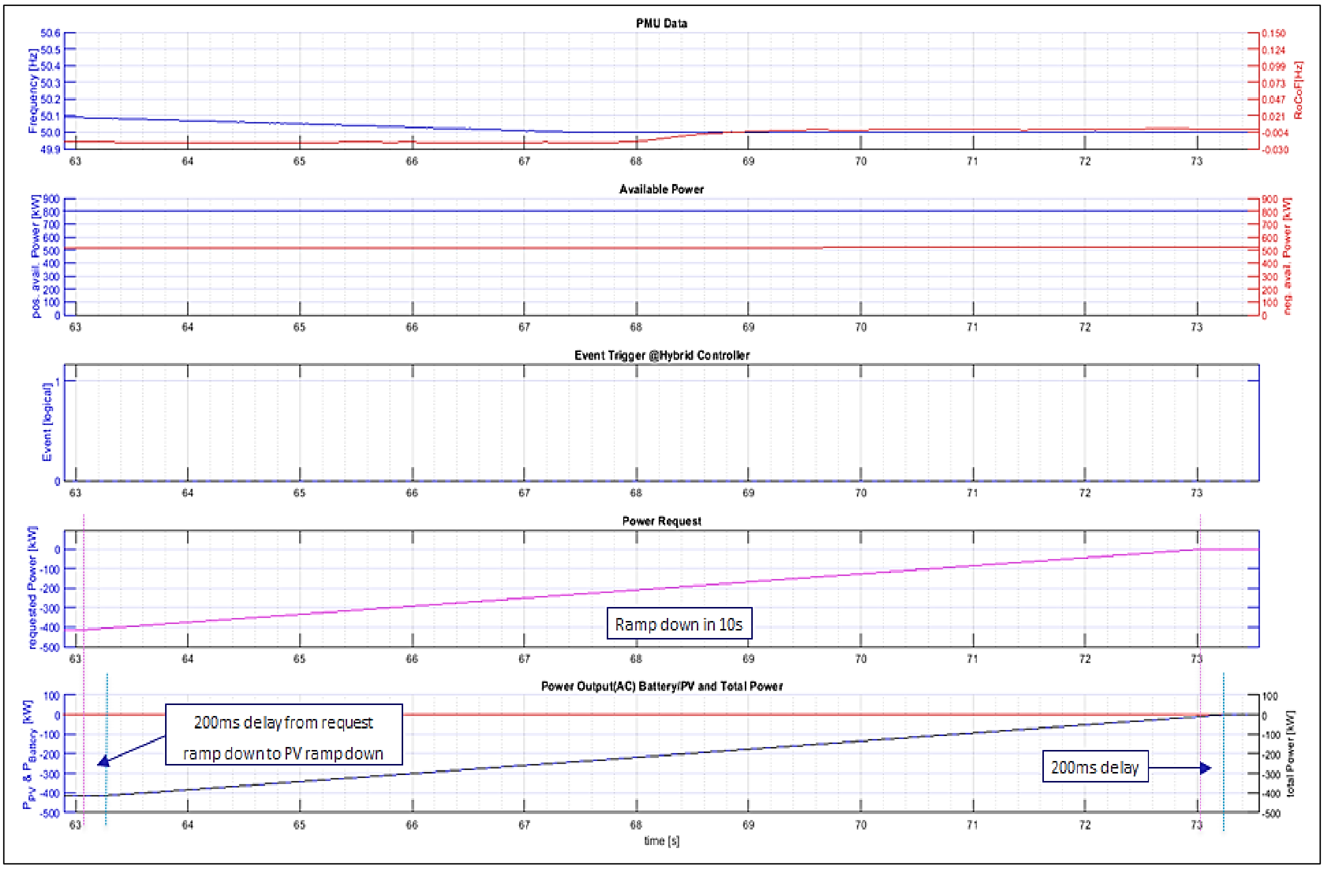

Figure 9(c): 10 second negative power ramp down request followed by the PV inverter during over frequency event.

4. Simulation behaviour with real frequency event data

4.1 Data of the under frequency event in UK on 23.02.2018 at 4:32 AM

This section shows the behaviour of the EFCC hybrid simulation model during a real frequency event which was measured by the phasor measurement unit at Willersey on 23-02-2018 at 4:32 AM (CET).

The RoCoF and event detection flags were triggered as expected. As the frequency event occurred when the PV plant was unavailable (night) the model requested 160 kW which corresponds to 20% of positive power available (battery). The power request was sent once the frequency stayed below the first threshold limit of 49.7 Hz for 420 ms. In response, the battery provided the requested power with a delay of 50 ms at a rate of 8000 kW/s.

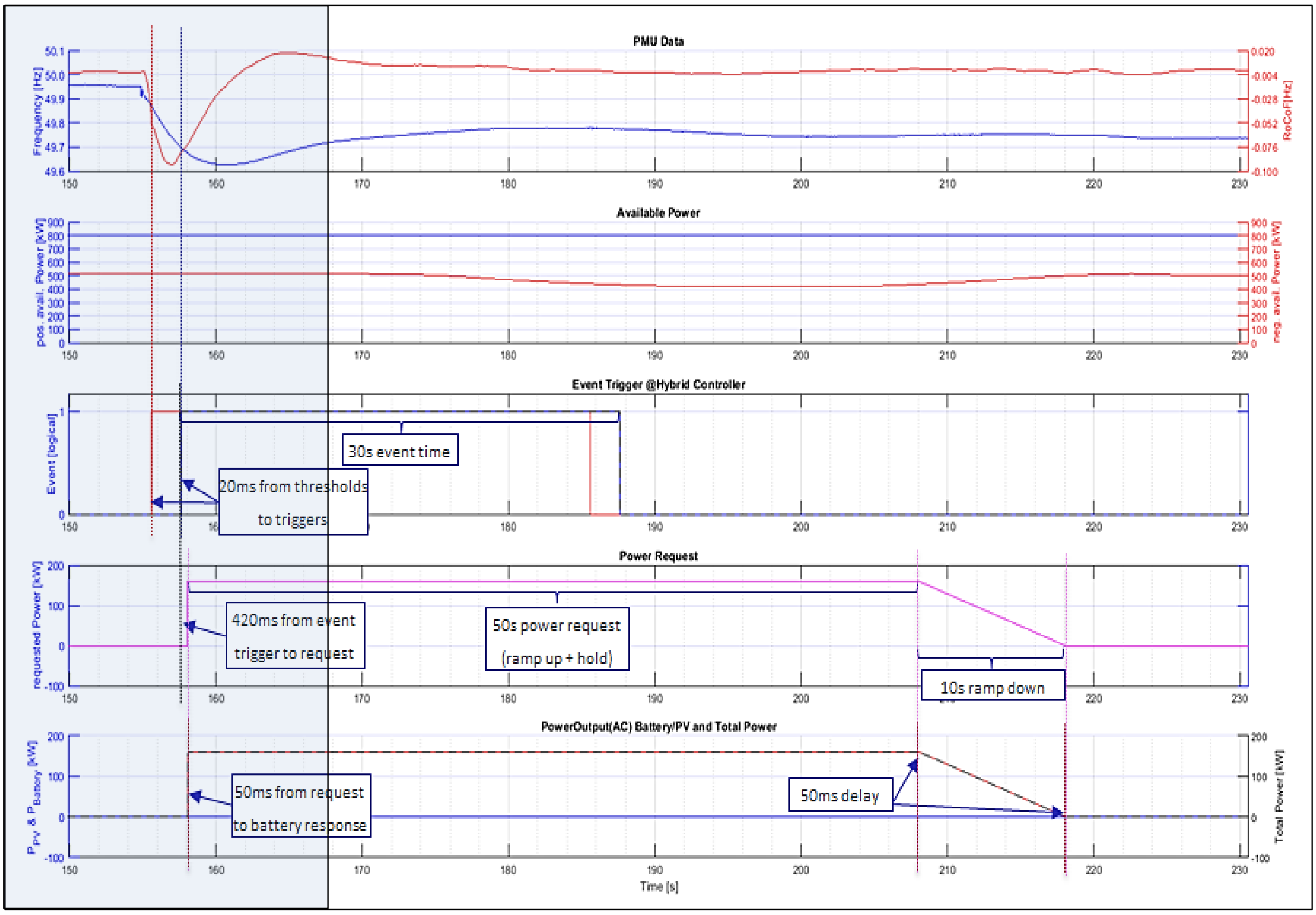

Figure 10(a): Real frequency event in GB on 23.02.2018 at 4:32 AM. Blue part in more detail in Figure 10(b).

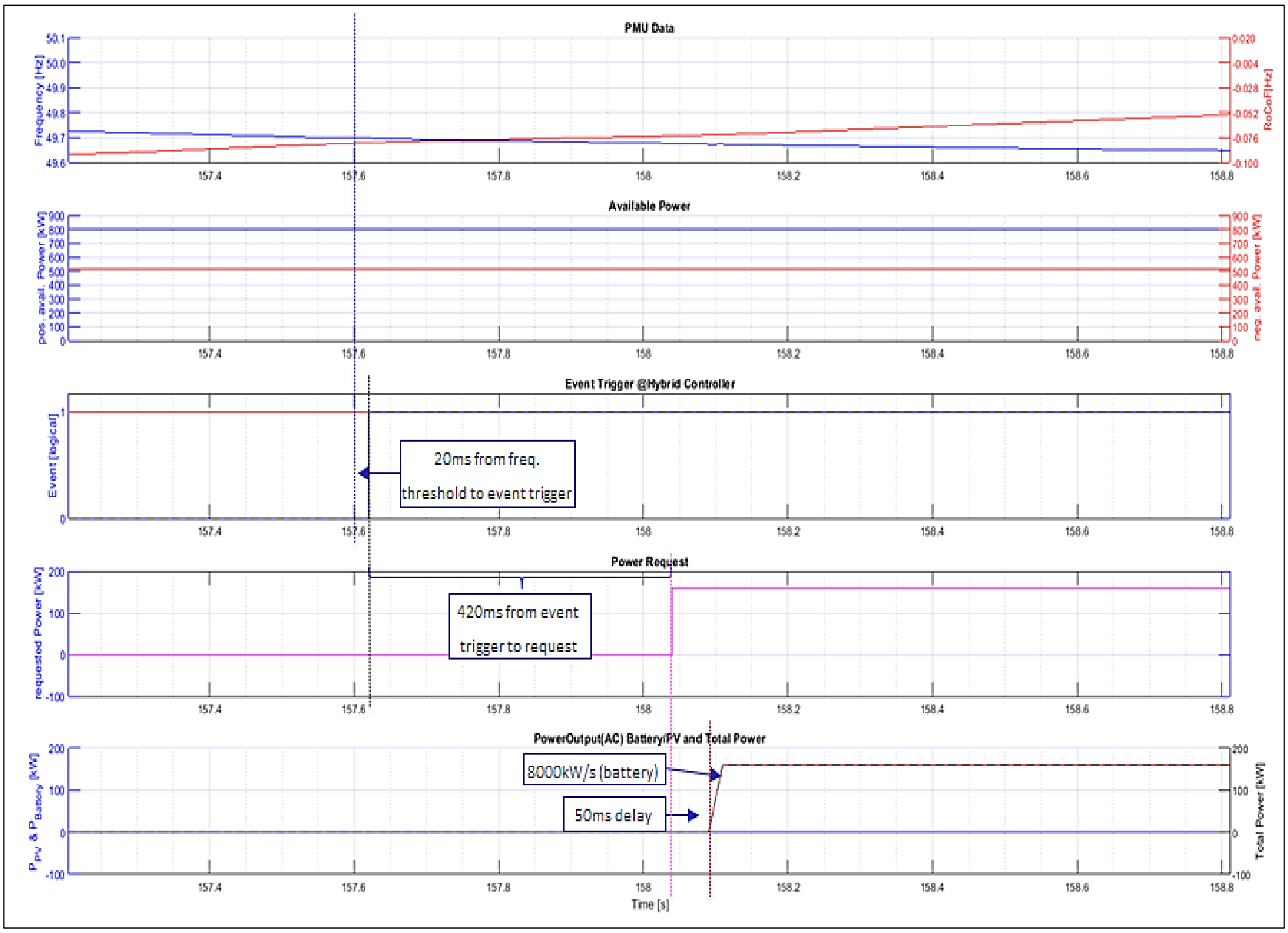

Figure 10(b): Behaviour of the Hybrid model during a real frequency event on 23.02.2018 at 4:32 AM.

5. Limitations and suggested future work

The model doesn’t include detection for slow frequency event with a low RoCoF. During the time when power system experience lower rate of change of frequency for long duration of time the frequency can go below the thresholds. Therefore the model should have a failsafe option of detecting the event during smaller RoCoF. However the absence of the event detection for slow frequency event does not affect the efficiency of the model in responding to EFCC related events.

The model doesn’t consider the unavailability of the battery system. As a result the battery system is always assumed to be available. To make the model more realistic, battery SoC management system can be implemented and new test cases can be designed where the battery is not able to provide ramp support to the PV system due to critical state of charge of the battery.

The model at present does not model the behaviour of a voltage disturbance nearby as a result of the generation fault disconnecting MW and triggering a combined voltage and frequency depression. This is needed in a more advanced model.

This model was prepared before conducting the NIA DESERT solar PV+Battery hybrid tests and successfully delivered results as to what to expect from the real implemented system.

The results were used to constantly improve the control logic of the NIA DESERT project and for reference when adapting the system. Developing the model potentially reduced the time for improving the real control as resources for solving complex control issues have already been used in developing the simulation.

1. Appendix

Real frequency event data from PMU – 23.02.2018 at 4:32 AM

Time	Frequency	Time	Frequency	Time	Frequency
04:31:54.240	49.899864	04:31:55.520	49.775768	04:31:56.820	49.686939
04:31:54.260	49.897095	04:31:55.540	49.773529	04:31:56.840	49.685081
04:31:54.280	49.896748	04:31:55.560	49.771683	04:31:56.860	49.684044
04:31:54.300	49.896847	04:31:55.580	49.769123	04:31:56.880	49.683708
04:31:54.320	49.894772	04:31:55.600	49.767155	04:31:56.900	49.682053
04:31:54.340	49.893284	04:31:55.620	49.766697	04:31:56.920	49.680962
04:31:54.360	49.890911	04:31:55.640	49.764839	04:31:56.940	49.680782
04:31:54.380	49.885376	04:31:55.660	49.762787	04:31:56.960	49.679817
04:31:54.400	49.882996	04:31:55.680	49.761223	04:31:56.980	49.679359
04:31:54.420	49.885239	04:31:55.700	49.758987	04:31:57.000	49.678532
04:31:54.440	49.88586	04:31:55.720	49.757824	04:31:57.020	49.676815
04:31:54.460	49.883034	04:31:55.740	49.757107	04:31:57.040	49.676132
04:31:54.480	49.880718	04:31:55.760	49.755951	04:31:57.060	49.674583
04:31:54.500	49.880077	04:31:55.780	49.755123	04:31:57.080	49.673088
04:31:54.520	49.878063	04:31:55.800	49.75322	04:31:57.100	49.673244
04:31:54.540	49.874832	04:31:55.820	49.750526	04:31:57.120	49.671864
04:31:54.560	49.87252	04:31:55.840	49.749233	04:31:57.140	49.670712
04:31:54.580	49.870964	04:31:55.860	49.748276	04:31:57.160	49.67075
04:31:54.600	49.869701	04:31:55.880	49.746929	04:31:57.180	49.669189
04:31:54.620	49.868172	04:31:55.900	49.746071	04:31:57.200	49.66848
04:31:54.640	49.865044	04:31:55.920	49.744896	04:31:57.220	49.668747
04:31:54.660	49.861698	04:31:55.940	49.743244	04:31:57.240	49.667702
04:31:54.680	49.859077	04:31:55.960	49.742081	04:31:57.260	49.666565
04:31:54.700	49.856491	04:31:55.980	49.740791	04:31:57.280	49.665497
04:31:54.720	49.854473	04:31:56.000	49.739304	04:31:57.300	49.664463
04:31:54.740	49.85239	04:31:56.020	49.737679	04:31:57.320	49.663651
04:31:54.760	49.850246	04:31:56.040	49.736134	04:31:57.340	49.662739
04:31:54.780	49.848404	04:31:56.060	49.735809	04:31:57.360	49.66227
04:31:54.800	49.845722	04:31:56.080	49.735039	04:31:57.380	49.661816
04:31:54.820	49.842976	04:31:56.100	49.732506	04:31:57.400	49.660496
04:31:54.840	49.84127	04:31:56.120	49.731194	04:31:57.420	49.65987
04:31:54.860	49.839005	04:31:56.140	49.731022	04:31:57.440	49.660942
04:31:54.880	49.83699	04:31:56.160	49.72942	04:31:57.460	49.660797
04:31:54.900	49.83569	04:31:56.180	49.727283	04:31:57.480	49.659122
04:31:54.920	49.833046	04:31:56.200	49.725769	04:31:57.500	49.657532
04:31:54.940	49.831093	04:31:56.220	49.724037	04:31:57.520	49.65625
04:31:54.960	49.82901	04:31:56.240	49.722149	04:31:57.540	49.656361
04:31:54.980	49.826267	04:31:56.260	49.721306	04:31:57.560	49.656189
04:31:55.000	49.825542	04:31:56.280	49.720814	04:31:57.580	49.654324
04:31:55.020	49.823936	04:31:56.300	49.718994	04:31:57.600	49.653309
04:31:55.040	49.82114	04:31:56.320	49.71619	04:31:57.620	49.652992
04:31:55.060	49.820213	04:31:56.340	49.714447	04:31:57.640	49.652149
04:31:55.080	49.818565	04:31:56.360	49.714306	04:31:57.660	49.652206
04:31:55.100	49.815388	04:31:56.380	49.712841	04:31:57.680	49.652245
04:31:55.120	49.813778	04:31:56.400	49.710705	04:31:57.700	49.650974
04:31:55.140	49.812981	04:31:56.420	49.709785	04:31:57.720	49.649925
04:31:55.160	49.810631	04:31:56.440	49.708221	04:31:57.740	49.649292
04:31:55.180	49.808117	04:31:56.460	49.706562	04:31:57.760	49.648876
04:31:55.200	49.806656	04:31:56.480	49.705692	04:31:57.780	49.649021

04:31:55.220	49.805092	04:31:56.500	49.704067	04:31:57.800	49.647938
04:31:55.240	49.803291	04:31:56.520	49.701801	04:31:57.820	49.646423
04:31:55.260	49.801277	04:31:56.540	49.700588	04:31:57.840	49.646389
04:31:55.280	49.79884	04:31:56.560	49.700375	04:31:57.860	49.646187
04:31:55.300	49.796719	04:31:56.580	49.700233	04:31:57.880	49.645844
04:31:55.320	49.794827	04:31:56.600	49.698917	04:31:57.900	49.645668
04:31:55.340	49.792946	04:31:56.620	49.69706	04:31:57.920	49.645527
04:31:55.360	49.791153	04:31:56.640	49.696217	04:31:57.940	49.645981
04:31:55.380	49.789822	04:31:56.660	49.694344	04:31:57.960	49.644783
04:31:55.400	49.788269	04:31:56.680	49.692719	04:31:57.980	49.643208
04:31:55.420	49.785374	04:31:56.700	49.69276	04:31:58.000	49.643585
04:31:55.440	49.782906	04:31:56.720	49.691067	04:31:58.020	49.642872
04:31:55.460	49.781384	04:31:56.740	49.689175	04:31:58.040	49.641247
04:31:55.480	49.779068	04:31:56.760	49.689022	04:31:58.060	49.641792
04:31:55.500	49.777279	04:31:56.780	49.68816	04:31:58.080	49.642521
		04:31:56.800	49.687408	04:31:58.100	49.641541
04:31:58.120	49.640884	04:31:59.580	49.624805	04:32:01.040	49.633209
04:31:58.140	49.640339	04:31:59.600	49.625427	04:32:01.060	49.63324
04:31:58.160	49.639645	04:31:59.620	49.625324	04:32:01.080	49.633572
04:31:58.180	49.639397	04:31:59.640	49.625397	04:32:01.100	49.634571
04:31:58.200	49.639656	04:31:59.660	49.624977	04:32:01.120	49.634453
04:31:58.220	49.639774	04:31:59.680	49.624569	04:32:01.140	49.634689
04:31:58.240	49.638695	04:31:59.700	49.626167	04:32:01.160	49.63533
04:31:58.260	49.638748	04:31:59.720	49.626575	04:32:01.180	49.634254
04:31:58.280	49.639877	04:31:59.740	49.625122	04:32:01.200	49.633659
04:31:58.300	49.63847	04:31:59.760	49.624416	04:32:01.220	49.634674
04:31:58.320	49.63636	04:31:59.780	49.625328	04:32:01.240	49.635479
04:31:58.340	49.636444	04:31:59.800	49.626759	04:32:01.260	49.63678
04:31:58.360	49.637024	04:31:59.820	49.625854	04:32:01.280	49.637398
04:31:58.380	49.636703	04:31:59.840	49.624203	04:32:01.300	49.636574
04:31:58.400	49.635857	04:31:59.860	49.624722	04:32:01.320	49.636509
04:31:58.420	49.634548	04:31:59.880	49.625557	04:32:01.340	49.636616
04:31:58.440	49.634247	04:31:59.900	49.62569	04:32:01.360	49.636765
04:31:58.460	49.634998	04:31:59.920	49.626472	04:32:01.380	49.637516
04:31:58.480	49.634678	04:31:59.940	49.626408	04:32:01.400	49.637779
04:31:58.500	49.63443	04:31:59.960	49.625008	04:32:01.420	49.638111
04:31:58.520	49.634331	04:31:59.980	49.624989	04:32:01.440	49.638771
04:31:58.540	49.633743	04:32:00.000	49.625637	04:32:01.460	49.638828
04:31:58.560	49.634109	04:32:00.020	49.625309	04:32:01.480	49.639385
04:31:58.580	49.634129	04:32:00.040	49.625088	04:32:01.500	49.640186
04:31:58.600	49.633259	04:32:00.060	49.62579	04:32:01.520	49.639694
04:31:58.620	49.632736	04:32:00.080	49.626755	04:32:01.540	49.639595
04:31:58.640	49.63203	04:32:00.100	49.626415	04:32:01.560	49.639622
04:31:58.660	49.631611	04:32:00.120	49.625576	04:32:01.580	49.639374
04:31:58.680	49.632065	04:32:00.140	49.62645	04:32:01.600	49.640408
04:31:58.700	49.631947	04:32:00.160	49.627239	04:32:01.620	49.640564
04:31:58.720	49.630917	04:32:00.180	49.62661	04:32:01.640	49.640156
04:31:58.740	49.630539	04:32:00.200	49.626457	04:32:01.660	49.640823
04:31:58.760	49.630524	04:32:00.220	49.626106	04:32:01.680	49.641331
04:31:58.780	49.630135	04:32:00.240	49.626064	04:32:01.700	49.642014
04:31:58.800	49.630417	04:32:00.260	49.627716	04:32:01.720	49.642742
04:31:58.820	49.630997	04:32:00.280	49.627853	04:32:01.740	49.643188
04:31:58.840	49.630928	04:32:00.300	49.626221	04:32:01.760	49.642876
04:31:58.860	49.630272	04:32:00.320	49.625977	04:32:01.780	49.642136
04:31:58.880	49.62989	04:32:00.340	49.627041	04:32:01.800	49.643372
04:31:58.900	49.629547	04:32:00.360	49.628231	04:32:01.820	49.644855
04:31:58.920	49.628944	04:32:00.380	49.628319	04:32:01.840	49.64402
04:31:58.940	49.629097	04:32:00.400	49.627735	04:32:01.860	49.643341
04:31:58.960	49.629318	04:32:00.420	49.628178	04:32:01.880	49.644569
04:31:58.980	49.628616	04:32:00.440	49.628155	04:32:01.900	49.645588
04:31:59.000	49.628006	04:32:00.460	49.627682	04:32:01.920	49.646049
04:31:59.020	49.628223	04:32:00.480	49.628586	04:32:01.940	49.64613
04:31:59.040	49.627975	04:32:00.500	49.629425	04:32:01.960	49.645866
04:31:59.060	49.627056	04:32:00.520	49.628967	04:32:01.980	49.646885
04:31:59.080	49.627056	04:32:00.540	49.628799	04:32:02.000	49.647339
04:31:59.100	49.627003	04:32:00.560	49.629654	04:32:02.020	49.646542
04:31:59.120	49.626873	04:32:00.580	49.630135	04:32:02.040	49.647053
04:31:59.140	49.62711	04:32:00.600	49.629837	04:32:02.060	49.647564
04:31:59.160	49.626442	04:32:00.620	49.629498	04:32:02.080	49.647827
04:31:59.180	49.626057	04:32:00.640	49.630371	04:32:02.100	49.649242
04:31:59.200	49.626125	04:32:00.660	49.630535	04:32:02.120	49.64949
04:31:59.220	49.626122	04:32:00.680	49.629299	04:32:02.140	49.649151

04:31:59.240	49.626457	04:32:00.700	49.629169	04:32:02.160	49.650166
04:31:59.260	49.626476	04:32:00.720	49.629242	04:32:02.180	49.651085
04:31:59.280	49.626984	04:32:00.740	49.629803	04:32:02.200	49.651531
04:31:59.300	49.62719	04:32:00.760	49.630657	04:32:02.220	49.65115
04:31:59.320	49.625866	04:32:00.780	49.629719	04:32:02.240	49.649956
04:31:59.340	49.625435	04:32:00.800	49.629391	04:32:02.260	49.65086
04:31:59.360	49.625927	04:32:00.820	49.630402	04:32:02.280	49.653305
04:31:59.380	49.625141	04:32:00.840	49.63055	04:32:02.300	49.653893
04:31:59.400	49.624722	04:32:00.860	49.631165	04:32:02.320	49.653374
04:31:59.420	49.625523	04:32:00.880	49.632061	04:32:02.340	49.653179
04:31:59.440	49.626156	04:32:00.900	49.63105	04:32:02.360	49.653366
04:31:59.460	49.626572	04:32:00.920	49.63065	04:32:02.380	49.654106
04:31:59.480	49.625942	04:32:00.940	49.631931	04:32:02.400	49.654842
04:31:59.500	49.625179	04:32:00.960	49.632454	04:32:02.420	49.654945
04:31:59.520	49.625923	04:32:00.980	49.632576	04:32:02.440	49.654522
04:31:59.540	49.626156	04:32:01.000	49.632217	04:32:02.460	49.654797
04:31:59.560	49.625076	04:32:01.020	49.63224	04:32:02.480	49.656155
04:32:02.500	49.656322	04:32:03.960	49.682037	04:32:05.420	49.703903
04:32:02.520	49.655846	04:32:03.980	49.682377	04:32:05.440	49.704117
04:32:02.540	49.656849	04:32:04.000	49.682194	04:32:05.460	49.704517
04:32:02.560	49.6577	04:32:04.020	49.682339	04:32:05.480	49.704502
04:32:02.580	49.658218	04:32:04.040	49.68338	04:32:05.500	49.704884
04:32:02.600	49.659065	04:32:04.060	49.683475	04:32:05.520	49.705494
04:32:02.620	49.658546	04:32:04.080	49.682751	04:32:05.540	49.706032
04:32:02.640	49.658054	04:32:04.100	49.683575	04:32:05.560	49.706585
04:32:02.660	49.658981	04:32:04.120	49.685028	04:32:05.580	49.706013
04:32:02.680	49.659378	04:32:04.140	49.685093	04:32:05.600	49.705948
04:32:02.700	49.659454	04:32:04.160	49.684814	04:32:05.620	49.707706
04:32:02.720	49.659691	04:32:04.180	49.685432	04:32:05.640	49.708672
04:32:02.740	49.659267	04:32:04.200	49.685783	04:32:05.660	49.708065
04:32:02.760	49.660278	04:32:04.220	49.685932	04:32:05.680	49.706757
04:32:02.780	49.661629	04:32:04.240	49.686031	04:32:05.700	49.70649
04:32:02.800	49.661308	04:32:04.260	49.686729	04:32:05.720	49.708103
04:32:02.820	49.66185	04:32:04.280	49.687744	04:32:05.740	49.708641
04:32:02.840	49.662666	04:32:04.300	49.687077	04:32:05.760	49.707829
04:32:02.860	49.662842	04:32:04.320	49.68726	04:32:05.780	49.708267
04:32:02.880	49.663471	04:32:04.340	49.688076	04:32:05.800	49.708591
04:32:02.900	49.663666	04:32:04.360	49.68755	04:32:05.820	49.708809
04:32:02.920	49.664017	04:32:04.380	49.68848	04:32:05.840	49.709896
04:32:02.940	49.664101	04:32:04.400	49.689495	04:32:05.860	49.710285
04:32:02.960	49.663914	04:32:04.420	49.689007	04:32:05.880	49.70985
04:32:02.980	49.665276	04:32:04.440	49.689255	04:32:05.900	49.709457
04:32:03.000	49.666332	04:32:04.460	49.689537	04:32:05.920	49.709686
04:32:03.020	49.665485	04:32:04.480	49.690277	04:32:05.940	49.711021
04:32:03.040	49.664463	04:32:04.500	49.691456	04:32:05.960	49.711704
04:32:03.060	49.665161	04:32:04.520	49.690895	04:32:05.980	49.710991
04:32:03.080	49.666679	04:32:04.540	49.690266	04:32:06.000	49.710495
04:32:03.100	49.667671	04:32:04.560	49.690655	04:32:06.020	49.71032
04:32:03.120	49.667747	04:32:04.580	49.69149	04:32:06.040	49.710732
04:32:03.140	49.66732	04:32:04.600	49.692669	04:32:06.060	49.711327
04:32:03.160	49.668404	04:32:04.620	49.692661	04:32:06.080	49.711342
04:32:03.180	49.669704	04:32:04.640	49.692627	04:32:06.100	49.711834
04:32:03.200	49.669575	04:32:04.660	49.693275	04:32:06.120	49.712917
04:32:03.220	49.669544	04:32:04.680	49.69352	04:32:06.140	49.713585
04:32:03.240	49.668972	04:32:04.700	49.69405	04:32:06.160	49.713581
04:32:03.260	49.669178	04:32:04.720	49.694649	04:32:06.180	49.713543
04:32:03.280	49.670273	04:32:04.740	49.693787	04:32:06.200	49.713196
04:32:03.300	49.670128	04:32:04.760	49.69297	04:32:06.220	49.713257
04:32:03.320	49.670513	04:32:04.780	49.694153	04:32:06.240	49.714123
04:32:03.340	49.67104	04:32:04.800	49.69561	04:32:06.260	49.714252
04:32:03.360	49.671242	04:32:04.820	49.696072	04:32:06.280	49.714767
04:32:03.380	49.672234	04:32:04.840	49.696049	04:32:06.300	49.715355
04:32:03.400	49.672489	04:32:04.860	49.695908	04:32:06.320	49.714539
04:32:03.420	49.672306	04:32:04.880	49.69606	04:32:06.340	49.714771
04:32:03.440	49.672371	04:32:04.900	49.696438	04:32:06.360	49.716278
04:32:03.460	49.672634	04:32:04.920	49.696609	04:32:06.380	49.716393
04:32:03.480	49.67366	04:32:04.940	49.697643	04:32:06.400	49.715294
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04:32:03.520	49.673615	04:32:04.980	49.696514	04:32:06.440	49.715572
04:32:03.540	49.673885	04:32:05.000	49.697258	04:32:06.460	49.717064
04:32:03.560	49.675247	04:32:05.020	49.698414	04:32:06.480	49.716644
04:32:03.580	49.675888	04:32:05.040	49.698608	04:32:06.500	49.716309

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04:32:03.620	49.675117	04:32:05.080	49.698677	04:32:06.540	49.716431
04:32:03.640	49.674805	04:32:05.100	49.699375	04:32:06.560	49.715828
04:32:03.660	49.676662	04:32:05.120	49.699921	04:32:06.580	49.71648
04:32:03.680	49.678379	04:32:05.140	49.699444	04:32:06.600	49.717022
04:32:03.700	49.678127	04:32:05.160	49.699566	04:32:06.620	49.71722
04:32:03.720	49.677761	04:32:05.180	49.699883	04:32:06.640	49.717136
04:32:03.740	49.677368	04:32:05.200	49.700462	04:32:06.660	49.717472
04:32:03.760	49.678314	04:32:05.220	49.701366	04:32:06.680	49.718739
04:32:03.780	49.680435	04:32:05.240	49.701035	04:32:06.700	49.718803
04:32:03.800	49.680103	04:32:05.260	49.700951	04:32:06.720	49.717735
04:32:03.820	49.679161	04:32:05.280	49.702236	04:32:06.740	49.717937
04:32:03.840	49.679813	04:32:05.300	49.70269	04:32:06.760	49.719032
04:32:03.860	49.680134	04:32:05.320	49.702526	04:32:06.780	49.719551
04:32:03.880	49.680386	04:32:05.340	49.703079	04:32:06.800	49.718334
04:32:03.900	49.68092	04:32:05.360	49.702557	04:32:06.820	49.717339
04:32:03.920	49.681007	04:32:05.380	49.702248	04:32:06.840	49.718544
04:32:03.940	49.681328	04:32:05.400	49.703407	04:32:06.860	49.719837
04:32:06.880	49.720284	04:32:08.340	49.7313	04:32:09.800	49.740044
04:32:06.900	49.720379	04:32:08.360	49.731663	04:32:09.820	49.738979
04:32:06.920	49.719769	04:32:08.380	49.731743	04:32:09.840	49.740116
04:32:06.940	49.719444	04:32:08.400	49.731869	04:32:09.860	49.739704
04:32:06.960	49.720135	04:32:08.420	49.731331	04:32:09.880	49.737602
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04:32:07.000	49.720337	04:32:08.460	49.732109	04:32:09.920	49.740036
04:32:07.020	49.720623	04:32:08.480	49.732731	04:32:09.940	49.739792
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04:32:07.060	49.721104	04:32:08.520	49.732803	04:32:09.980	49.741093
04:32:07.080	49.722057	04:32:08.540	49.73225	04:32:10.000	49.739868
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04:32:07.120	49.722004	04:32:08.580	49.732471	04:32:10.040	49.739876
04:32:07.140	49.722027	04:32:08.600	49.732979	04:32:10.060	49.74004
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04:32:07.180	49.721405	04:32:08.640	49.732689	04:32:10.100	49.740028
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04:32:07.300	49.725613	04:32:08.760	49.733196	04:32:10.220	49.741577
04:32:07.320	49.722874	04:32:08.780	49.732655	04:32:10.240	49.743359
04:32:07.340	49.722759	04:32:08.800	49.733463	04:32:10.260	49.742233
04:32:07.360	49.724739	04:32:08.820	49.734383	04:32:10.280	49.740955
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04:32:07.420	49.72422	04:32:08.880	49.734375	04:32:10.340	49.740997
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04:32:07.560	49.726109	04:32:09.020	49.736095	04:32:10.480	49.743702
04:32:07.580	49.726162	04:32:09.040	49.735825	04:32:10.500	49.742897
04:32:07.600	49.725731	04:32:09.060	49.735214	04:32:10.520	49.74247
04:32:07.620	49.725647	04:32:09.080	49.734238	04:32:10.540	49.741974
04:32:07.640	49.726151	04:32:09.100	49.733891	04:32:10.560	49.742561
04:32:07.660	49.726994	04:32:09.120	49.735725	04:32:10.580	49.742992
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04:32:07.700	49.7258	04:32:09.160	49.735996	04:32:10.620	49.743462
04:32:07.720	49.725651	04:32:09.180	49.73632	04:32:10.640	49.743752
04:32:07.740	49.72747	04:32:09.200	49.735825	04:32:10.660	49.743996
04:32:07.760	49.727859	04:32:09.220	49.735146	04:32:10.680	49.744045
04:32:07.780	49.727829	04:32:09.240	49.736378	04:32:10.700	49.74287
04:32:07.800	49.727798	04:32:09.260	49.736801	04:32:10.720	49.743145
04:32:07.820	49.727333	04:32:09.280	49.736313	04:32:10.740	49.744678
04:32:07.840	49.727551	04:32:09.300	49.736614	04:32:10.760	49.744228
04:32:07.860	49.727436	04:32:09.320	49.736591	04:32:10.780	49.743568
04:32:07.880	49.727272	04:32:09.340	49.736458	04:32:10.800	49.744232
04:32:07.900	49.728554	04:32:09.360	49.736786	04:32:10.820	49.743992
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04:32:07.940	49.728844	04:32:09.400	49.737328	04:32:10.860	49.743538

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04:32:07.980	49.728485	04:32:09.440	49.736794	04:32:10.900	49.744488
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04:32:08.020	49.728664	04:32:09.480	49.737633	04:32:10.940	49.744602
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04:32:08.140	49.729668	04:32:09.600	49.737839	04:32:11.060	49.744633
04:32:08.160	49.730392	04:32:09.620	49.738029	04:32:11.080	49.744934
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04:32:08.200	49.730419	04:32:09.660	49.738075	04:32:11.120	49.745991
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04:32:08.280	49.730457	04:32:09.740	49.738449	04:32:11.200	49.746044
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04:32:11.280	49.746502	04:32:12.740	49.754028	04:32:14.200	49.759777
04:32:11.300	49.745659	04:32:12.760	49.754757	04:32:14.220	49.759735
04:32:11.320	49.746269	04:32:12.780	49.755337	04:32:14.240	49.759987
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04:32:11.620	49.747631	04:32:13.080	49.756161	04:32:14.540	49.760414
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04:32:11.680	49.748871	04:32:13.140	49.754929	04:32:14.600	49.761513
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04:32:11.820	49.748878	04:32:13.280	49.756145		
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04:32:12.020	49.750107	04:32:13.480	49.757378		
04:32:12.040	49.749676	04:32:13.500	49.756886		
04:32:12.060	49.750362	04:32:13.520	49.756809		
04:32:12.080	49.75148	04:32:13.540	49.757671		
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04:32:12.420	49.752689	04:32:13.880	49.759361		
04:32:12.440	49.753029	04:32:13.900	49.759781		
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