# Grid Code Frequency Response Working Group Requirements for System Inertia

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# Overview

- Summary or Work to Date
- Pre / Post fault Wind Curtailment
- Manufacturer Engagement
- Further Work

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# Summary of Work Completed to Date

- Additional Study work
  - Spread Sheet
  - Digsilent Power Factory
  - BM Dashboard – Network Operations
- The effect of Inertia on the Transmission System
- Manufacturer Engagement
- Assessment of manufacturer capabilities
  - Power Recovery
  - Patents
- Further Work

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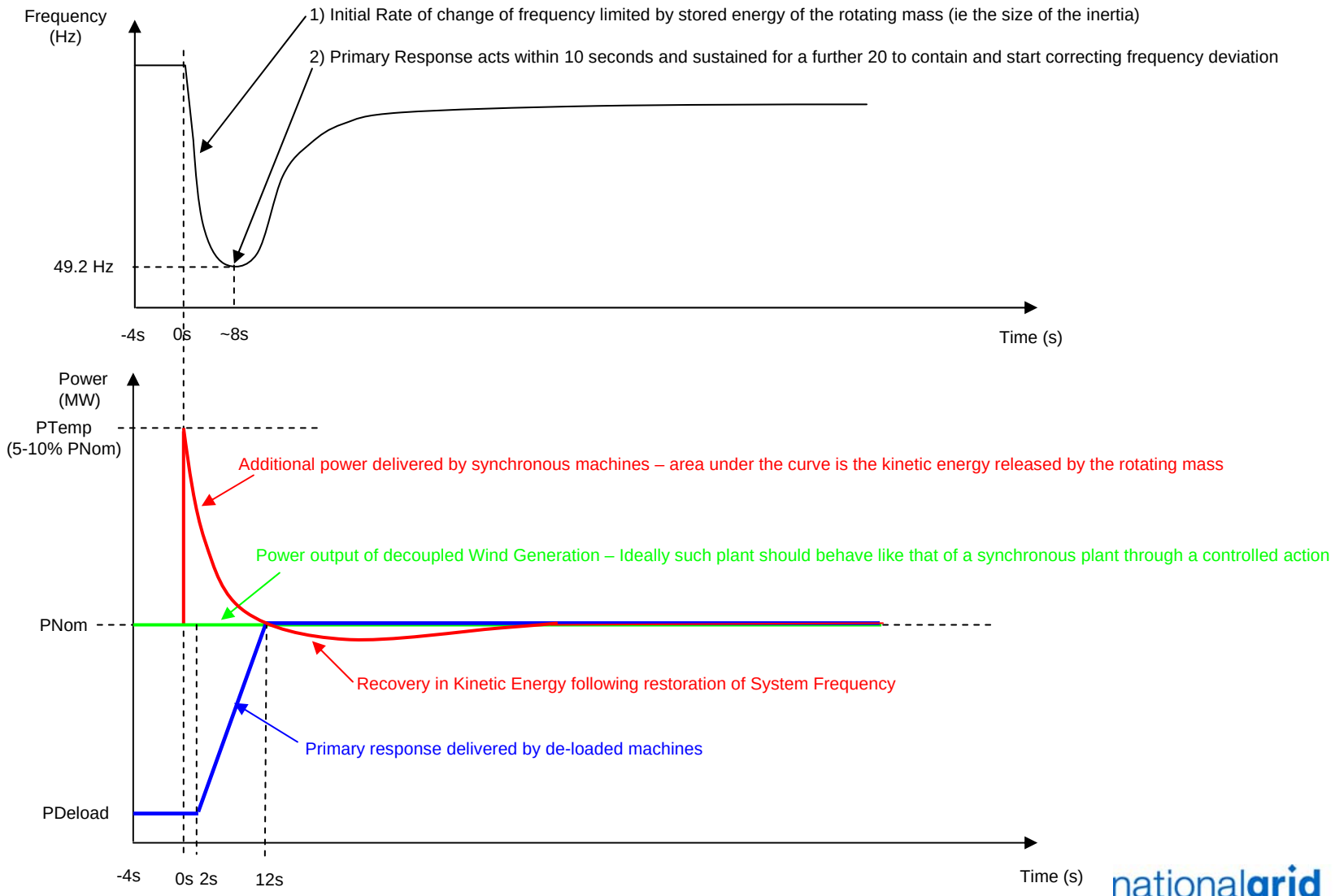
# Spread Sheet Results – Effect of Inertia – 1800 MW Loss 1

- The spread sheet calculation has been developed to demonstrate the effect of inertia:-
- Key Points
  - 25 GW load
  - 23.2GW of Coal
  - 3.6 GW of Pumped Storage (Response)
  - 50% Delivery of Pumped Storage – ie 1.8GW
  - Generation Loss = 1.8GW
  - Demand Reduction – 2%/Hz
  - Zero Secondary Response Provided – Beyond Study Timescales

# Spread Sheet Results – Effect of Inertia – 1800MW loss 2

| H Equivalent (MWs/MVA) | ROCOF (Hz/s) | Loss (MW) | Min Frequency (Hz) | Time to Min Frequency (s) |
|---|---|---|---|---|
| 0 | 0.67 | 1800 | 47.99 | 5.75 |
| 1 | 0.466 | 1800 | 48.37 | 6.6 |
| 2 | 0.3575 | 1800 | 48.62 | 7.1 |
| 3 | 0.2898 | 1800 | 48.8 | 7.6 |
| 4 | 0.2437 | 1800 | 48.94 | 7.85 |
| 5 | 0.2102 | 1800 | 49.05 | 8.1 |
| 6 | 0.1848 | 1800 | 49.14 | 8.3 |
| 7 | 0.16492 | 1800 | 49.22 | 8.5 |
| 8 | 0.148875 | 1800 | 49.28 | 8.7 |
| 9 | 0.13567 | 1800 | 49.33 | 8.7 |
| 10 | 0.124625 | 1800 | 49.37 | 8.8 |
| 11 | 0.11524 | 1800 | 49.42 | 8.9 |
| 12 | 0.107168 | 1800 | 49.45 | 8.9 |

# A summary of the Requirement / Issue

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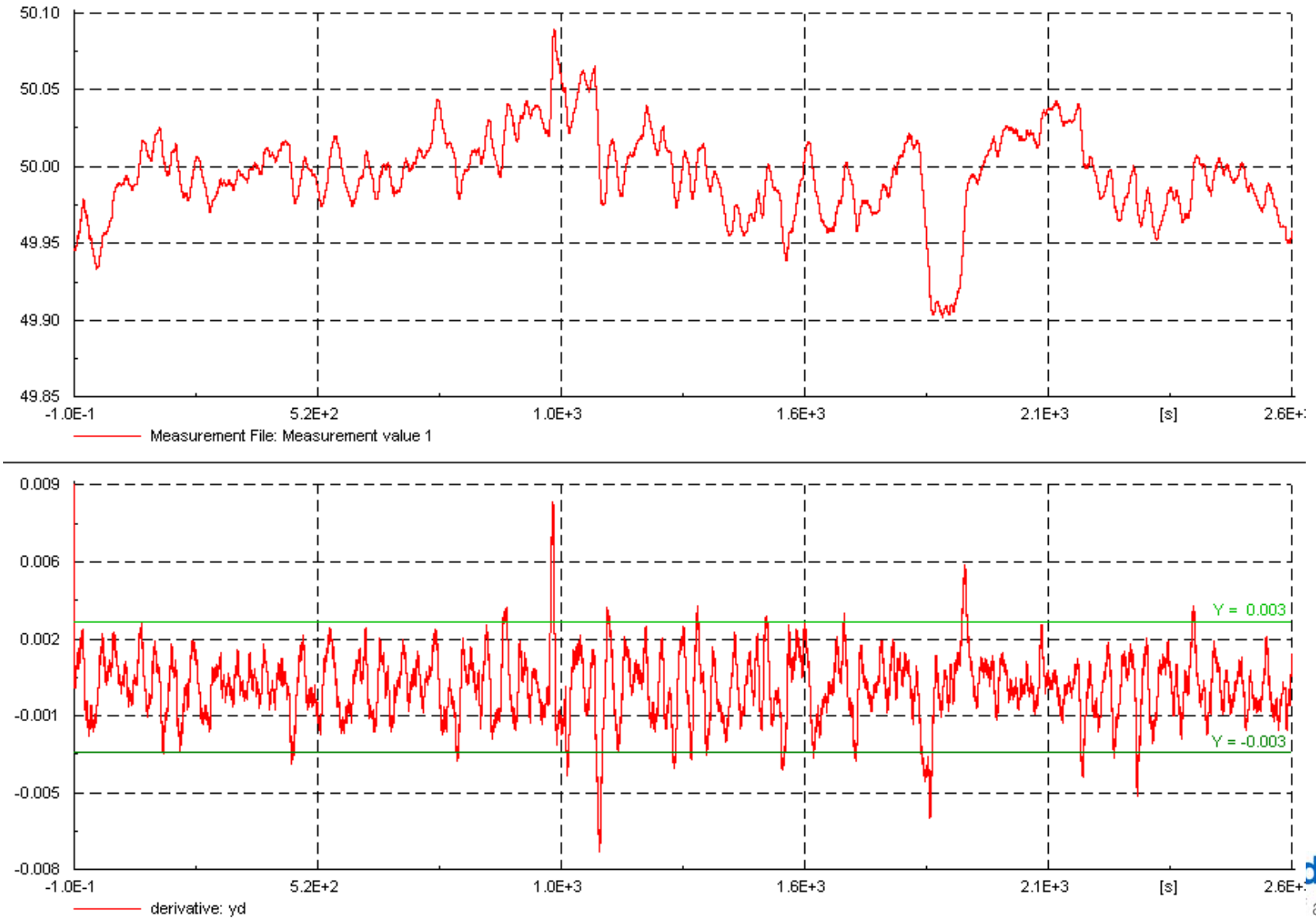
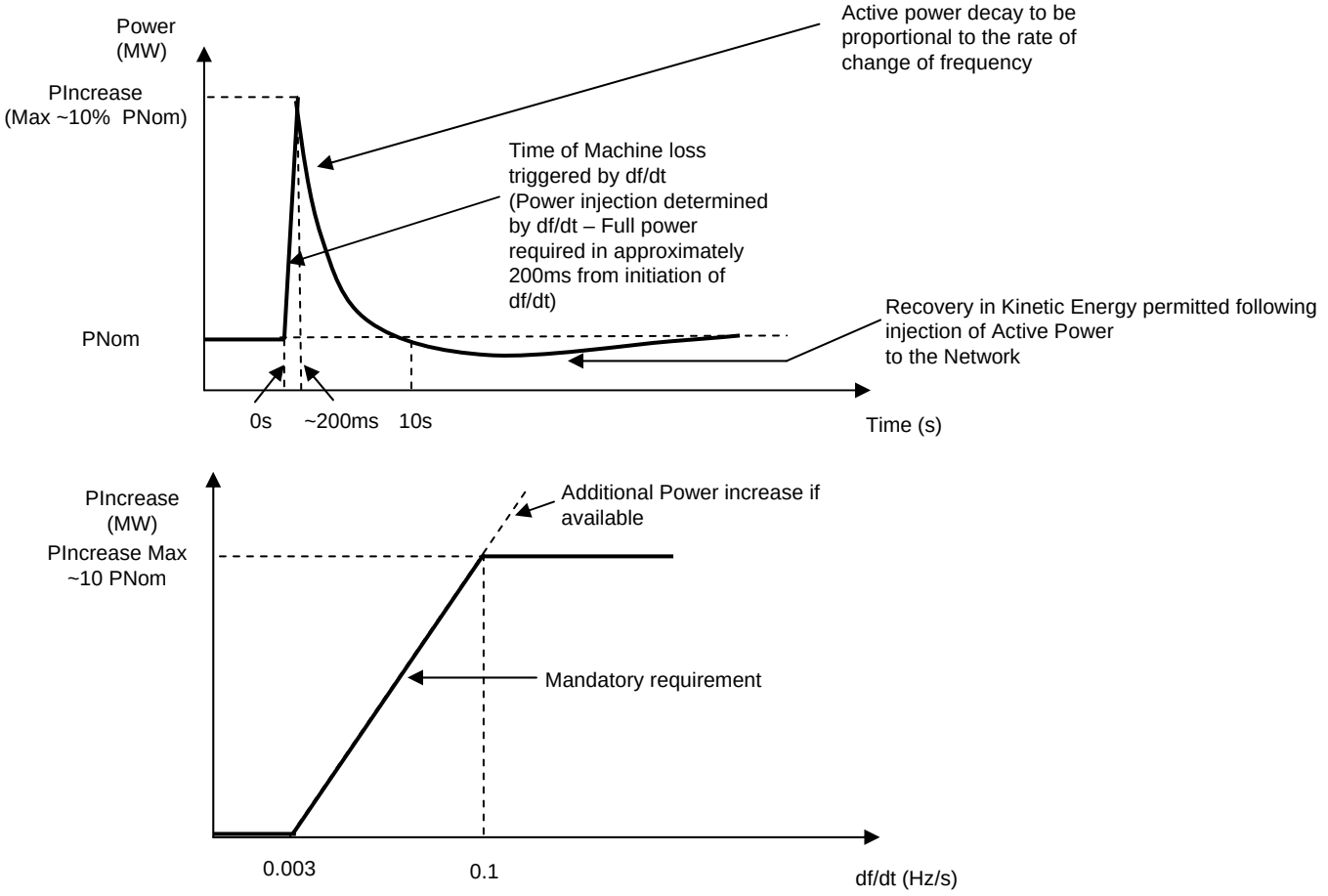
# Deadband


50.10
50.05
50.00
49.95
49.90
49.85
-1.0E-1
5.2E+2
1.0E+3
1.6E+3
2.1E+3
[s]
Measurement File: Measurement value 1
0.009
0.006
0.002
-0.001
-0.005
-0.008
Y = 0.003
Y = -0.003
derivative: yd

# High Level Requirements (1)

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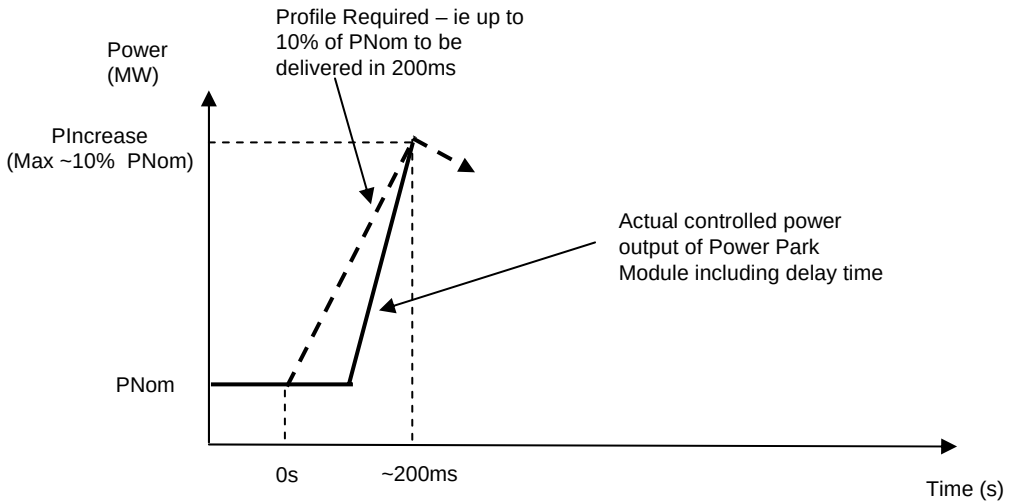
# High Level Requirements (2) – Detail of initial Short term Power Injection

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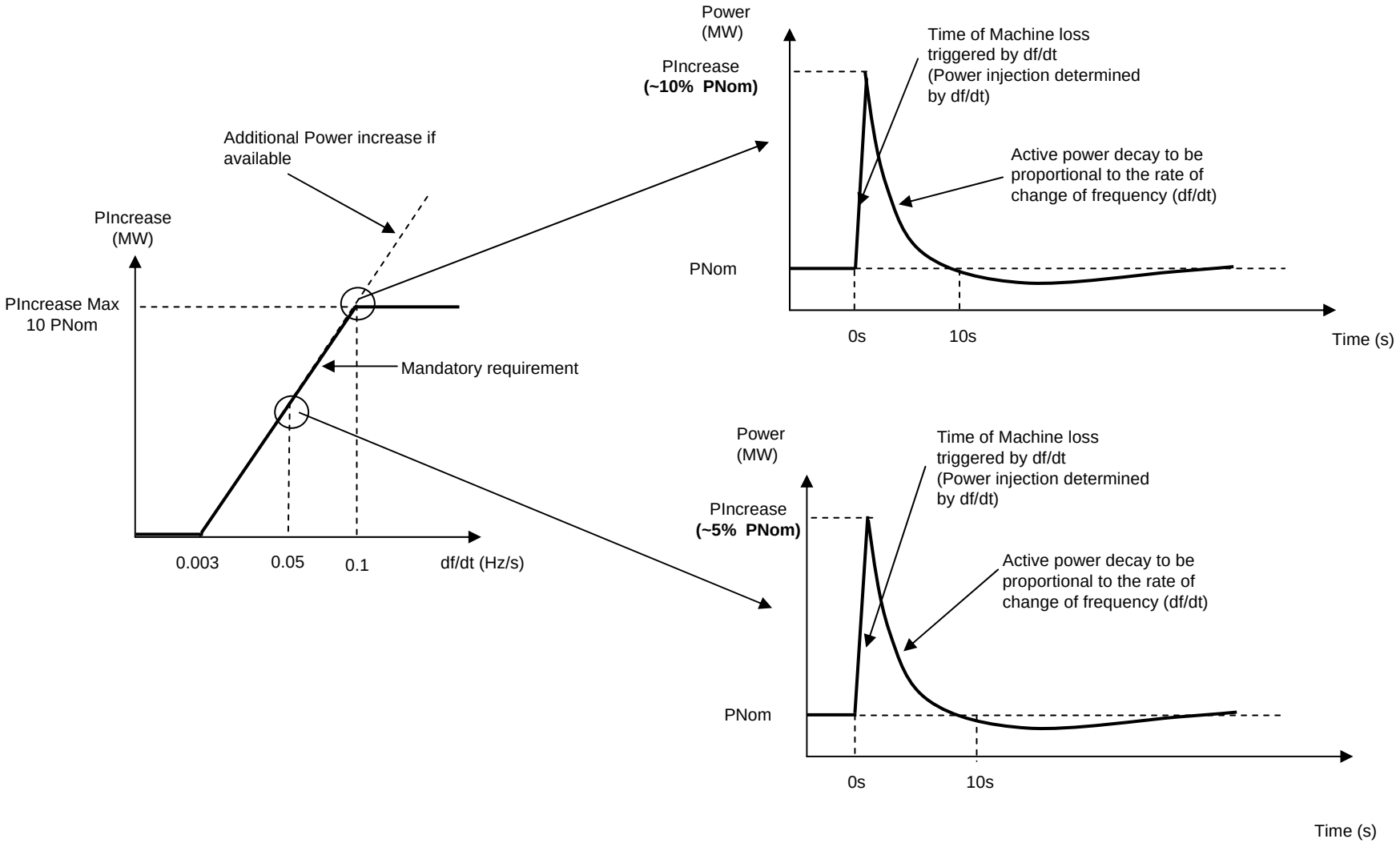
# High Level Requirements (2)

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# Power Injection Capability and Recovery

*Courtesy of Enercon – Taken from Figures 6 and 7 of Reference [1]*

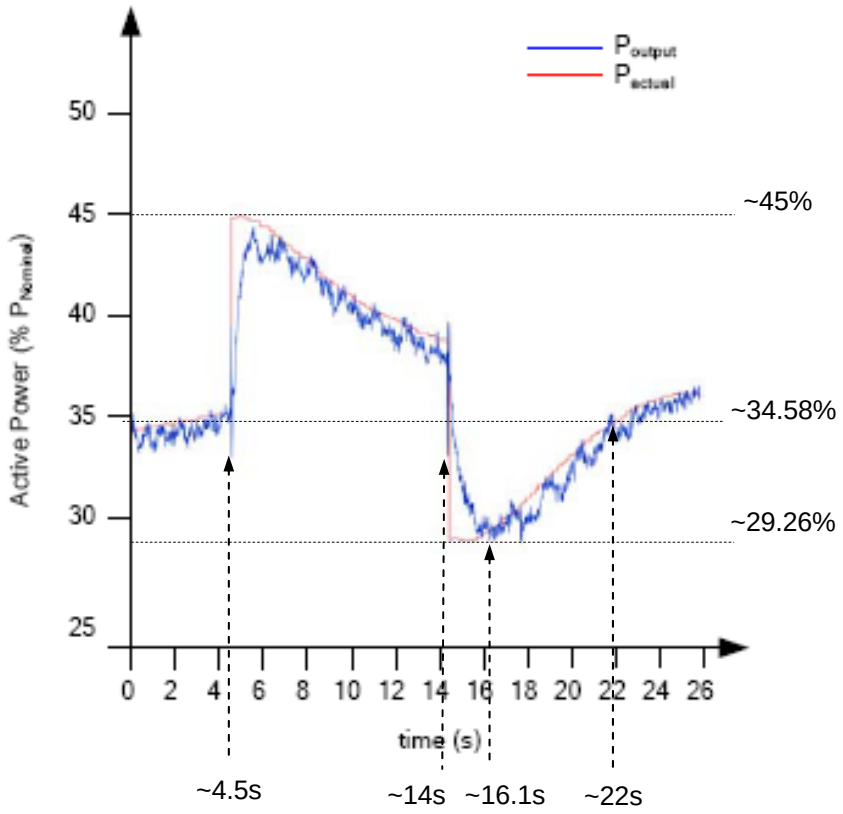


Figure 6 - Power Control including Rotational Speed – *Note black dotted lines with extrapolated additional values additional to original figure quoted by Enercon*

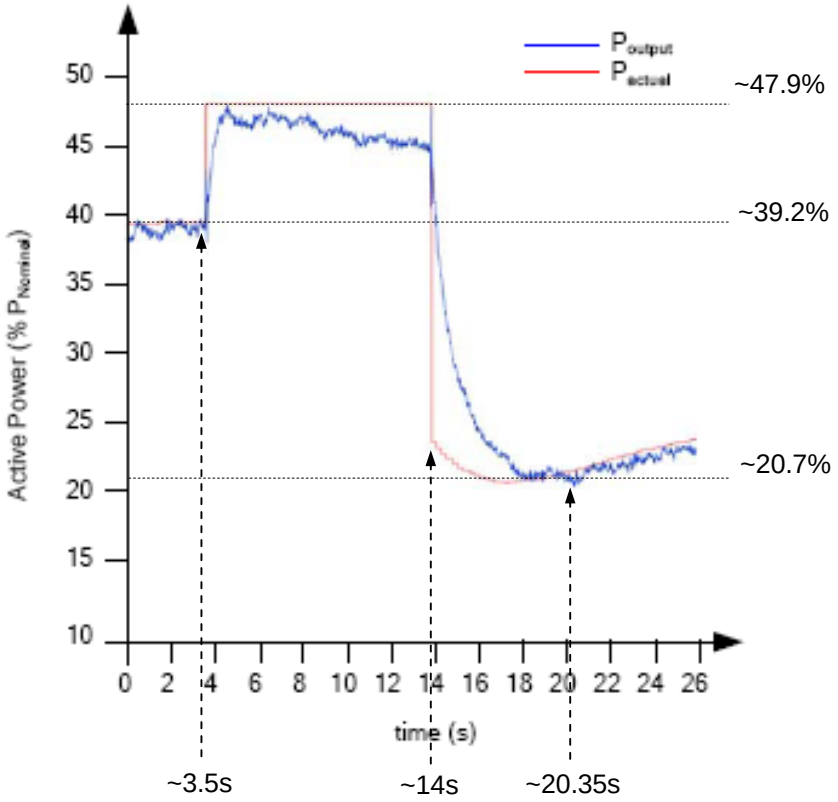


Figure 7 - Power Control excluding Rotational Speed – *Note black dotted lines with extrapolated additional values additional to original figure quoted by Enercon*

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# Power Injection Capability and Recovery

*Courtesy of Vestas – Taken from Figure 8 of Reference [3]*

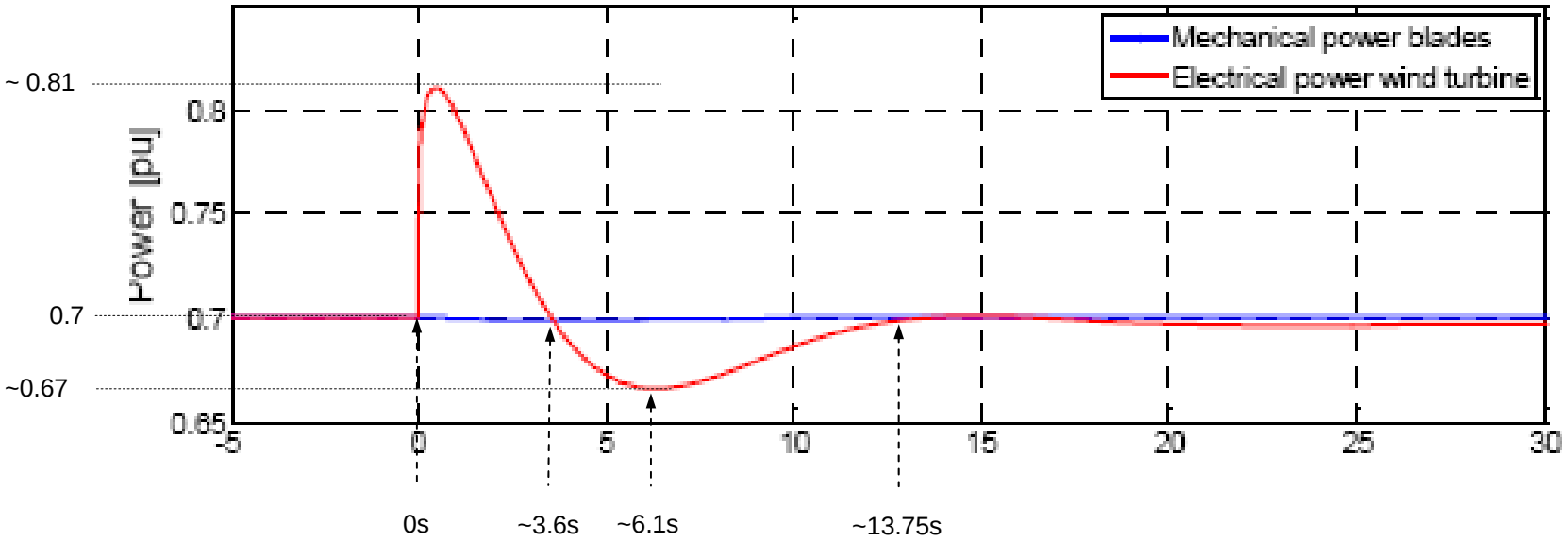


Figure 8 - Wind Power with Inertia emulation – *Note black dotted lines with extrapolated additional values additional to original figure quoted by Vestas*

# Power Injection Delivery

*Courtesy of Vestas – Taken from Figure 3 of Reference [2]*

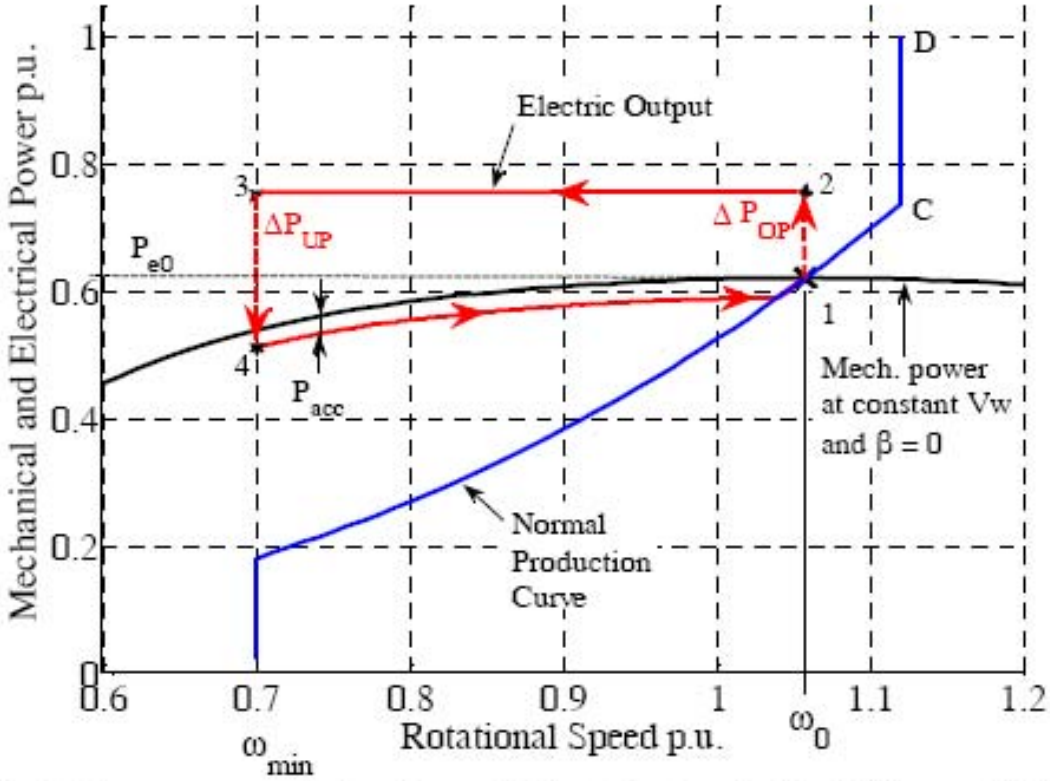


Fig. 3. WT power vs. rotational speed. The blue line is the WT normal (static) production power. The black line is the blade's mechanical power for a constant wind speed. The red line is the electric power set point for over-production process.

# Manufacturer Engagement

- High level principles and concepts were issued to a wide range of manufacturers at the end of June 2010
- Ongoing dialogue
- Early stages but issues include
  - Power Recovery
  - Recovery time
  - Variations in wind speed
  - Patents
  - Impact of response on the Power System
  - Further modelling work required

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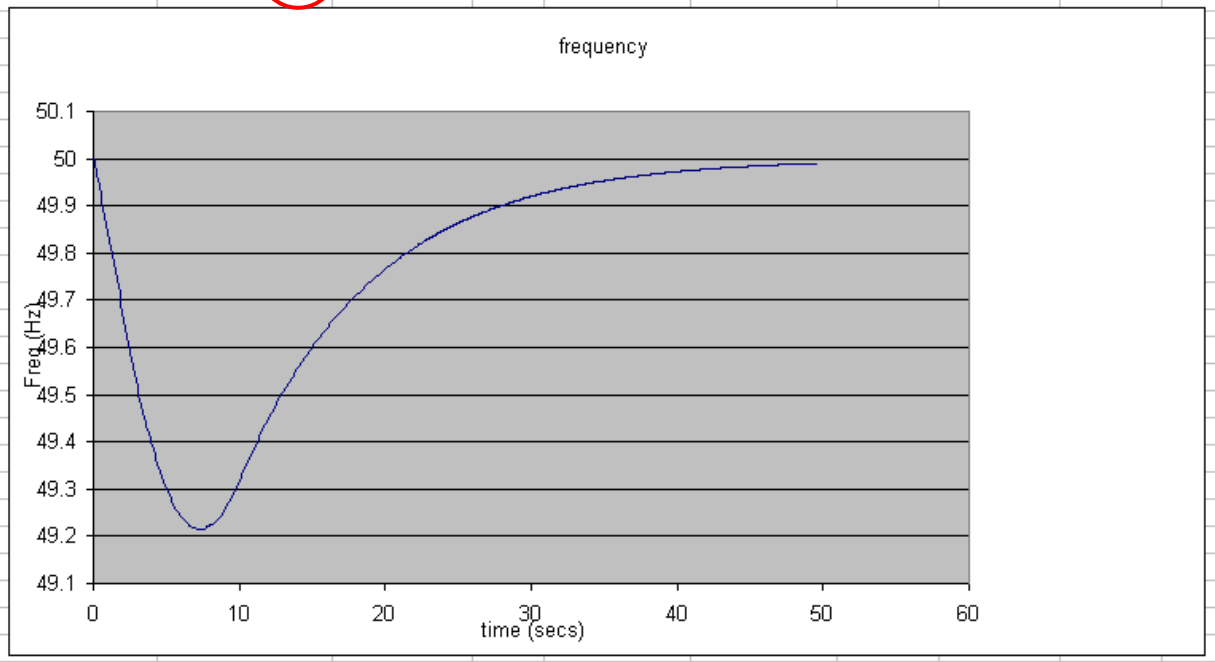
# Study Results (1) – Spread Sheet Without Energy Recovery

| Generation | GW generating | GW capacity | H | trip size (GW) | Provide response? | | |
|---|---|---|---|---|---|---|---|
| Wind | 16.36 | 17.4 | 0 | | 0.6 | | |
| Nuclear | 6.90 | 6.9 | 6.5 | 1.8 | 0 | | |
| Carbon capture | 0.00 | 0 | 0 | | 0 | | |
| SCC | 0.00 | 0 | 0 | | 0 | | |
| Conventional Coal | 0.00 | 0 | 0 | 0 | 0 | | |
| Conventional Gas | 0.00 | 0 | 0 | | 0 | | |
| Pumped storage | 1.80 | 3.6 | 4.5 | | 1 | | |
| | | | 0 | | 0 | | |
| Demonstration | 0.00 | 0 | 0 | 0 | 0 | post trip H | 1.89 |
| Total | 25.06 | 27.9 | 2.19 | 1.8 | | | |

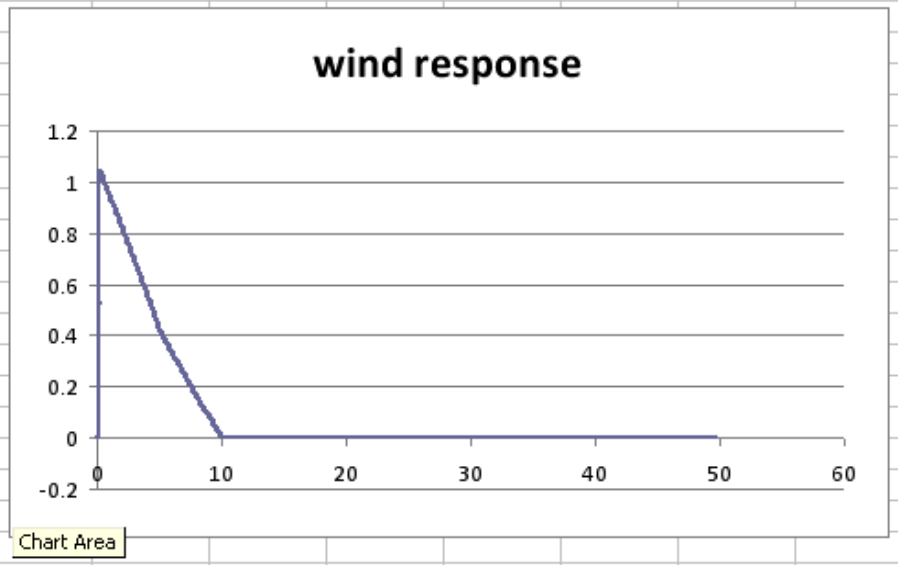



| | Scenarios | | |
|---|---|---|---|
| | | Gone Green | |
| | 2020 | 2025 | 2030 |
| | 16.5 | 9.5 | 2.8 |
| | 6.9 | 9.7 | 10.6 |
| | 1.6 | 5.8 | 11.6 |
| Totals | 25 | 25 | 25 |

| | |
|---|---|
| calculation step size | 0.1 |
| no. of steps to measure ROCOF | 100 |
| ROCOF measured over (secs) | 10 |
| ROCOF (Hz/sec) | 0.06847 |

# Study Results (1) – Spread Sheet – H = 0 Without Energy Recovery

| response characteristic | | | wind specific response | |
|---|---|---|---|---|
| %output | time | slope | | |
| 0 | 0 | 50 | 0 | 0 |
| 10 | 0.2 | -1.21212 | 0 | 4 |
| 6 | 3.5 | -1.33333 | 2 | 5 |
| 4 | 5 | -0.83333 | 12 | 9 |
| 1.5 | 8 | -0.75 | 16 | 13 |
| 0 | 10 | 0 | 16 | 15 |
| 0 | 12 | | 16 | 20 |




| | |
|---|---|
| max percentage response = | 10 |
| capacity (GW) = | 17.4 |
| perecntage of plant providing response = | 60 |
| pre-fault generation (GW) = | 16.356 |

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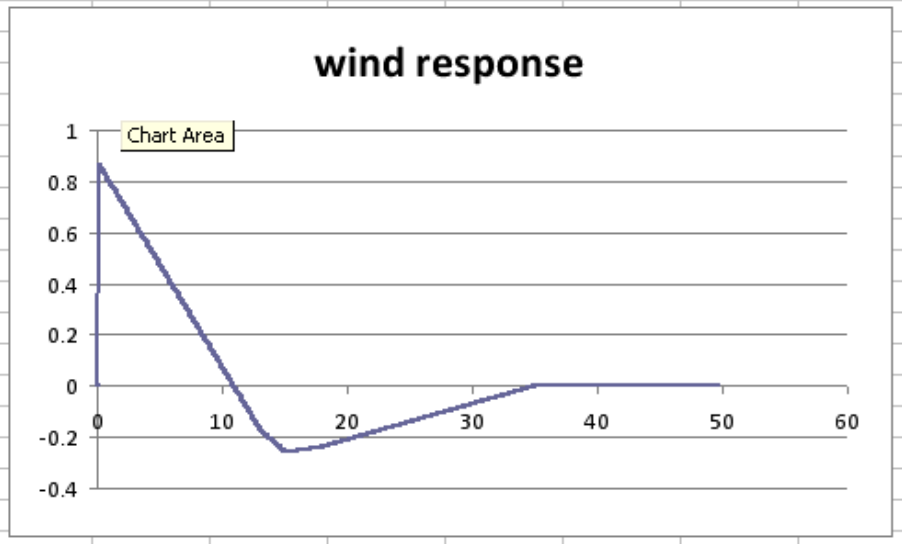
# Study Results (2) – Spread Sheet – H = 0 With Energy Recovery

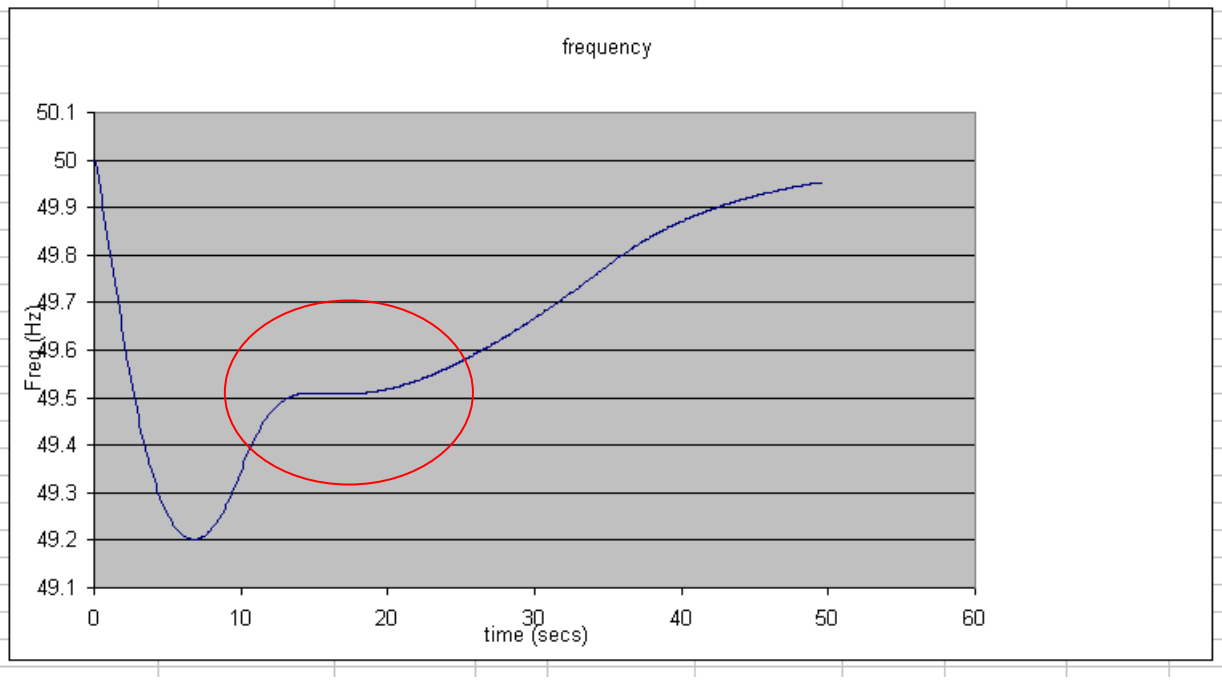
| response characteristic | | | | wind specific response | |
|---|---|---|---|---|---|
| %output | time | slope | | | |
| 0 | 0 | 100 | | 0 | 0 |
| 10 | 0.1 | -0.93023 | | 0 | 4 |
| -2 | 13 | -0.5 | | 2 | 5 |
| -3 | 15 | 0.083333 | | 12 | 9 |
| -2.75 | 18 | 0.161765 | | 16 | 13 |
| 0 | 35 | 0 | | 16 | 15 |
| 0 | 20 | | | 16 | 20 |




| | |
|---|---|
| max percentage response = | 10 |
| capacity (GW) = | 17.3 |
| perecntage of plant providing response = | 50 |
| pre-fault generation (GW) = | 16.435 |

# Study Results (2) – Spread Sheet With Energy Recovery

| Generation | GW generating | GW capacity | H | trip size (GW) | Provide response? | | |
|---|---|---|---|---|---|---|---|
| Wind | 16.44 | 17.3 | 0 | | 0.5 | | |
| Nuclear | 6.90 | 6.9 | 6.5 | 1.8 | 0 | | |
| Carbon capture | 0.00 | 0 | 0 | | 0 | | |
| SCC | 0.00 | 0 | 0 | | 0 | | |
| Conventional Coal | 0.00 | 0 | 0 | 0 | 0 | | |
| Conventional Gas | 0.00 | 0 | 0 | | 0 | | |
| Pumped storage | 1.80 | 3.6 | 4.5 | | 1 | | |
| | | | 0 | | 0 | | |
| Demonstration | 0.00 | 0 | 0 | 0 | 0 | post trip H | 1.90 |
| Total | 25.14 | 27.8 | 2.20 | 1.8 | | | |




| | Gone Green | | |
|---|---|---|---|
| | 2020 | 2025 | 2030 |
| | 16.5 | 9.5 | 2.8 |
| | 6.9 | 9.7 | 10.6 |
| | 1.6 | 5.8 | 11.6 |

| | | |
|---|---|---|
| Totals | 25 | 25 | 25 |

| | |
|---|---|
| calculation step size | 0.1 |
| no. of steps to measure ROCOF | 100 |
| ROCOF measured over (secs) | 10 |
| ROCOF (Hz/sec) | 0.065601 |

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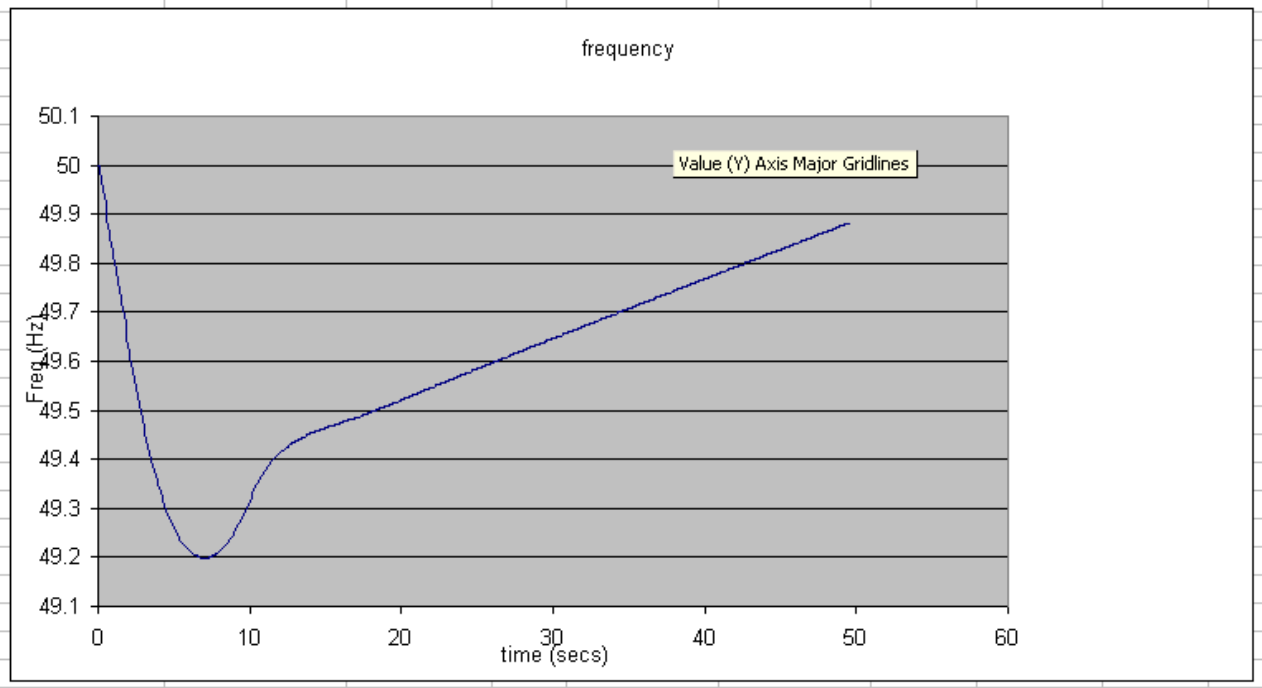
# Study Results (3) – Spread Sheet With Energy Recovery

| Generation | GW generating | GW capacity | H | trip size (GW) | Provide response? |
|---|---|---|---|---|---|
| Wind | 16.40 | 17.3 | 0 | | 0.52 |
| Nuclear | 6.90 | 6.9 | 6.5 | 1.8 | 0 |
| Carbon capture | 0.00 | 0 | 0 | | 0 |
| SCC | 0.00 | 0 | 0 | | 0 |
| Conventional Coal | 0.00 | 0 | 0 | 0 | 0 |
| Conventional Gas | 0.00 | 0 | 0 | | 0 |
| Pumped storage | 1.80 | 3.6 | 4.5 | | 1 |
| | | | 0 | | 0 |
| Demonstration | 0.00 | 0 | 0 | 0 | 0 |
| Total | 25.10 | 27.8 | 2.20 | 1.8 | |

post trip H 1.90

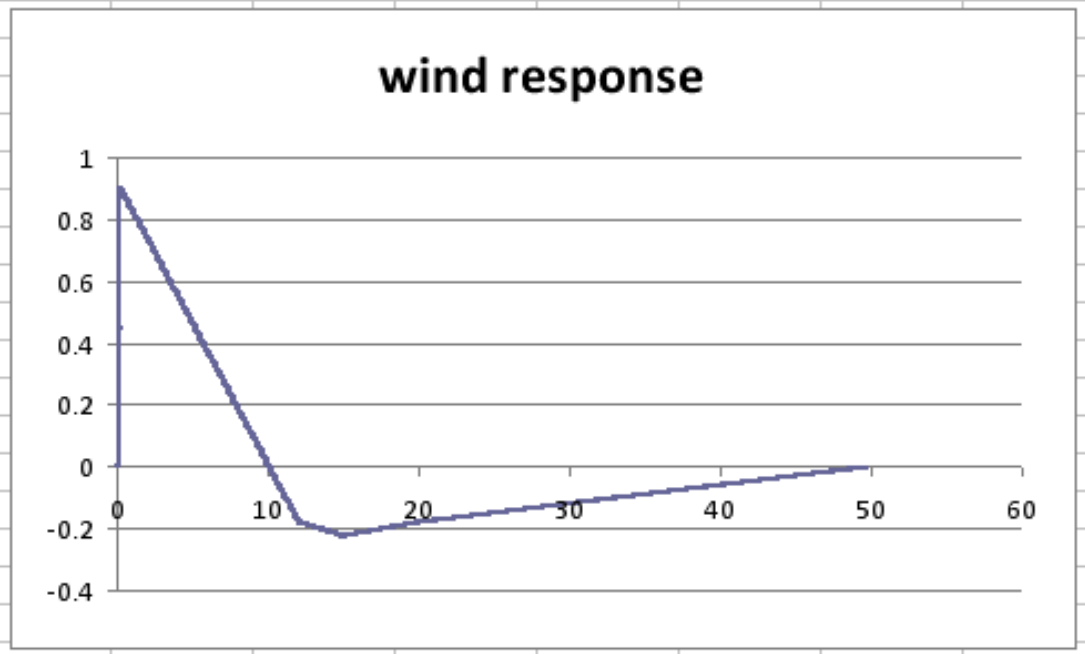
| | Gone Green | | |
|---|---|---|---|
| | 2020 | 2025 | 2030 |
| | 16.5 | 9.5 | 2.8 |
| | 6.9 | 9.7 | 10.6 |
| | 1.6 | 5.8 | 11.6 |
| Totals | 25 | 25 | 25 |




| | |
|---|---|
| calculation step size | 0.1 |
| no. of steps to measure ROCOF | 100 |
| ROCOF measured over (secs) | 10 |
| ROCOF (Hz/sec) | 0.068605 |

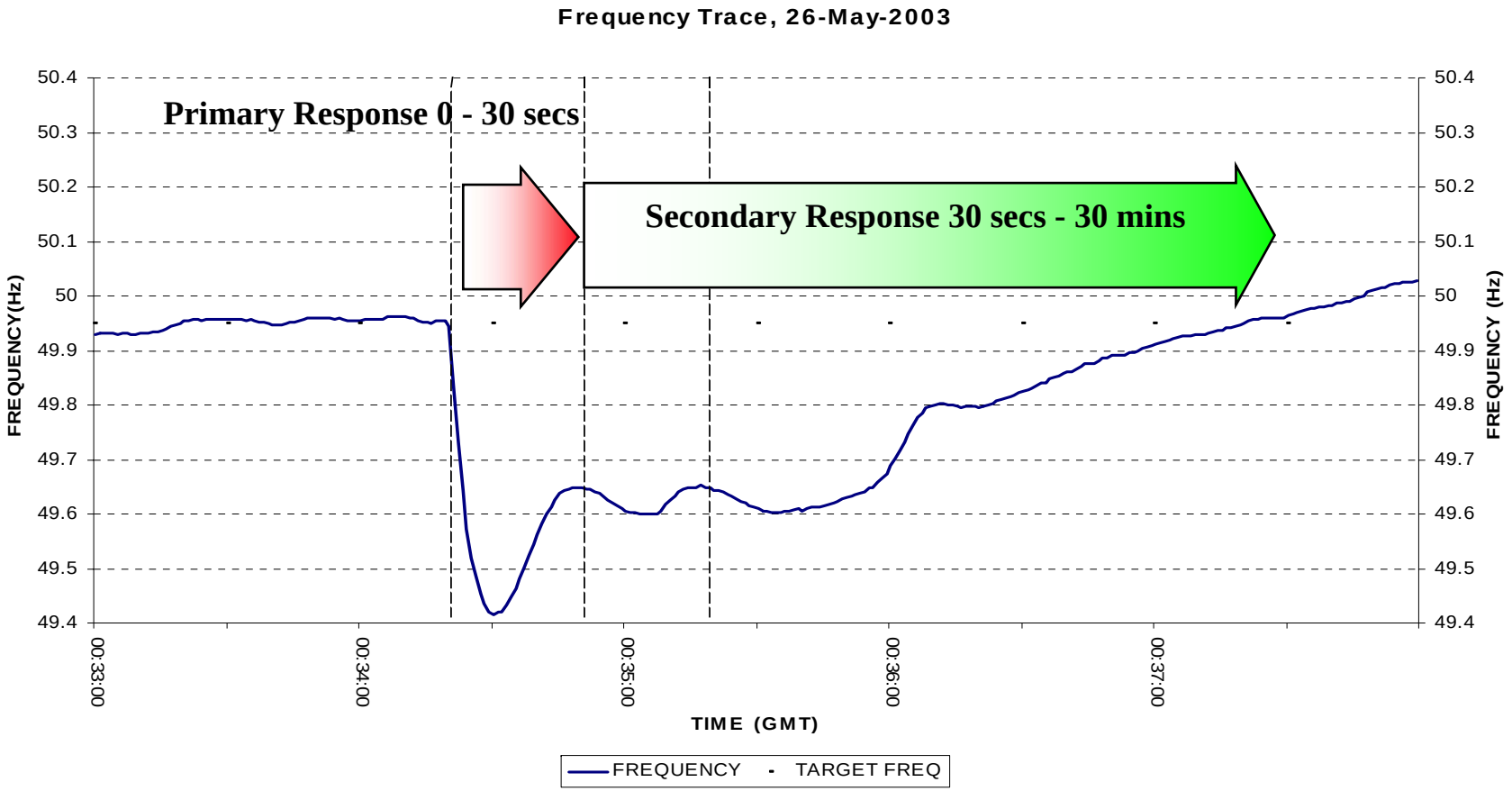
# Study Results (3) – Spread Sheet – H = 0 With Energy Recovery

| response characteristic | | | wind specific response | |
|---|---|---|---|---|
| %output | time | slope | | |
| 0 | 0 | 50 | 0 | 0 |
| 10 | 0.2 | -1.01695 | 0 | 4 |
| -2 | 12 | -0.16667 | 2 | 5 |
| -2.5 | 15 | 0.1 | 12 | 9 |
| -2 | 20 | 0.066667 | 16 | 13 |
| 0 | 50 | 0 | 16 | 15 |
| 0 | 60 | | 16 | 20 |



# Frequency Control Capability

## Example of a Secured Incident *26 May 2003 (1175 MW loss)*

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# Further Work Required

- Finalise modelling to determine settings based on the minimum needs of the Transmission System taking energy recovery into account
- Compare model results
  - Spread Sheet
  - Digsilent Power Factory
  - BM Dashboard
- Understand manufacturers Capabilities in more detail
  - Power Recovery, Recovery Time, Impact on the Transmission System
  - Effect of Wind Speed
- Finalise Settings
  - Maximum value of PIncrease / Time duration
  - Exponential decay requirements / Power recovery
  - Deadband settings
  - Active Power injection during lower rates of change of system frequency
- Legal drafting
- Timescales

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# References / Further Information


- [1] Contribution of Wind Energy Converters with Inertia Emulation to frequency control and frequency stability in Power Systems – Stephan Wachtel and Alfred Beekmann – Enercon – Presented at the 8th International Workshop on Large Scale Integration of Wind Power into Power Systems as well as on Offshore Wind Farms, Bremen Germany, 14 – 15 October 2009.
- [2] Variable Speed Wind Turbines Capability for Temporary Over-Production – German Claudio Tarnowski, Philip Carne Kjaer, Poul E Sorensen and Jacob Ostergaard
- [3] Study on Variable Speed Wind Turbine Capability for Frequency Response - German Claudio Tarnowski, Philip Carne Kjaer, Poul E Sorensen and Jacob Ostergaard
- [4] GE Energy – WindINERTIA™ Control fact sheet – Available on GE Website at :- http://www.ge-energy.com/businesses/ge_wind_energy/en/downloads/GEA17210.pdf
- [5] Transmission Provider Technical Requirements for the Connection of Power Plants to the Hydro-Quebec Transmission System – February 2006
- [6] Amendment Report SQSS Review Request GSR007 Review of Infeed Loss limits – Prepared by the SQSS Review Group for Submission to the Authority – 10th September 2009 available at:- http://www.nationalgrid.com/NR/rdonlyres/EF5C0829-1C5E-4258-8F73-70DC62C43F49/36936/SQSS1320Reportv10_final.pdf


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