FFCI expert working group

Enstore Energy Store Rating Data

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The power point can be freely used in the public domain.

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- **Section 1. The VSM data.**

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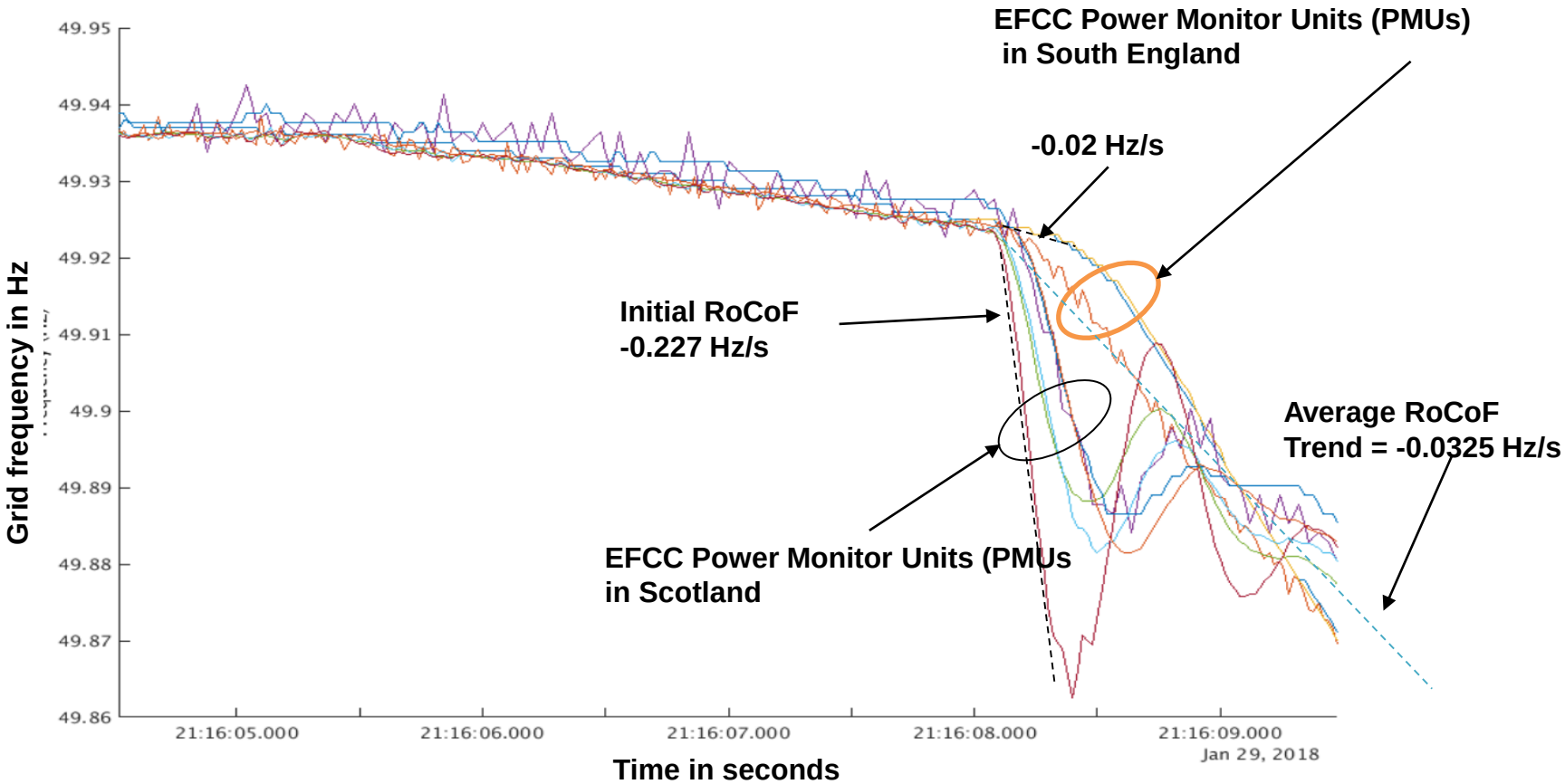
Grid data from the EFCC project for a real trip



- This shows how the RoCoF rate in regions near to a fault compared with regions away from a fault.
- There is a significant time for the UK total inertia to combine to give the average RoCoF.
- Limiting the initial RoCoF rate is very important to avoid generators tripping that are near the fault.
- The ratio of initial RoCoF to average RoCoF is 7 : 1 and is important in calculating total grid inertia.
- The VSM energy store rating is based on the average RoCoF rate.

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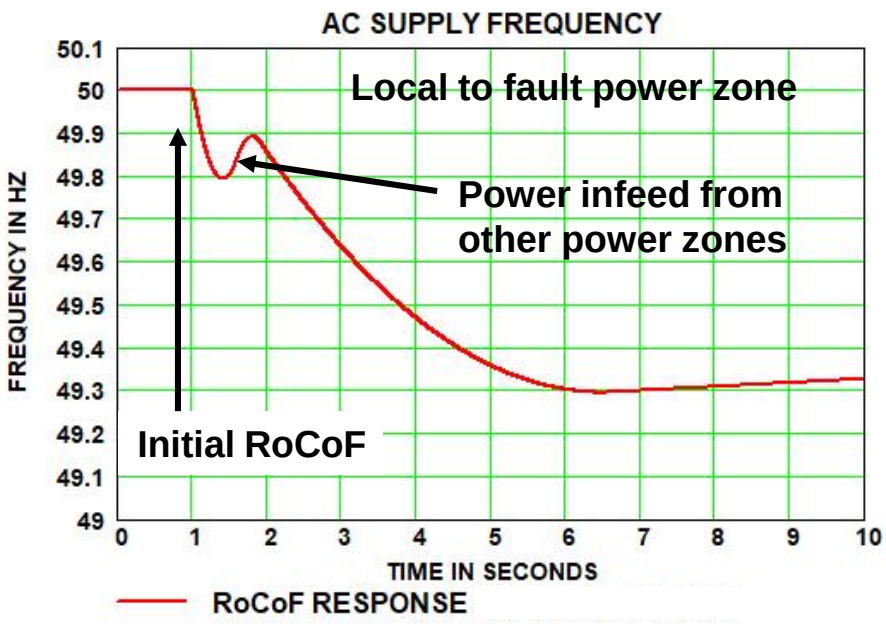
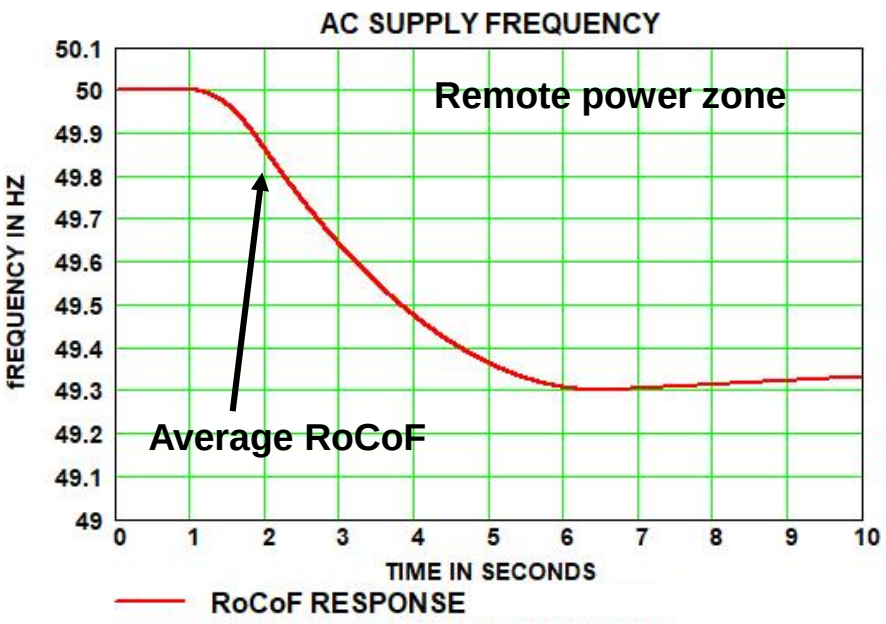
Inertia factors to be considered





- **The largest power transient is increasing from 1 GW to 1.8 GW.**
- **Richard Ierna raised several important energy store rating factors in the second meeting:**
  - **Must have a synthetic inertia response to power transients of both polarities.**
  - **Must provide synthetic inertia for the complete range of operating grid frequencies.**
  - **Must provide synthetic inertia to cover conditions with insufficient power reserves that cause the grid frequency to continue to fall. This is to give time for forced load disconnections to occur.**
  - **Must provide synthetic inertia to cover conditions with excess power reserves that cause the grid frequency to rise. This is to give time for forced generation load disconnections to occur.**
- **All of these factors require a larger VSM energy store based on the average RoCoF rates.**

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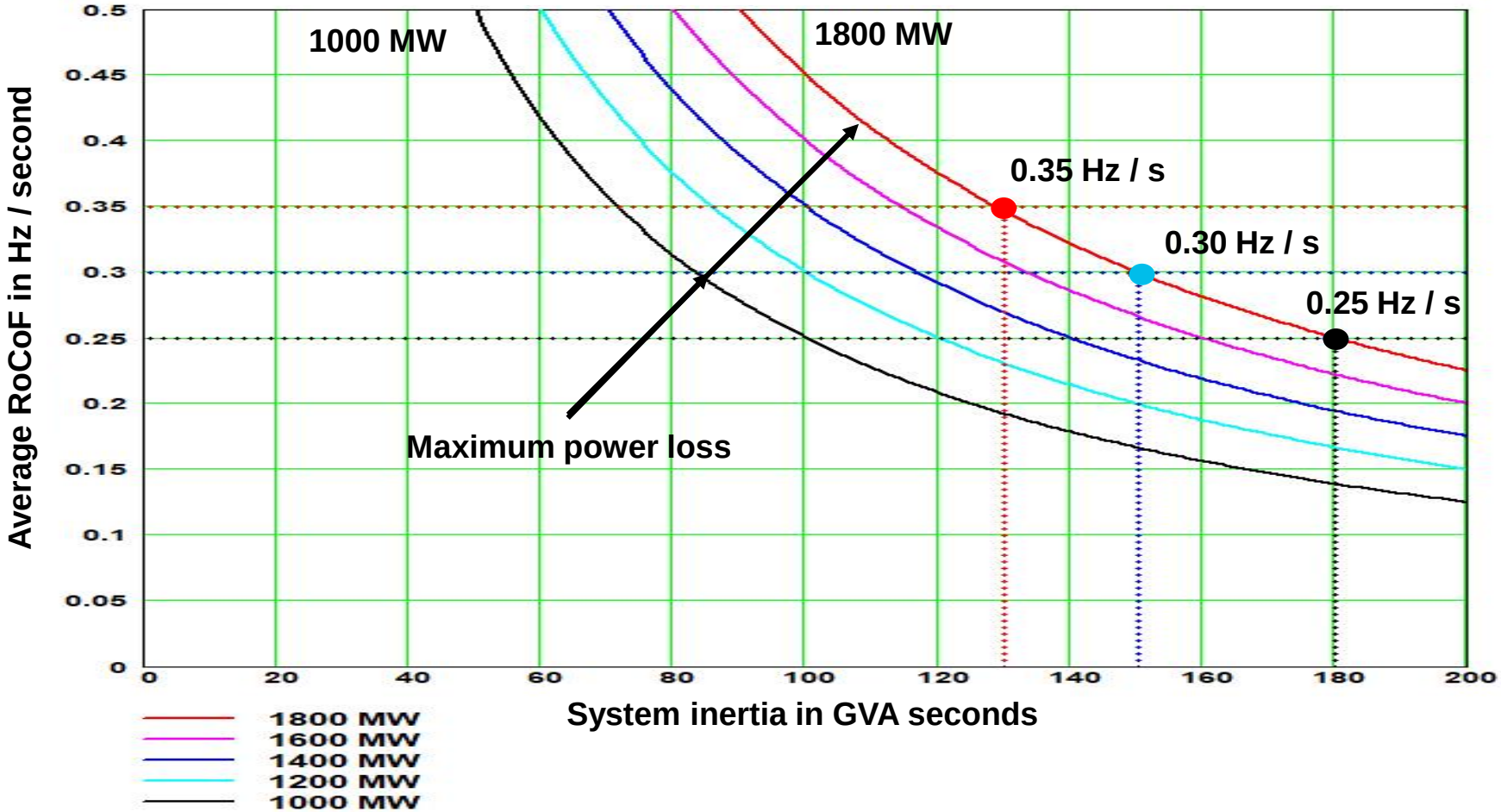
Selection the Average RoCoF rate

Shows three design choices for a 1800 MW transient of 0.25 to 0.35 Hz/ s



- **To have average RoCoF rates below 0.3 Hz / s with a 1800 MW generation power loss the grid inertia needs to be kept above 150 GVA s.**
- **This is the data used for rating the energy storage.**

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- **Section 2. Rating the energy store with H = 7.**

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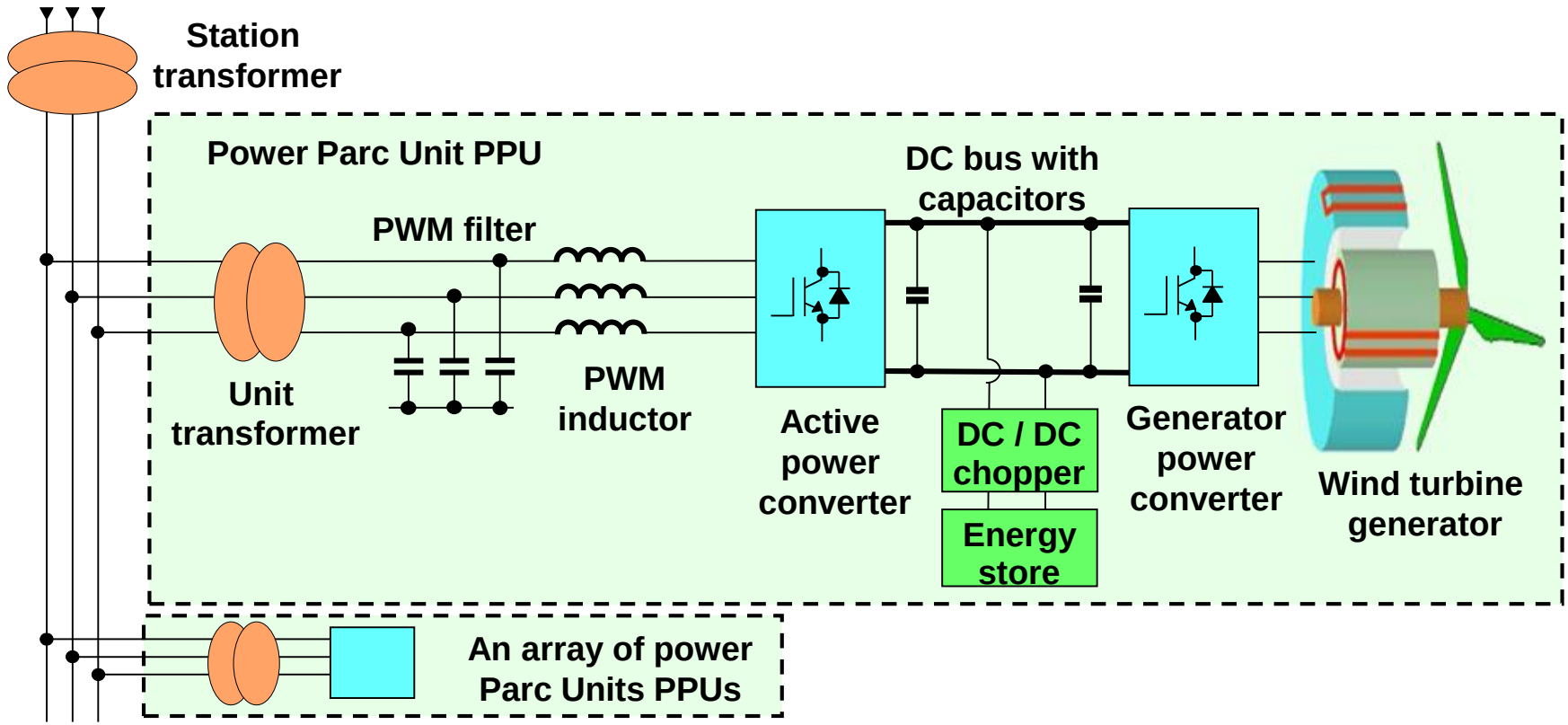
A typical wind power VSM system



- There are several design options and this shows the option with an energy store on the DC bus of a wind turbine.
- The same method could be used for electricity storage systems and solar power system that only use the active power converter.

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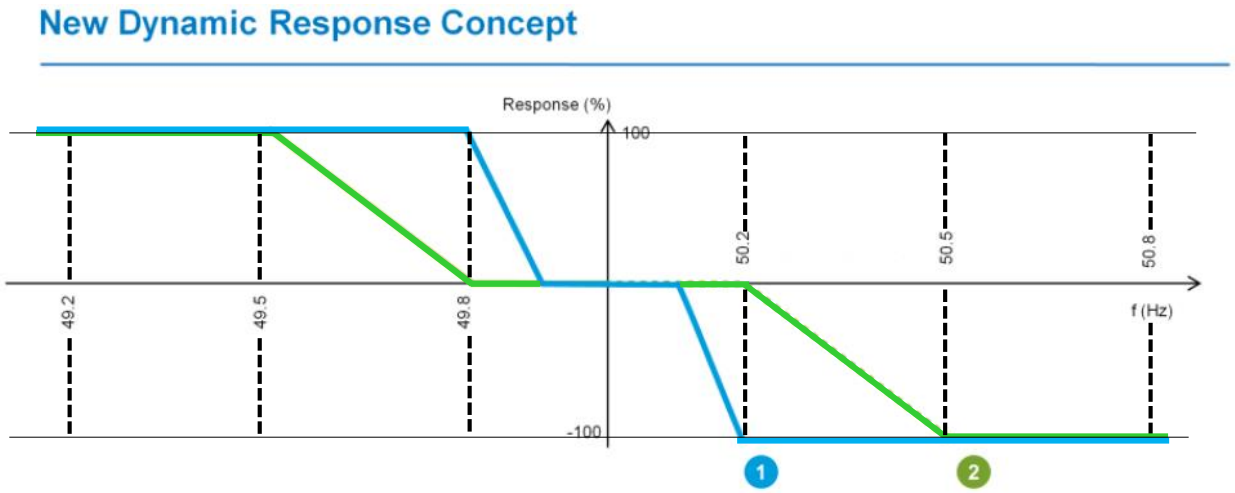
Energy storage rating factors



		LF Range *Hz (-ve dev.)*	HF Range *Hz (+ve dev.)*	Max Lag *s*	Max Ramp *s*	Duration
1	Dynamic Balancing (Pre-fault)	0.1 – 0.2		0.5	0.5	TBC
2	Dynamic Containment (Post-fault)	0.2 – 0.5	0.2 – 0.5	0.5	0.5	20 minutes

- **The image is based on slide 8 of the National Grid's " Faster Acting Response Webinar".**
- **The pre fault dynamic balancing is to hold the grid frequency in the range 50 +/- 0.2 Hz.**
- **The post fault dynamic containment works for grid frequencies outside 50 +/- 0.2 Hz and reaches the full rating at 49.5 and 50.5 Hz with a proposed time to full power of 1 second.**
- **These grid frequency ranges are the basis used for the simulations of the energy store.**
- **The inertia is 150 GWs that for a 1.8 GW power transient gives an average RoCoF of 0.3 Hz / s.**
- **The design is based on having maximum grid frequency limit of +/- 0.8 Hz with viable reserves.**
- **The initial simulations are for a 1 MW VSM power converter with H = 7.**

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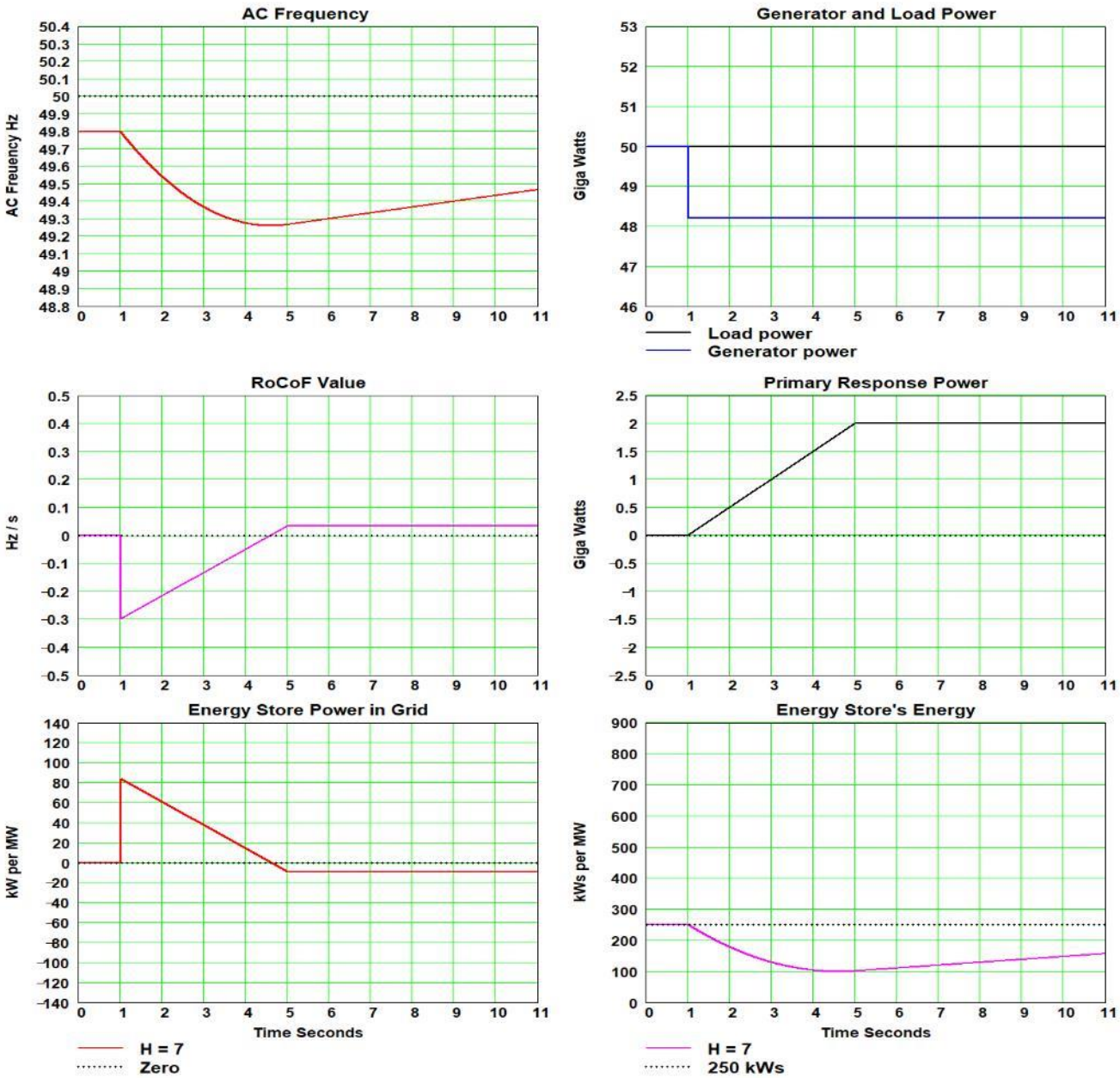
Initial frequency 49.8 Hz and viable +ve reserves H = 7.



- 49.8 Hz base design.
- RoCoF is -0.3 Hz / s.
- The energy store delivers a peak synthetic inertia power of 84 kW / MW with H = 7.
- Generation loss is 1.8 GW.
- Rise time of the 2 GW of the primary response dynamic containment power is 4 seconds to control the minimum frequency to 49.25 Hz.
- The energy store's nominal SOC is 250 kWs.
- The energy store normally operates at 50 % SOC with a +/- 100 kWs margin to allow for the store responding to small grid frequency phase changes.
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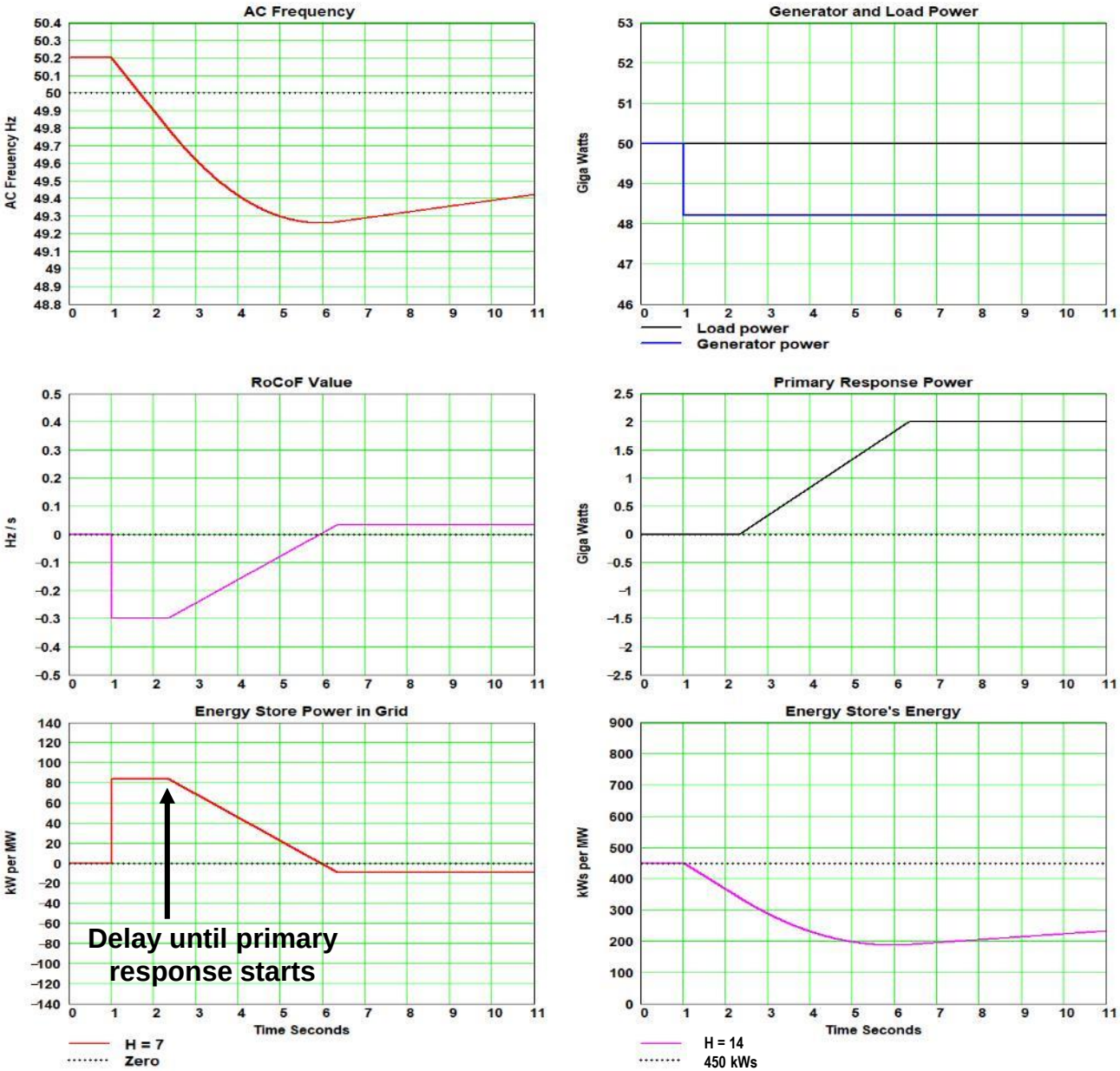
Initial frequency 50.2 Hz and viable +ve reserves H = 7.



- 50.2 Hz base design.
- RoCoF is -0.3 Hz / s.
- The energy store delivers a peak synthetic inertia power of 84 kW / MW with H = 7.
- Generation loss is 1.8 GW.
- Rise time of the 2 GW of the primary response dynamic containment power is 4 seconds to control the minimum frequency to 49.25 Hz.
- The energy store's nominal SOC is 450 kWs.

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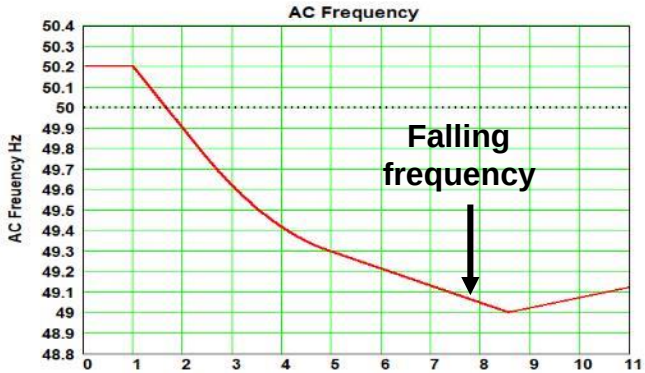
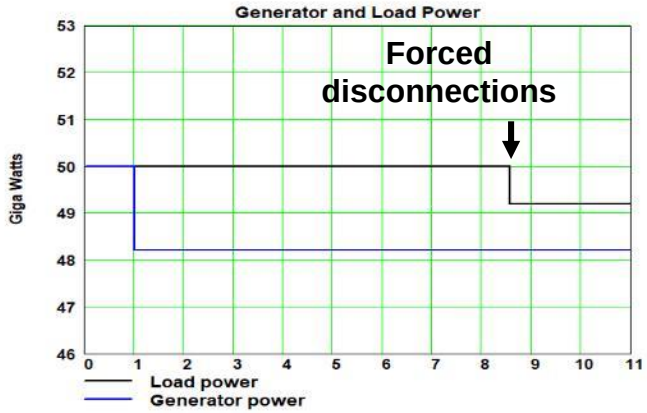
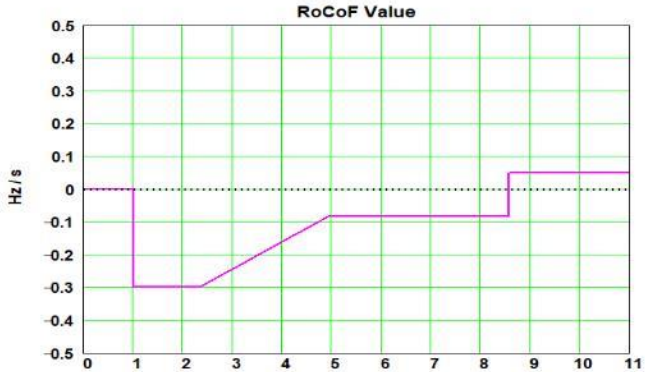
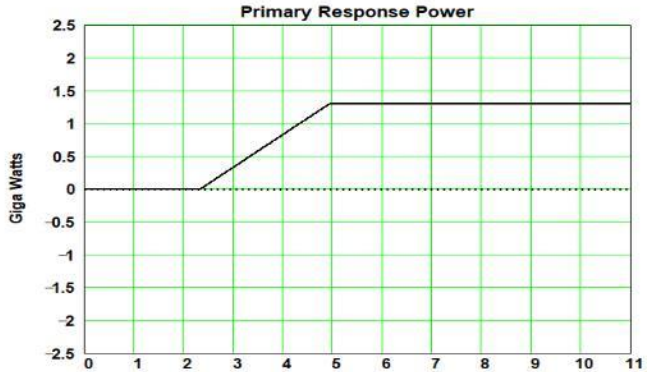
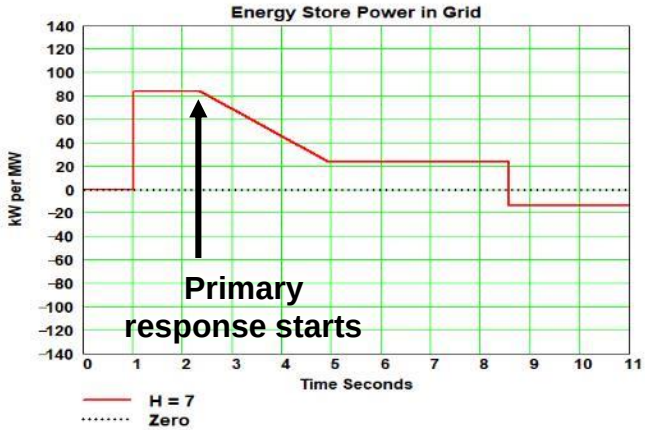
Initial frequency 50.2 Hz and unviable +ve reserves H = 7.

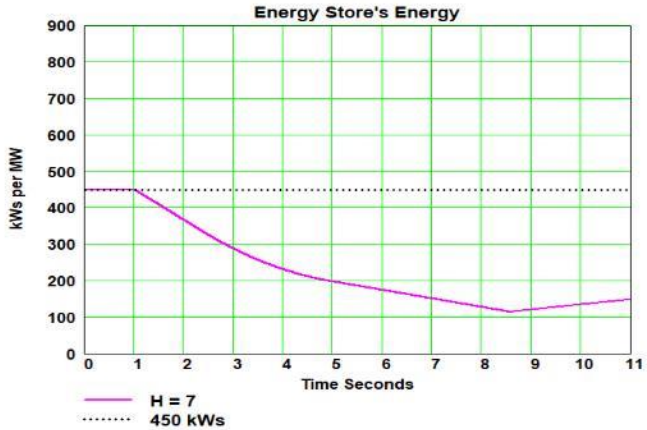












- Worst case Hz decrease.
- RoCoF is -0.3 Hz / s
- The energy store delivers a peak synthetic inertia power of 84 kW / MW with H = 7
- Generation loss is 1.8 GW.
- There is a loss of 0.7 GW in primary response dynamic containment with a 4 second rate of rise limit.
- The loss is 25 %.
- Initial frequency is 50.2 Hz falling to 49.0 Hz.
- The energy store's nominal SOC is 450 kWs that is needed for the worst case transient.
- Forced load disconnections made at 49 Hz.

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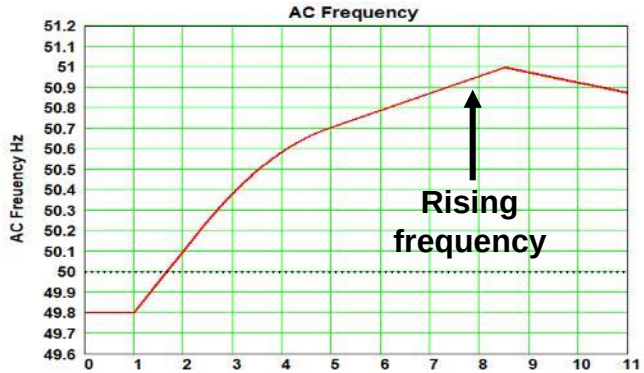
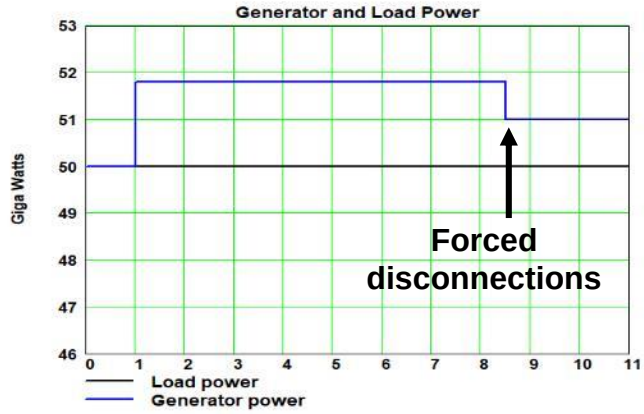
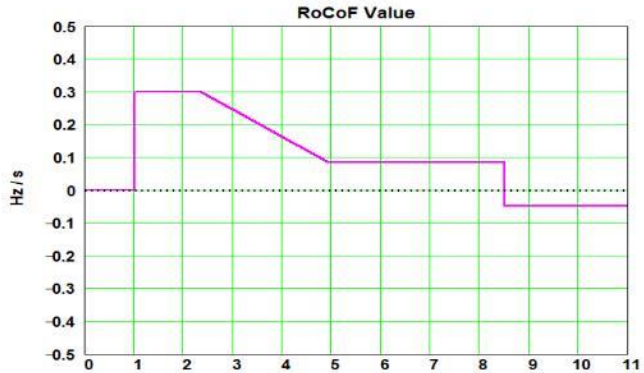
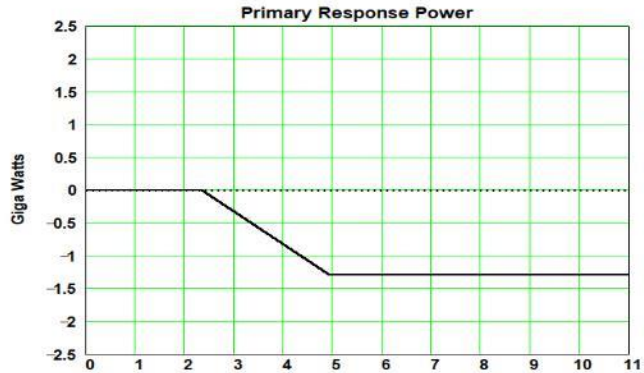
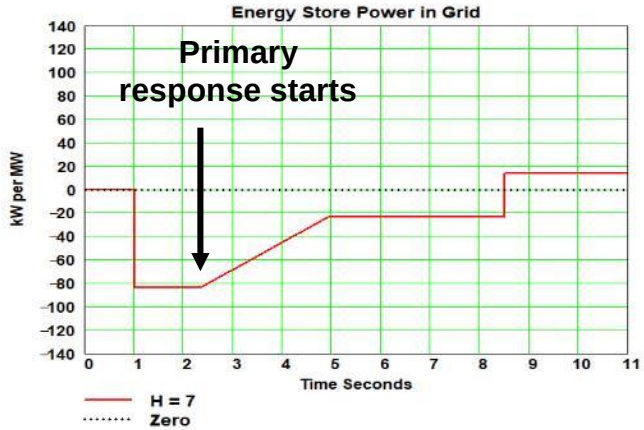
Initial frequency 49.8 Hz and unviable –ve reserves H = 7.

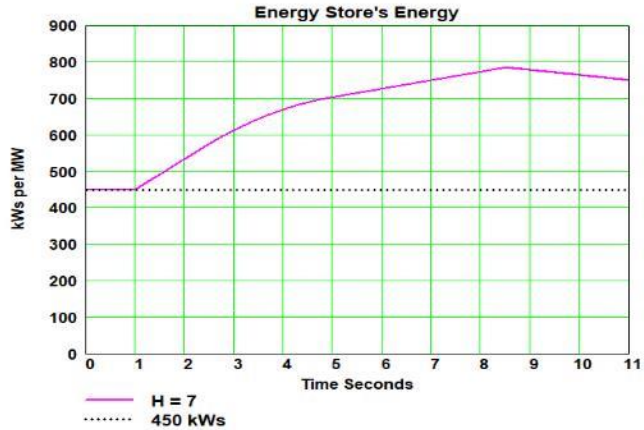












- Worst case Hz increase.
- RoCoF is +0.3 Hz / s
- The energy store delivers a peak synthetic inertia power of -84 kW / MW with H = 7
- Generation rise is 1.8 GW.
- There is a loss of 0.7 GW in primary response dynamic containment with a 4 second rate of rise limit.
- The loss is 25 %.
- Initial frequency is 49.8 Hz rising to 51.0 Hz.
- The energy store's nominal SOC is 450 kWs that is needed for the worst case transient.
- Generation disconnections made at 51 Hz.

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- **Section 3. Rating the energy store with H = 7 & faster reserves.**

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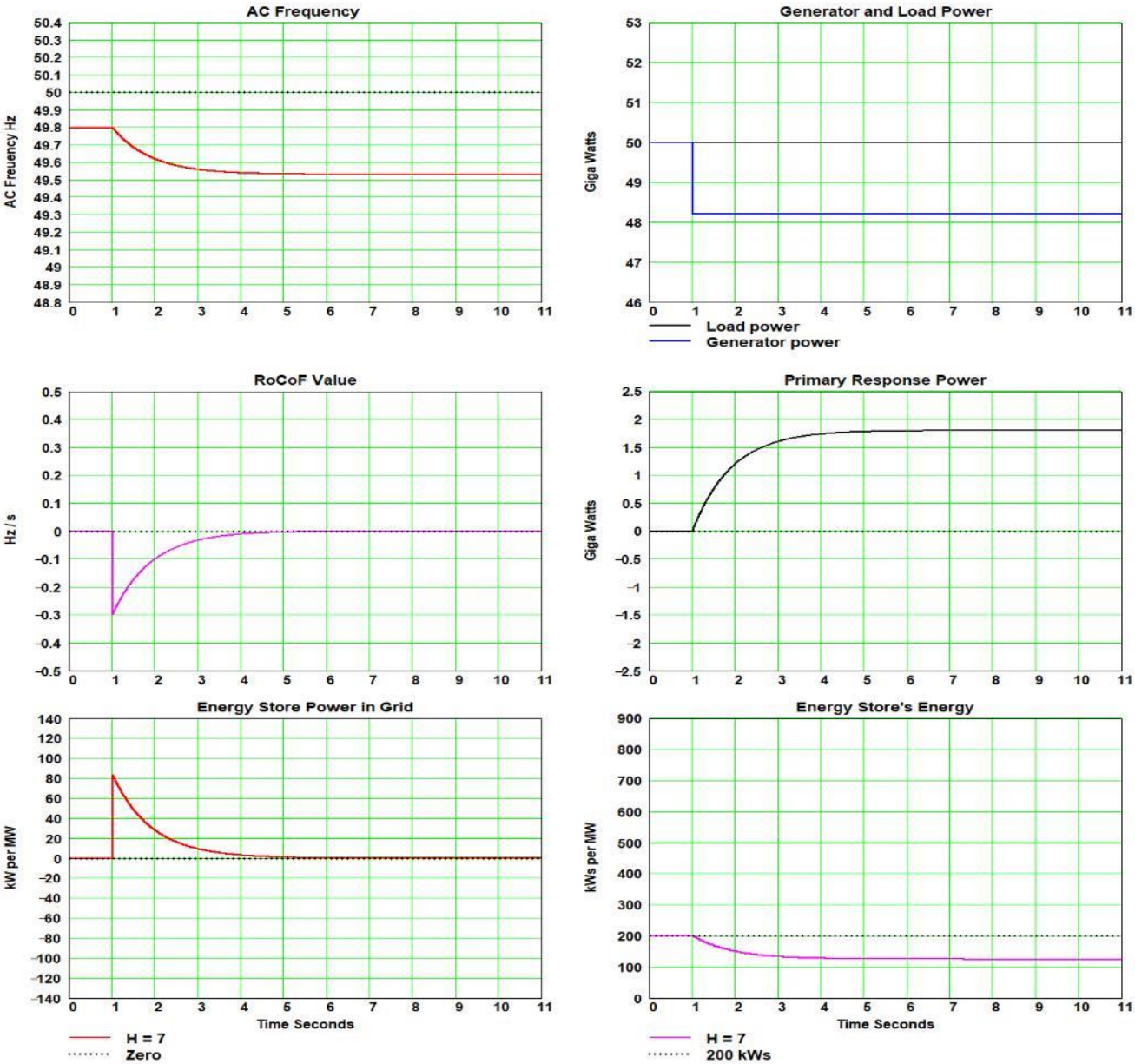
Initial frequency 49.8 Hz and viable +ve faster reserves H = 7.



- 49.8 Hz base design.
- RoCoF is -0.3 Hz / s
- The energy store delivers a peak synthetic inertia power of 84 kW / MW with H = 7.
- Generation loss is 1.8 GW.
- Rise time of the 2 GW of the primary response dynamic containment power is 1 seconds to improve the minimum frequency to 49.5 Hz.
- The energy store's nominal SOC is 200 kWs.

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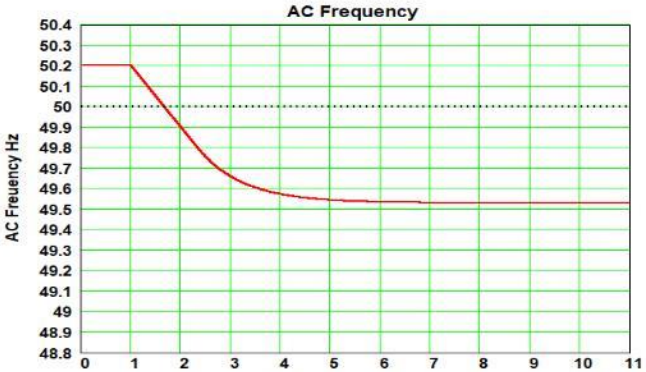
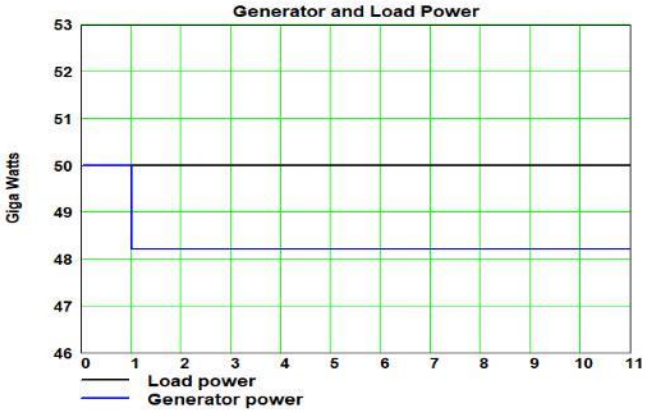
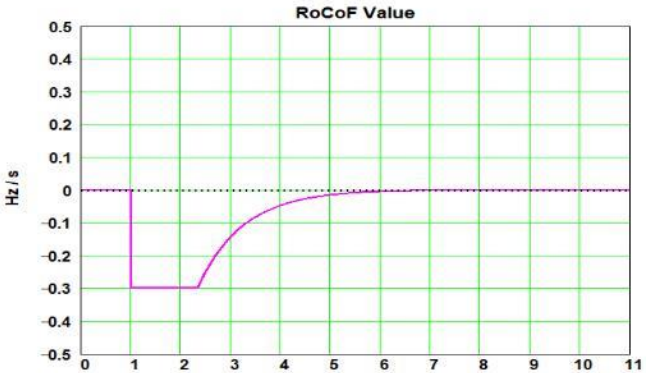
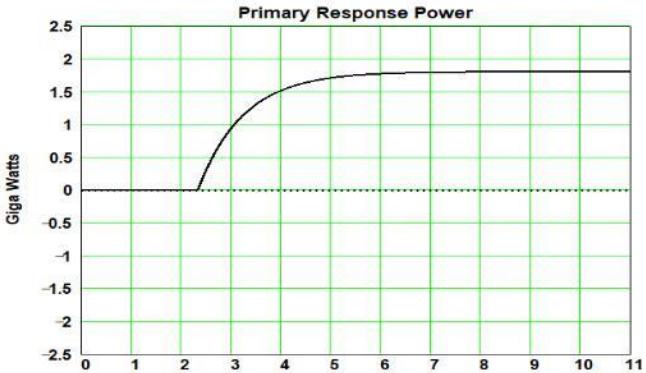
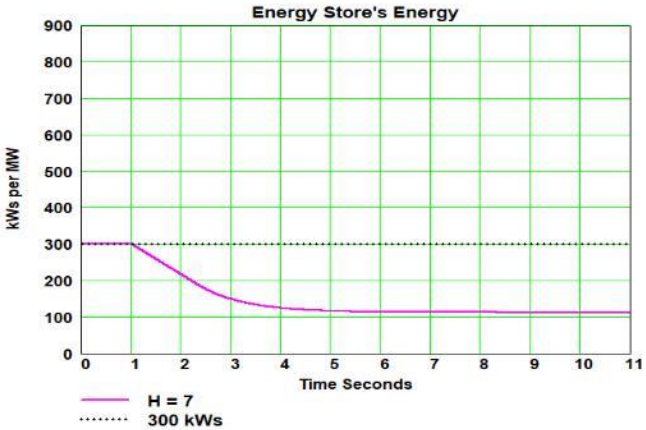
Initial frequency 50.2 Hz and viable +ve faster reserves H = 7.











- 50.2 Hz base design.
- RoCoF is -0.3 Hz / s
- The energy store delivers a peak synthetic inertia power of 84 kW / MW with H = 7.
- Generation loss is 1.8 GW.
- Rise time of the 2 GW of the primary response dynamic containment power is 1 seconds to improve the minimum frequency to 49.5 Hz.
- The energy store's nominal SOC is 300 kWs.

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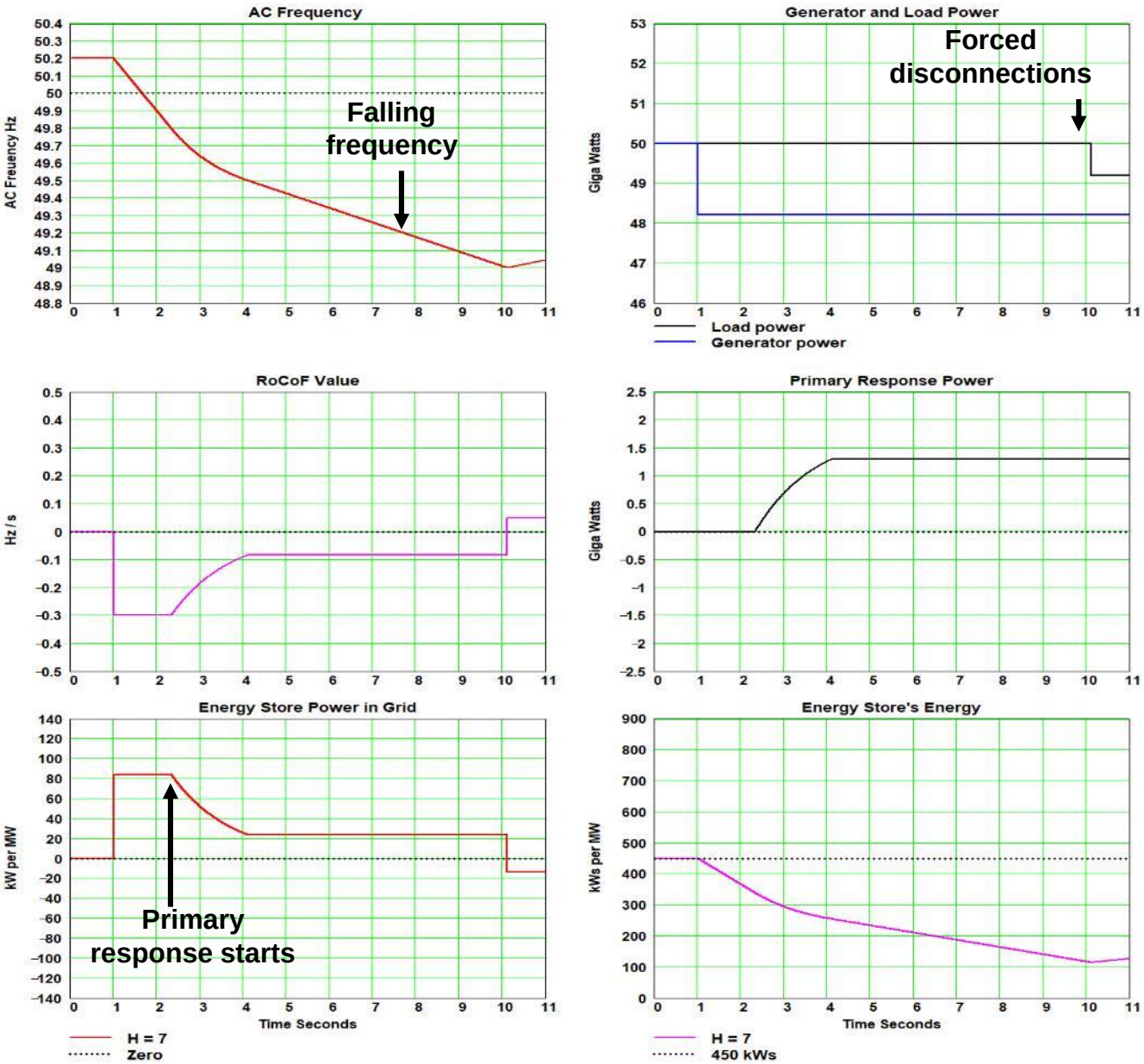
Initial frequency 50.2 Hz and unviable +ve faster reserves H = 7.



- Worst case Hz decrease.
- RoCoF is -0.3 Hz / s
- The energy store delivers a peak synthetic inertia power of 84 kW / MW with H = 7.
- Generation loss is 1.8 GW.
- There is a loss of 0.7 GW in primary response dynamic containment with a 1 second rate of rise limit.
- The loss is 25 %.
- Initial frequency is 50.2 Hz falling to 49.0 Hz.
- The energy store's nominal SOC is 450 kWs due to the larger transient.
- Forced load disconnections made at 49 Hz.

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- **Section 4. Rating the energy store with H = 14 & faster reserves.**

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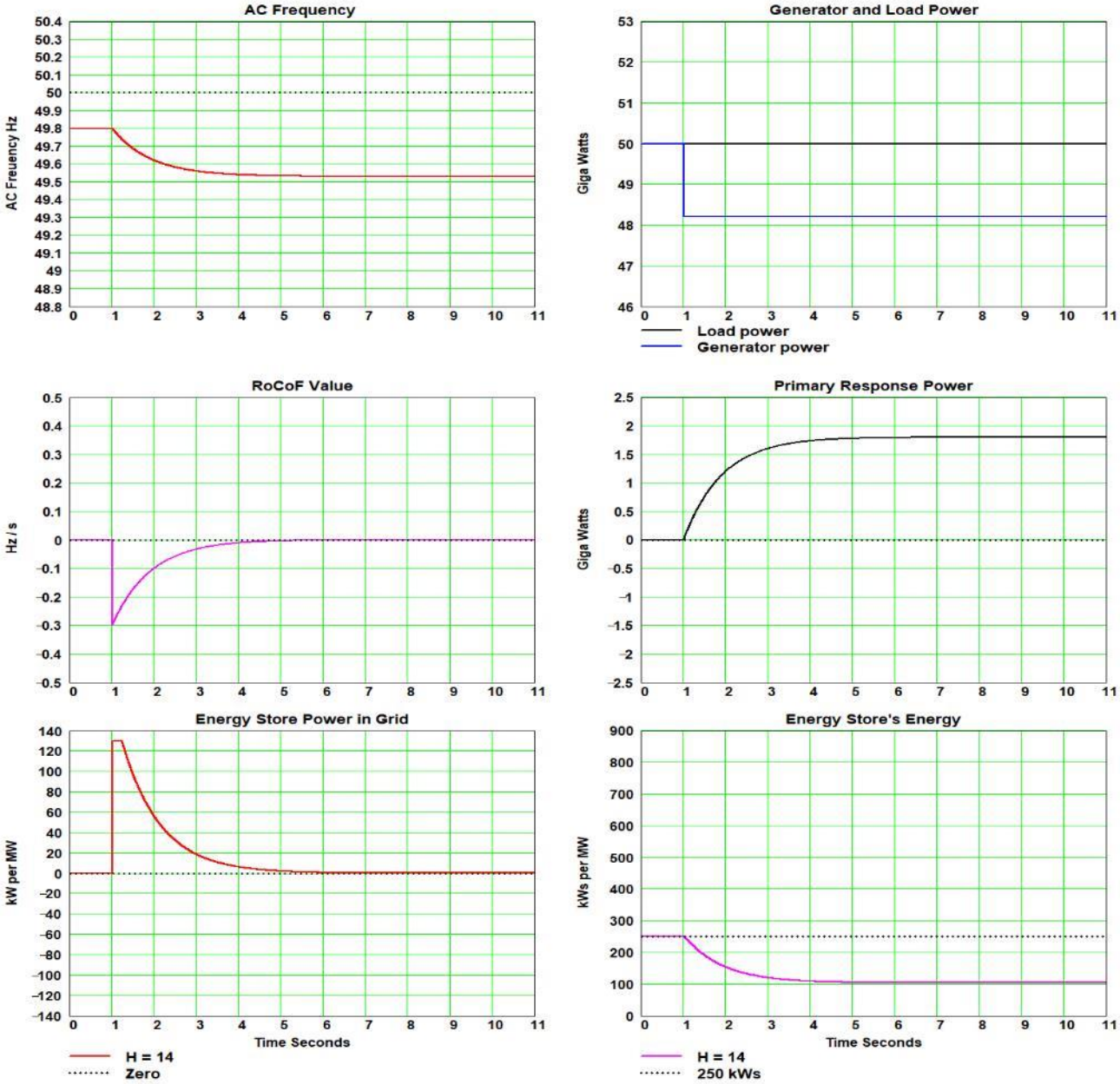
Initial frequency 49.8 Hz and viable +ve faster reserves H = 14



- 49.8 Hz base design.
- RoCoF is -0.3 Hz / s
- The energy store delivers a peak synthetic inertia power of 130 kW / MW with H = 14 and a 130 kW limit.
- Generation loss is 1.8 GW.
- Rise time of the 2 GW of the primary response dynamic containment power is 1 seconds to improve the minimum frequency to 49.5 Hz.
- The energy store's nominal SOC is 250 kWs.

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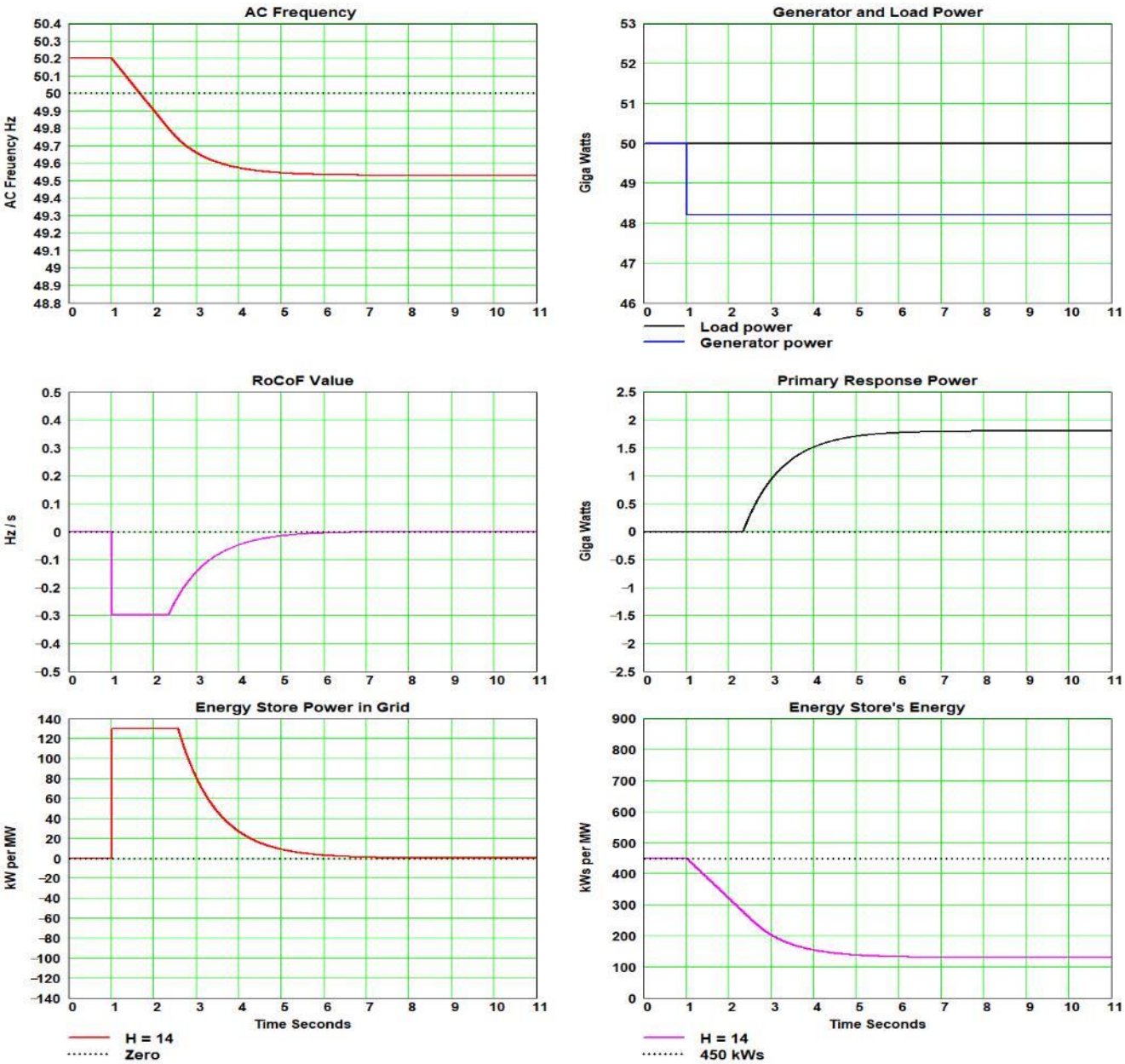
Initial frequency 50.2 Hz and viable +ve faster reserves H = 14



- 50.2 Hz base design.
- RoCoF is -0.3 Hz / s
- The energy store delivers a peak synthetic inertia power of 130 kW / MW with H = 14 and a 130 kW limit.
- Generation loss is 1.8 GW.
- Rise time of the 2 GW of the primary response dynamic containment power is 1 seconds to improve the minimum frequency to 49.5 Hz.
- The energy store's nominal SOC is 450 kWs.

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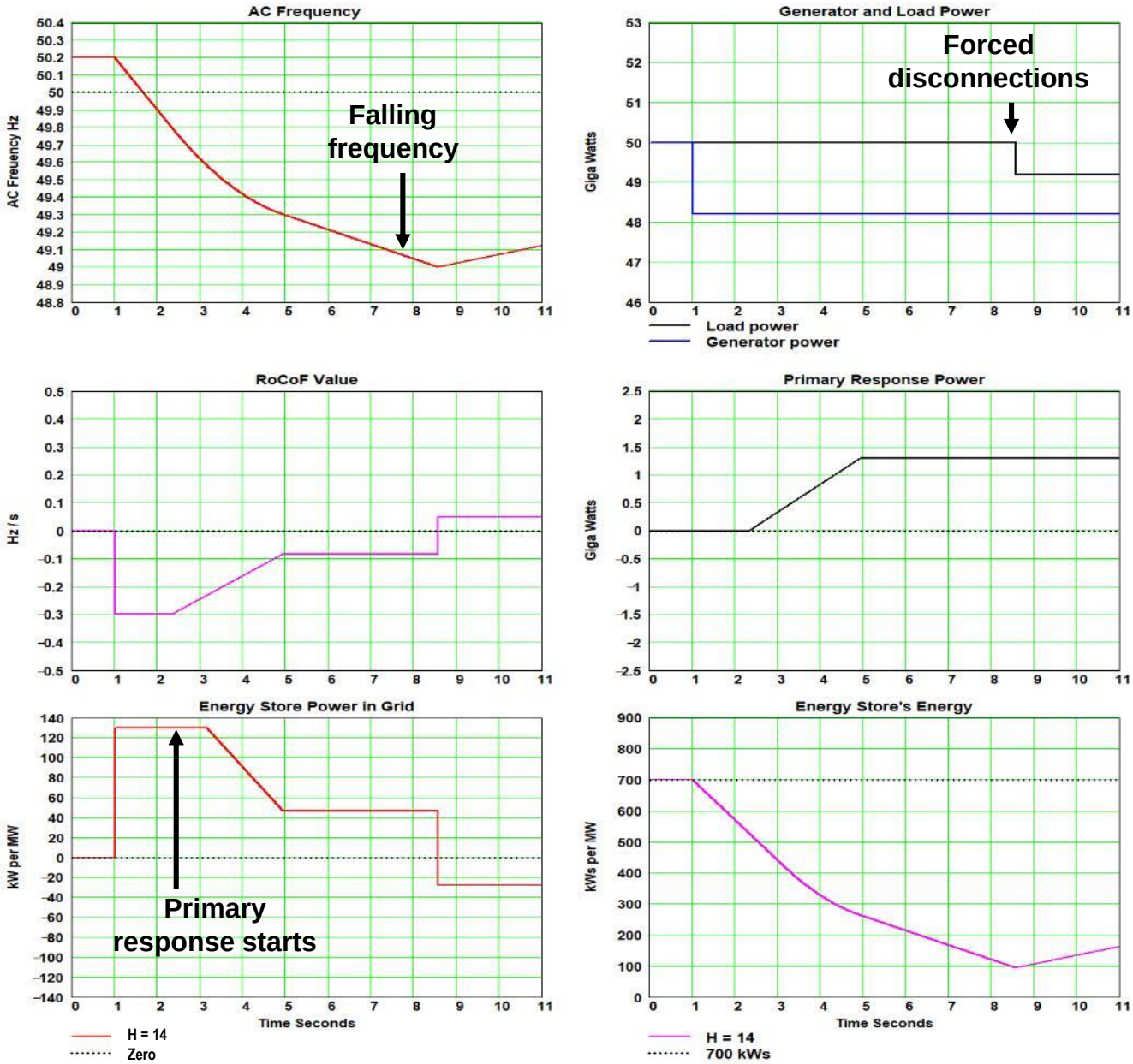
Initial frequency 50.2 Hz and unviable +ve reserves H = 14.



- Worst case Hz decrease.
- RoCoF is -0.3 Hz / s
- The energy store delivers a peak synthetic inertia power of 130 kW / MW with H = 14 and a 130 kW limit.
- Generation loss is 1.8 GW.
- There is a loss of 0.7 GW in primary response dynamic containment with a 1 second rate of rise limit.
- The loss is 25 %.
- Initial frequency is 50.2 Hz falling to 49.0 Hz.
- The energy store's nominal SOC is 700 kWs that is needed for the worst case transient.
- Forced load disconnections made at 49 Hz.

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- **Section 5. Rating the energy store with no reserves.**

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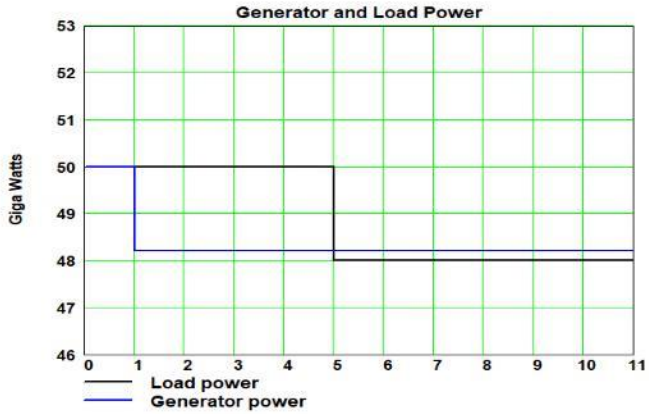
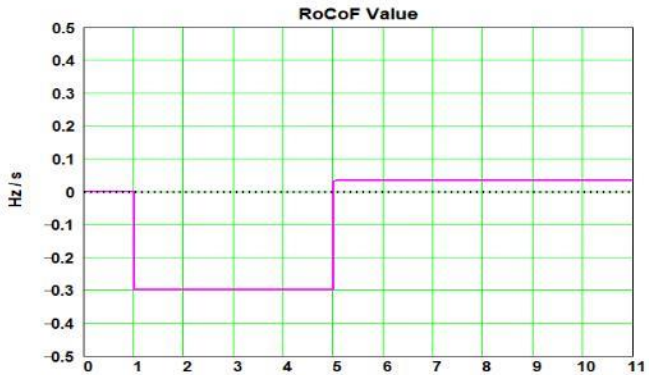
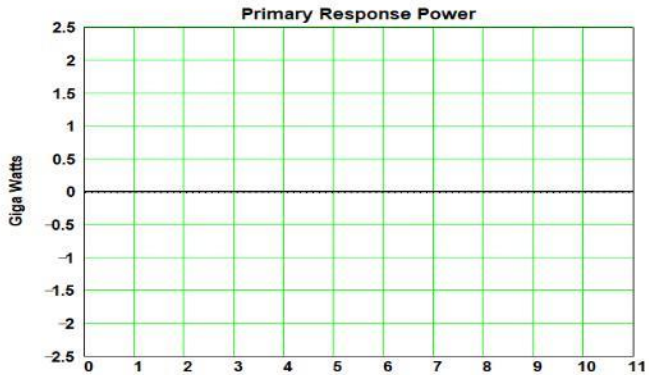
Initial frequency 50.2 Hz and no reserves H = 7 loss 1.8 GW







- Worst case Hz decrease.
- RoCoF is -0.3 Hz / s
- The energy store delivers a peak synthetic inertia power of 84 kW / MW with H = 7
- Generation loss is 1.8 GW.
- There is a total loss of the primary response dynamic containment.
- The energy store's nominal SOC is 450 kWs.
- Generation disconnections made at 49 Hz.
- This requires the same energy store as the data with a 25% loss of reserves.

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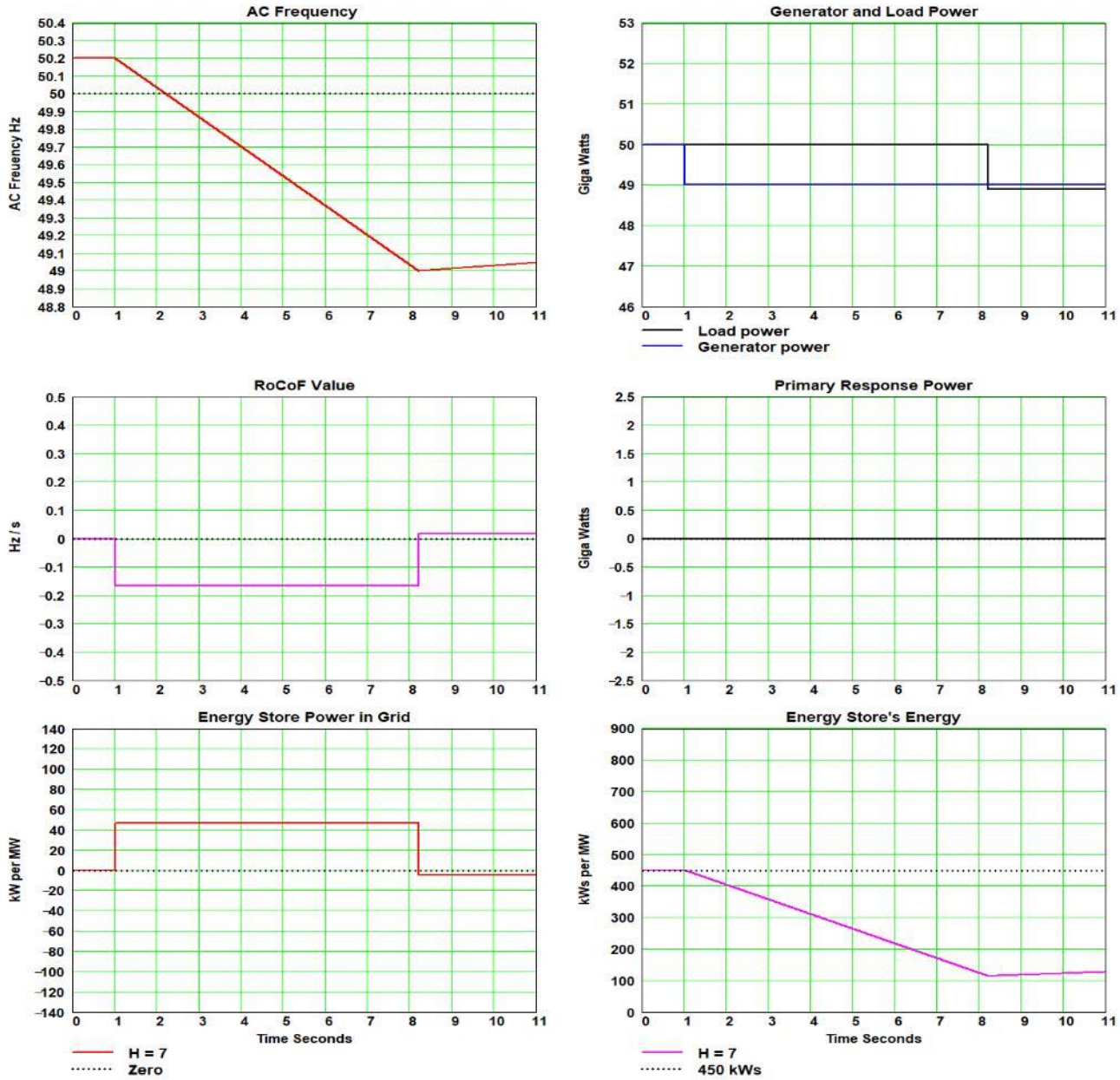
Initial frequency 50.2 Hz and no reserves H = 7 loss 1.0 GW



- Worst case Hz decrease.
- RoCoF is -0.167 Hz / s
- The energy store delivers a peak synthetic inertia power of 47 kW / MW with H = 7
- Generation loss is 1.0 GW.
- There is a total loss of the primary response dynamic containment.
- The energy store's nominal SOC is 450 kWs.
- Generation disconnections made at 49 Hz.
- This requires the same energy store as the data with a 25% loss of reserves.

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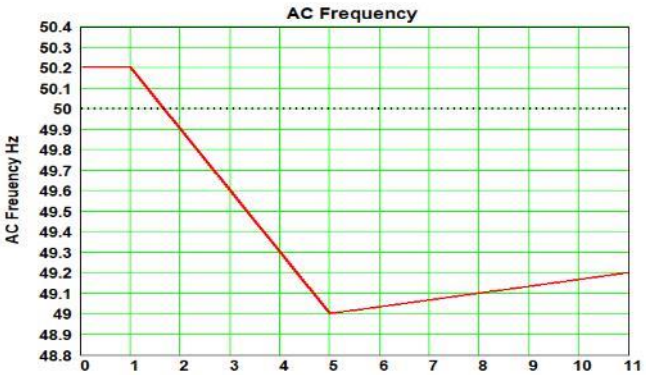
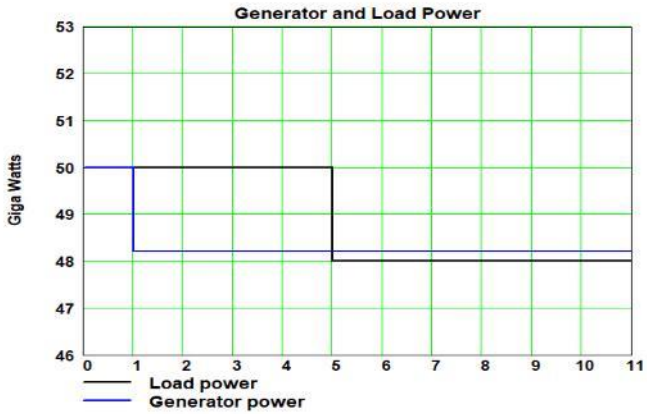
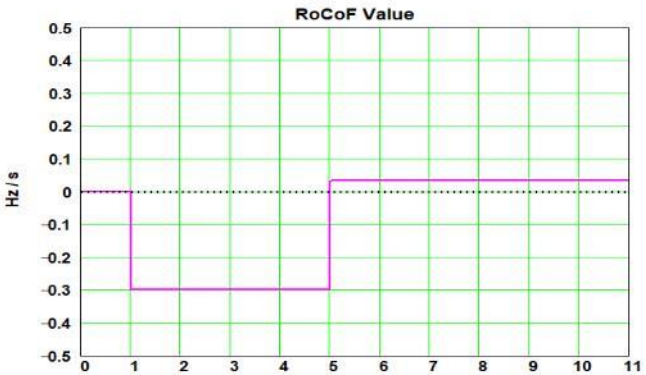
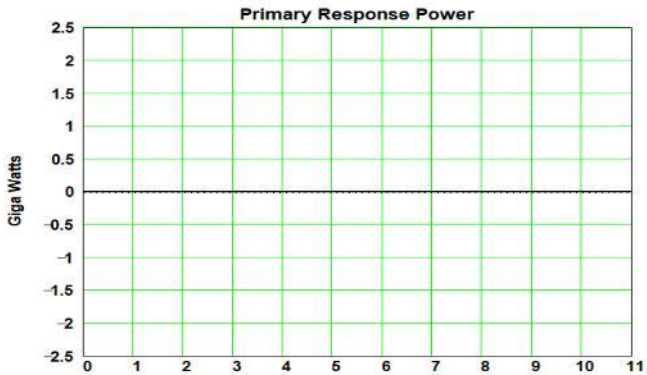
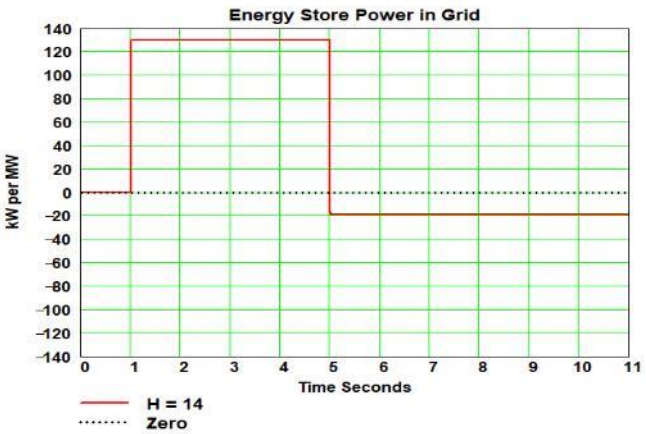
Initial frequency 50.2 Hz and no reserves H = 14 loss 1.8 GW











- Worst case Hz decrease.
- RoCoF is -0.3 Hz / s
- The energy store delivers a peak synthetic inertia power of 130 kW / MW with H = 14
- Generation loss is 1.8 GW.
- There is a total loss of the primary response dynamic containment.
- The energy store's nominal SOC is 700 kWs.
- Generation disconnections made at 49 Hz.
- This requires the same energy store as the data with a 25% loss of reserves.

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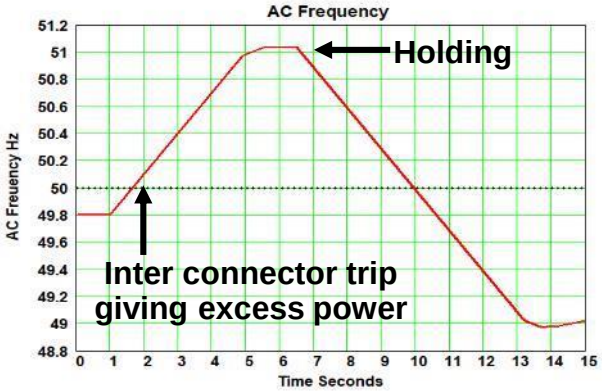
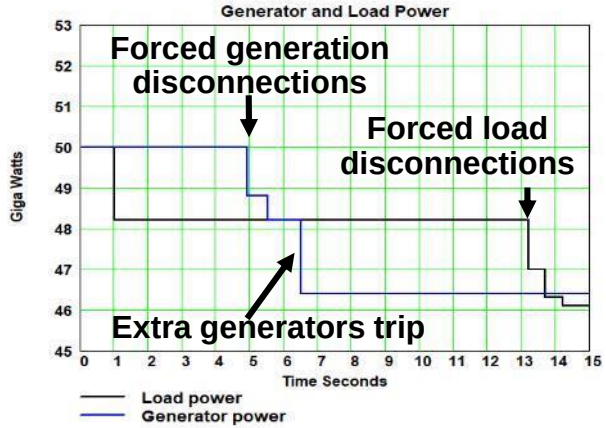
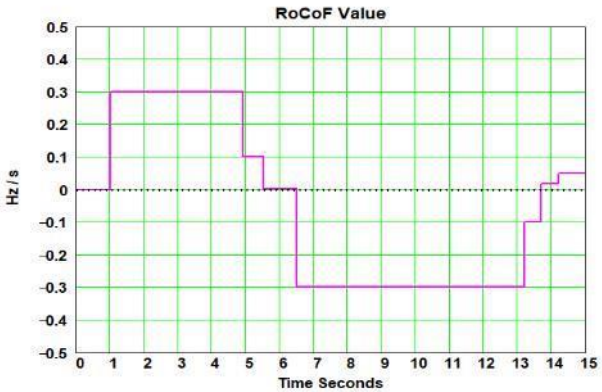
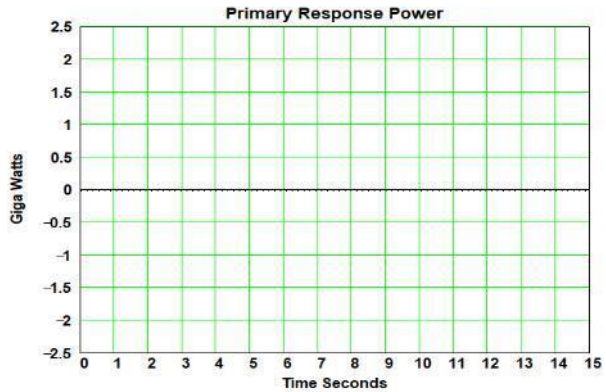
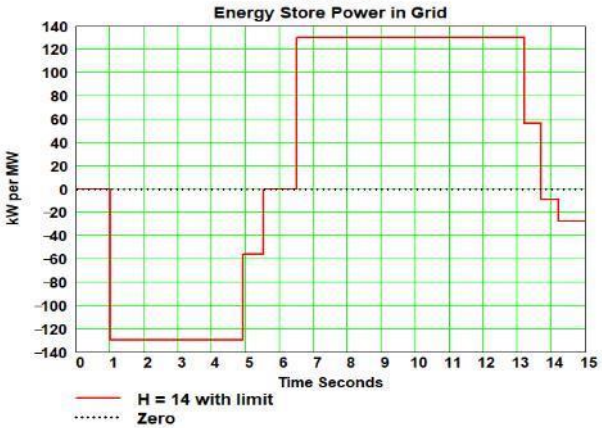
Initial frequency 49.8 Hz and no reserves H = 14 dual loss

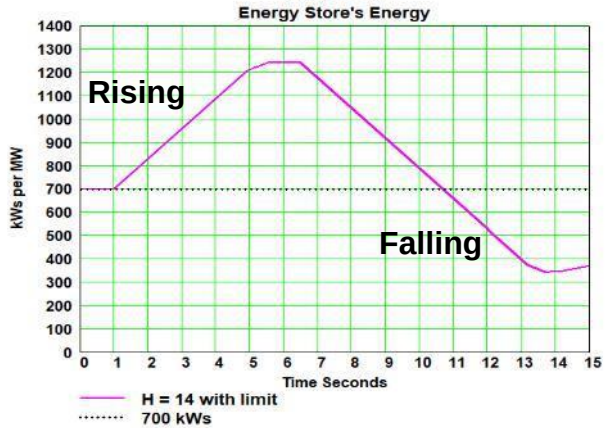












- This is the state at the input of an inter connector with a trip giving I.8 GW load loss.
- The grid frequency rises giving a forced generation trip of 1.8 GW at 51 Hz followed by other generators false tripping causing the frequency to fall.
- Forced load disconnections of an extra 1.9 GW happen at 49 Hz
- The energy store delivers a peak synthetic inertia power of 130 kW / MW with H = 14
- There is a total loss of the primary response dynamic containment.
- The energy store's nominal SOC is 700 kWs. This requires the same energy store as previous examples.
- If the disconnection frequency limits are 48 Hz and 52 Hz this will need an energy store of twice the energy rating.

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- **Section 6. Summary.**

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Summary part 1

The common test data is:

- Grid inertia 150 GWs.
- Change in generation power 1.8 GW.
- RoCoF is -0.3 Hz / second.
- Primary power reserve data based on the National Grid's " Faster Acting Response Webinar".

The results are:

Section number	VSM Inertia H factor	Inertia power kW / MW	Energy store kWs	Rate of rise seconds	Minimum Frequency Hz
2	7	84	900	4	49.25
3	7	84	900	1	49.50
4	14	130	1400	1	49.50

Notes

- The simulated VSM inertia is provided for –ve and + ve power transients..
- The simulated VSM inertia is provided for abnormal faults that require forced disconnections that have a loss of 25 % of the required primary response power reserves.
- The minimum frequency data is for faults with 100 % of reserves available.
- Designs are rated to cover abnormal faults from 50.2 Hz down to 49 Hz and 49.8 up to 51 Hz.
- When the energy store's specification is finalised the energy store can be designed.

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Summary part 2

The common test data is a Grid inertia 150 GWs with a total loss of reserves and the results are:

Section number	VSM Inertia H factor	Inertia power kW / MW	Energy store kWs	RoCoF Hz / s	Minimum Frequency Hz
5	7	84	900	-0.300	49.0
5	7	47	900	-0.167	49.0
5	14	130	1400	-0.300	49.0

The slide 26 shows that the system covers a large frequency rise followed by a large frequency fall.

The energy rating are the same as the corresponding Summary part 1 data showing that can rate on the basis of a total loss of reserves. To rate the VSM energy store the following data is needed:

- **Maximum starting frequency of 49.8 and 50.2 Hz are proposed.**
- **Minimum end frequencies of 49 Hz and 51 Hz are proposed.**
- **H factor in the range 7 to 14. The value of H = 7 is proposed to minimise costs.**
- **This gives an energy store rating 900 kWs. This allows for the store operating at 50 % SOC with a +/- 100 kWs margin to allow for the store responding to small grid frequency phase changes.**

To rate the inverter the following extra data is needed.

- **Maximum average RoCoF rate in Hz / s and 0.3 is proposed giving an inertia power of 84 kW / MW.**

Any new electricity storage used for either dynamic balancing or dynamic containment should have the VSM control added to give additional synthetic inertia power, which then enables a smaller inertia power, like H = 7 (84 kW / MW) to be used in both wind turbines and solar power systems.

The energy store cost is proportional to frequency range and MW rating, the energy store for the maximum design with 330 kW and 48 / 52 Hz frequencies is 8 times larger.

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Thank you

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Modification record

Issue 001	17-06-2018	• Initial issue.
Issue 002	25-06-2018	• Slide 26 added. Extra text added to slide 29.

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