Fault Ride Through Study Work

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National Grid – TNS Technical Policy

Summary

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- Actions
- Summary of Conclusions and studies from previous meeting
- Summary of the process used to set up and run a multi machine study
- Results
- Summary

Actions

- Investigate over voltage issues identified at the Generator terminals and AVR performance
- Produce System Peak Study (ie investigate the effect of lower voltages and faults adjacent to high volumes of Generation).
- Detail full assumptions made during system studies
- Investigate the impact on System Frequency
- Investigate voltage recovery to 0.9 p.u
- Investigate the initial operating point of the Generator (ie full output at full lead – Summer Min / Studies also run at Winter Peak under lagging mode)
- Investigate the effect on Station Auxiliaries?

Study Case presented at previous meeting held on 8 May 2014

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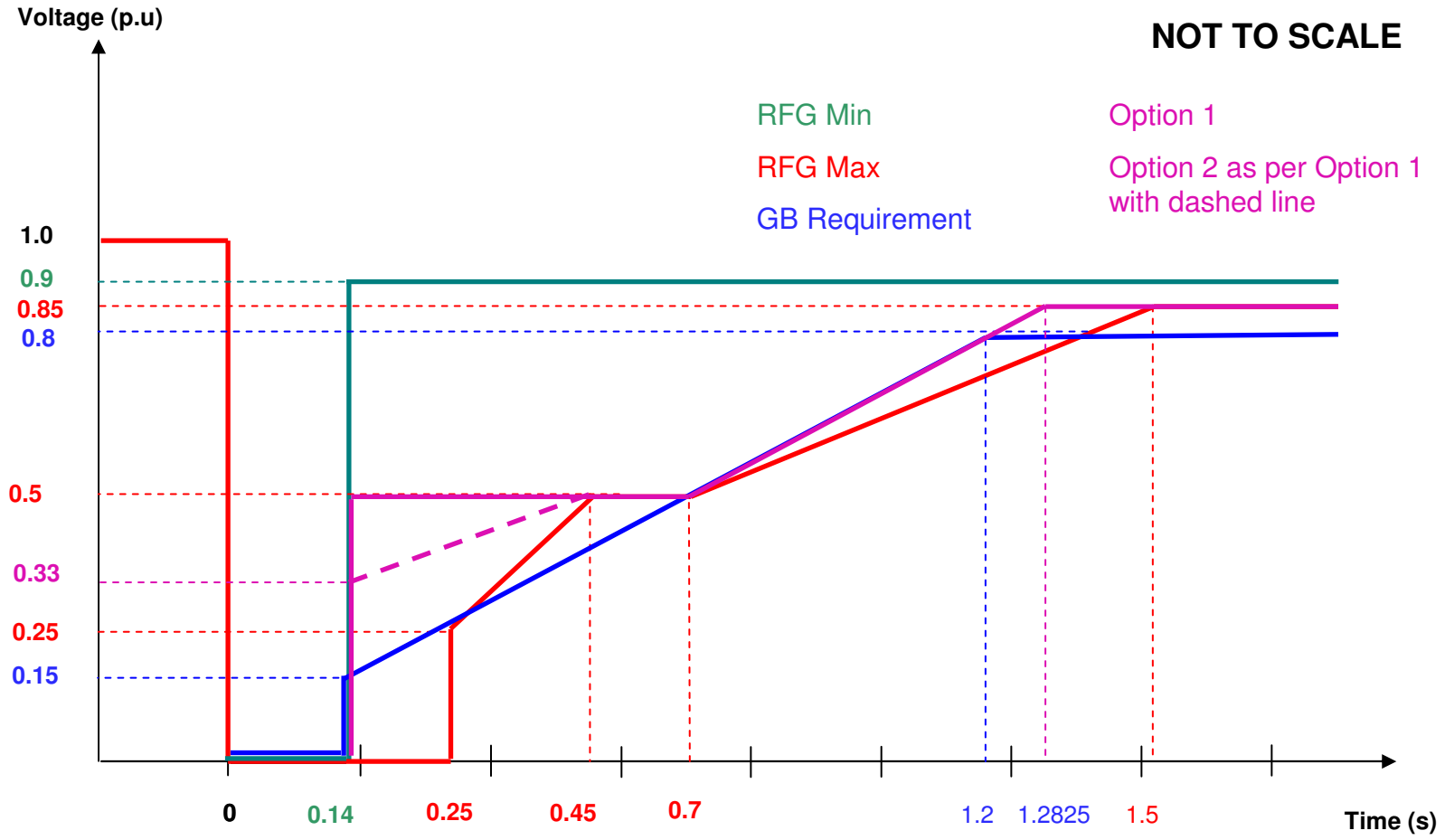
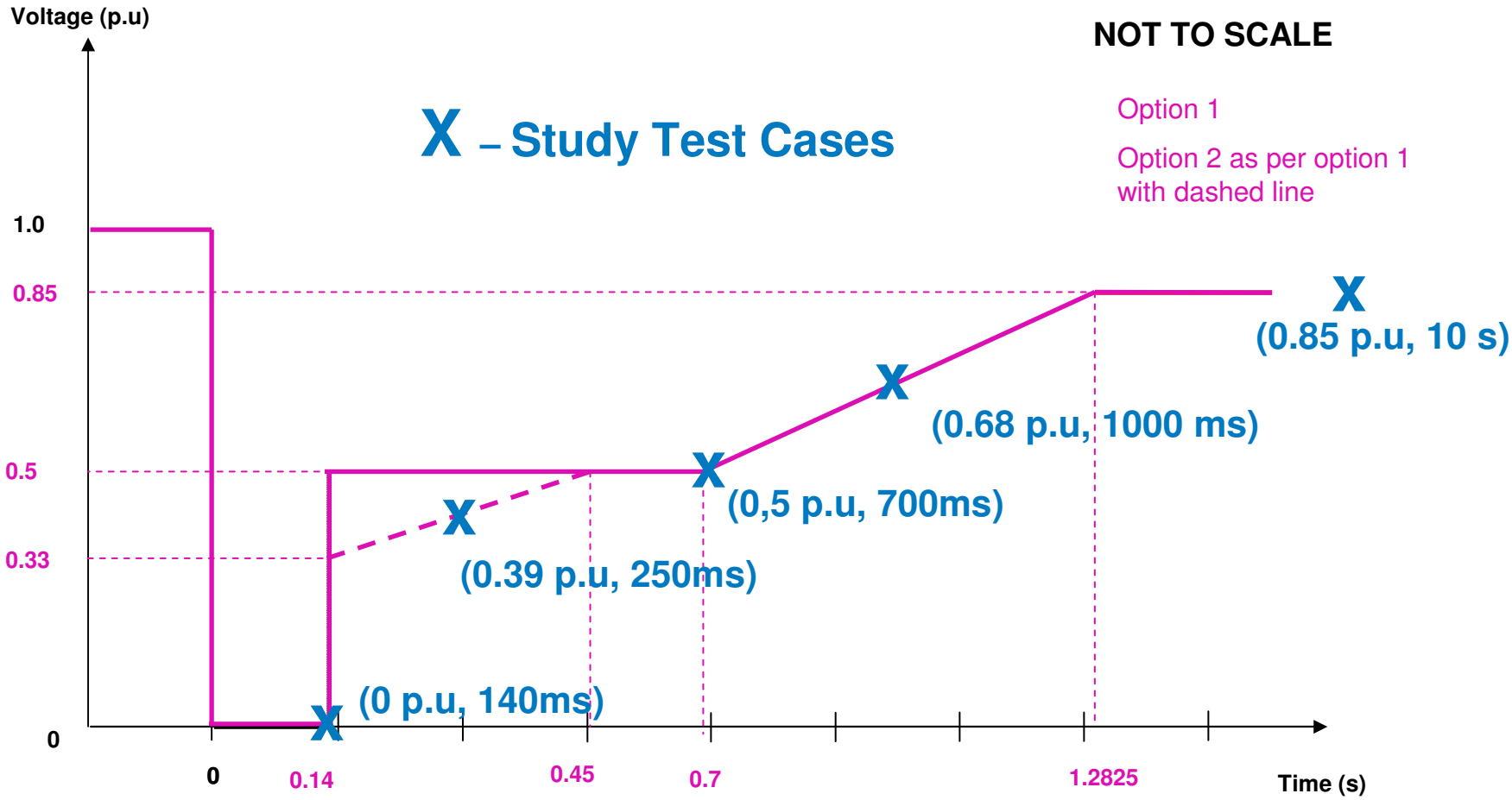
- Full GB Network under 2013 minimum demand conditions ~ 18GW
- Range of scenarios investigated (Low, Medium and High Non-Synchronous Plant)
- Range of faults applied to strategic parts of the network
  - Seabank
  - Drax / Eggborough
- Standard fault clearance times applied plus longer duration faults to cater for issues such as backup protection
- Test machines in fully leading mode of operation (0.95 PF lead) and HV busbar voltage set to 1.0p.u – Summer Min - Other machines operated as per guidance provided by Market Operations – Summer Min and Winter Peak
- Studies run in Digsilent Power Factor Factory

Voltage Duration Profile – Options compared with GB and ENTSO – E Requirement



ENTSO-E RfG - Voltage Duration Profile – Study Results



Process of setting up a Multi Machine Study

- Ensure the full network represents the correct level and type of demand
- Ensure the correct level of Generation based on the correct merit order
- Ensure the network contains all the correct outages and substation running arrangements
- Balance the study to ensure the total volume of Generation equates to the total volume of demand plus losses (slack bar equates to zero MW)
- Set the network up (ie adjust the Generator target voltage, switch reactive compensation equipment in /out and adjust Quad boosters) so that for all credible conditions the network is fully compliant with the requirements of the SQSS (ie no unacceptable overloads, unacceptable voltage conditions, unacceptable stability conditions or fault level issues.
- The conditions will vary significantly depending upon the level of demand, outage profile, merit order and time of year.

Generator Terminal Voltage Overvoltage Issues on Test Machines

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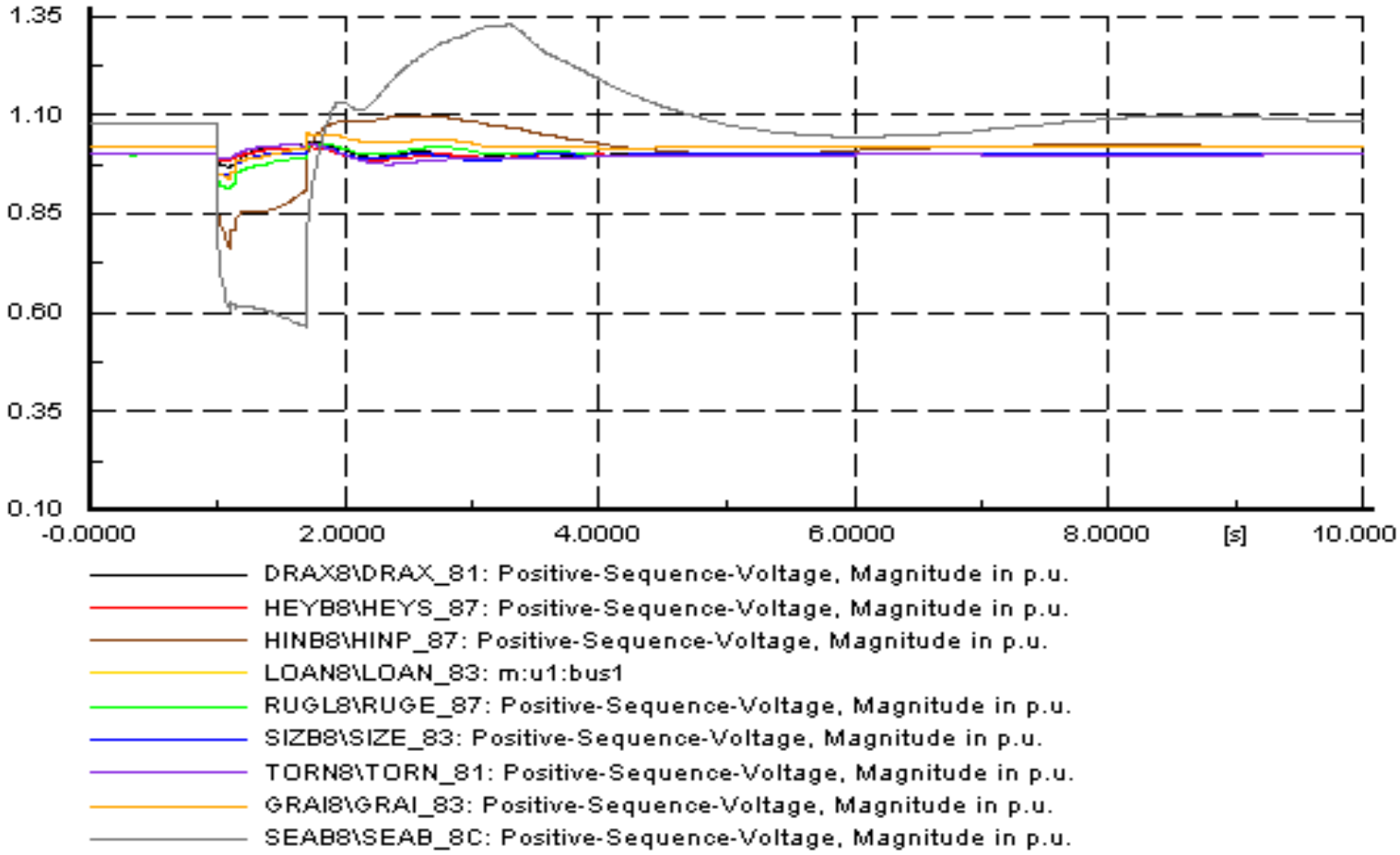
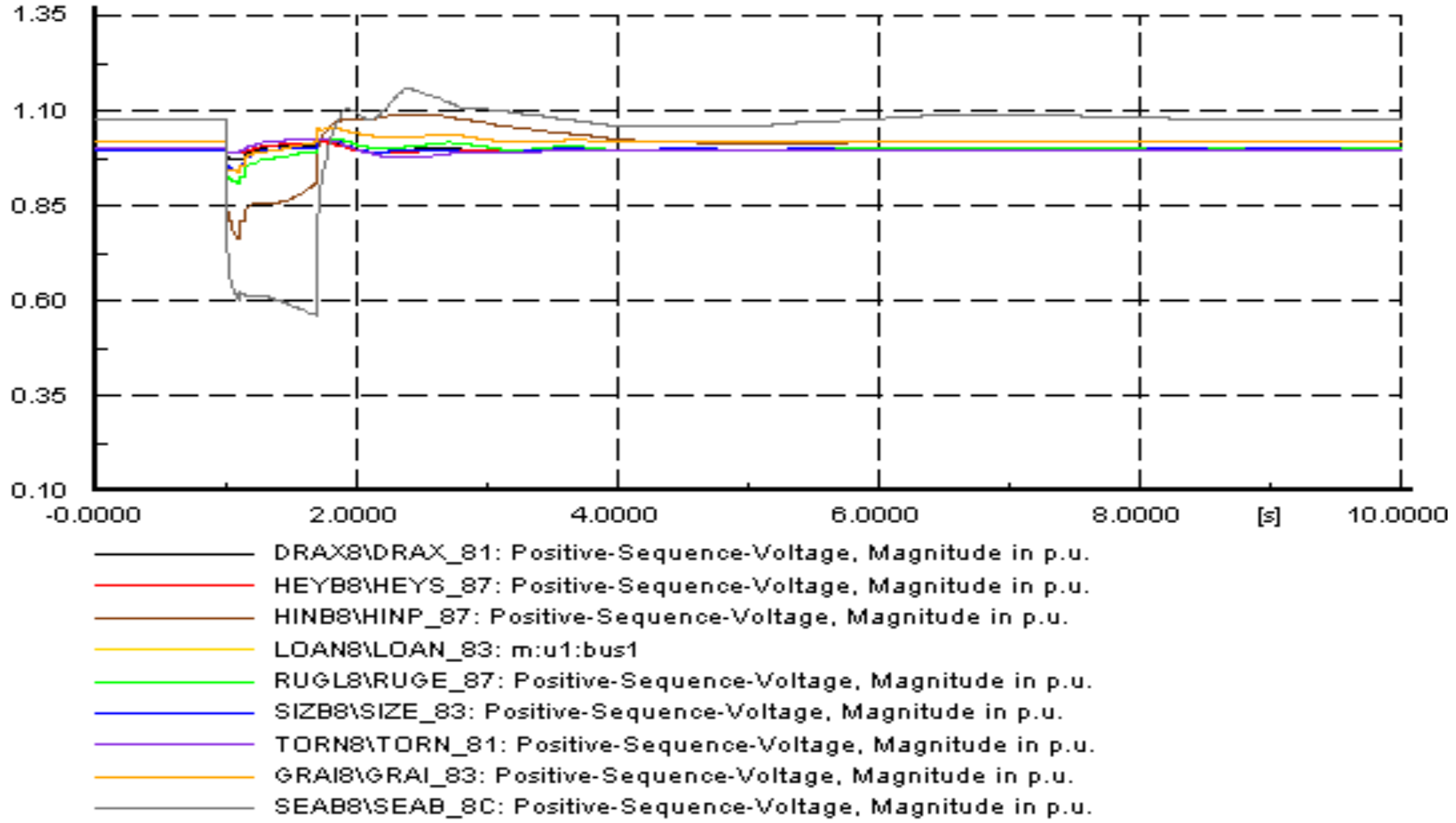
- Seabank - Investigated and identified to be part of an integrator winding up in the AVR
- Drax and Eggborough - Investigated /checked – further refinements were made to Drax AVR models
- These rectifications were implemented in studies subsequently run

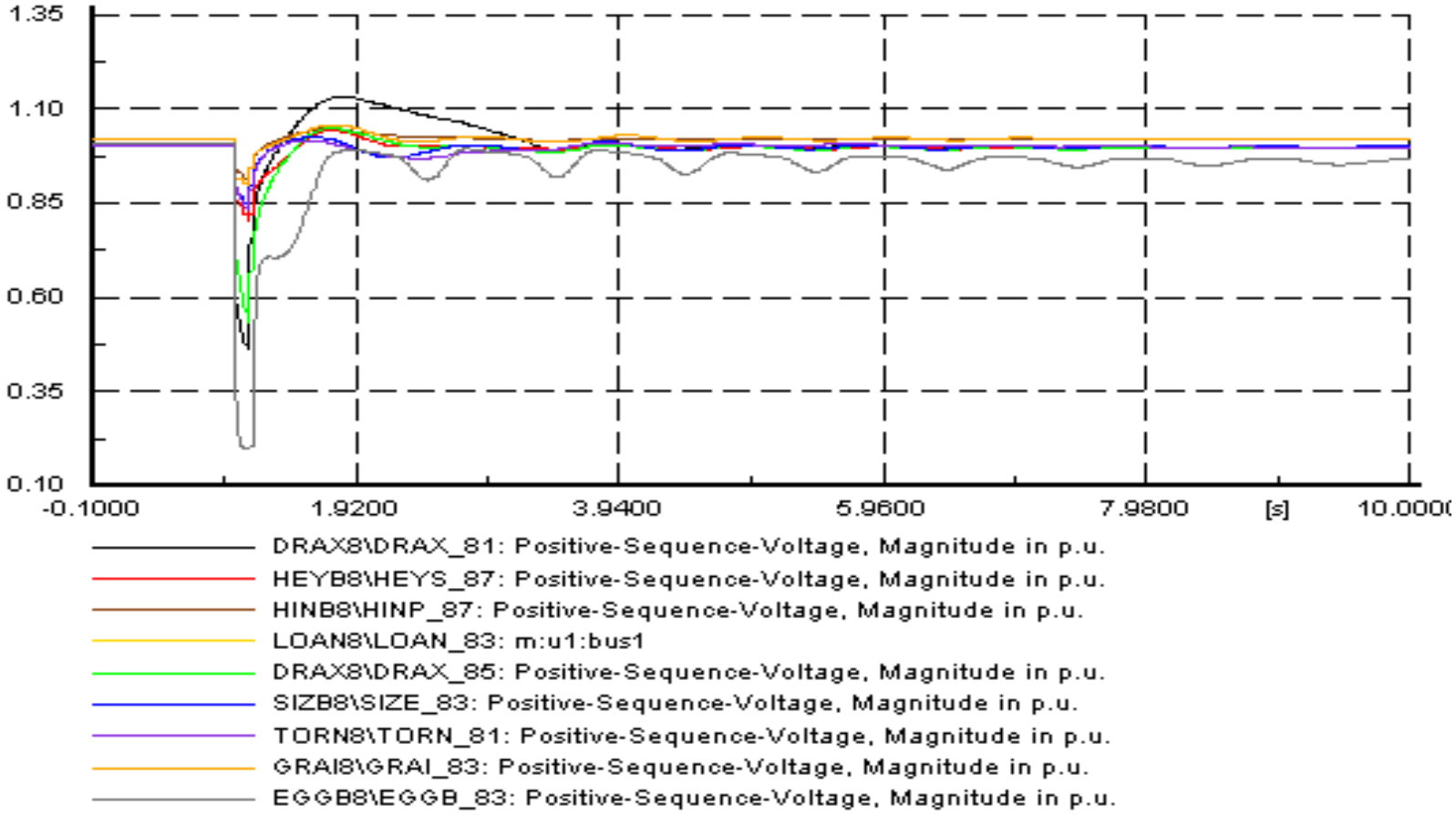
Generator Terminal Voltage
Overvoltage Issues at Seabank – Prior to Modification



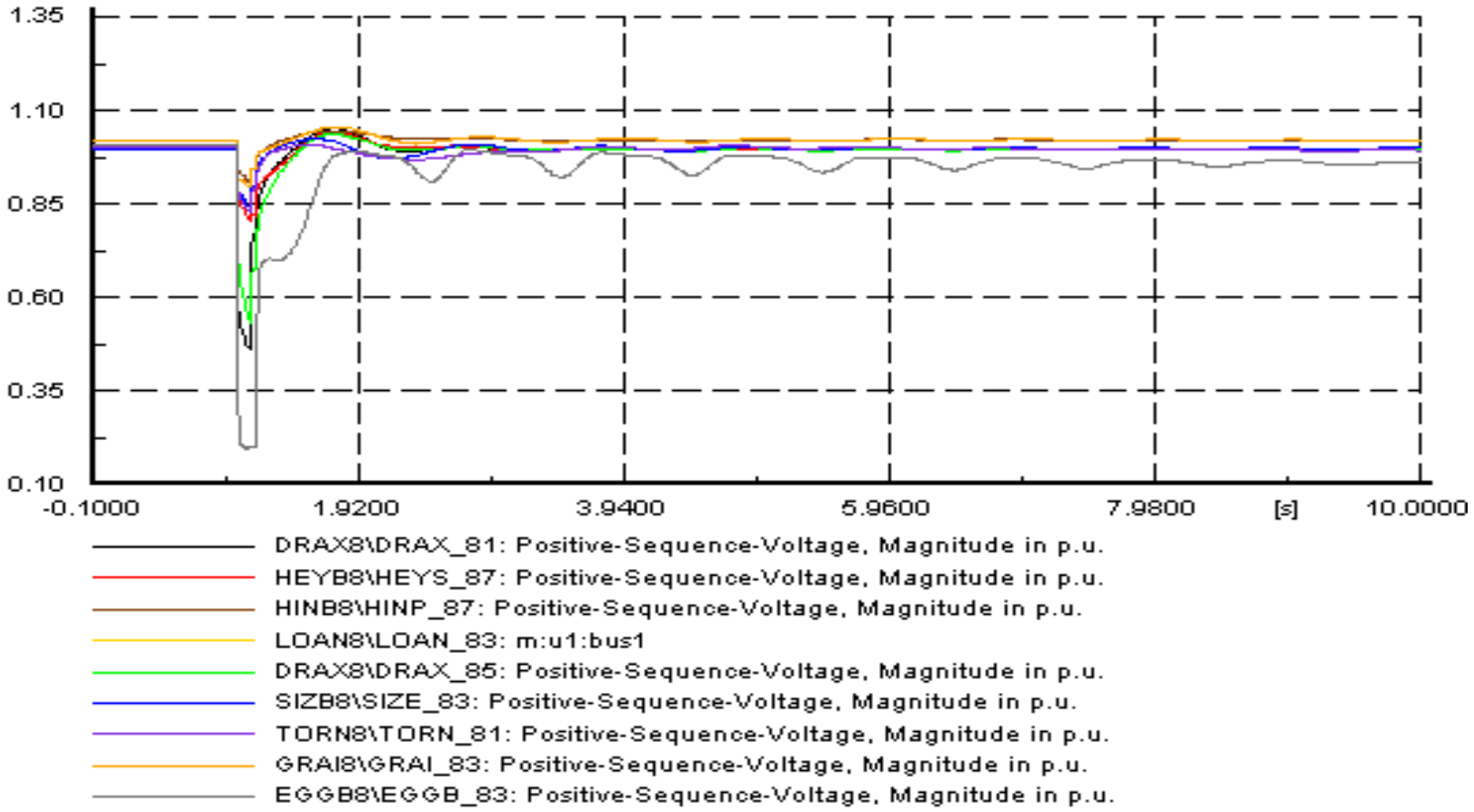
Generator Terminal Voltage
Overvoltage Issues at Seabank – after Modification



Generator Terminal Voltage Overvoltage Issues at Drax / Eggborough – Prior to Modification



Generator Terminal Voltage Overvoltage Issues at Drax / Eggborough – After Modification



Winter Peak Study

- Full GB Network under 2013 peak demand conditions ~ 54.73GW, 13997MVAr
- Low Non-Synchronous scenario based on 2013 peak conditions as per guidance from Market Operations
- Range of faults applied to strategic parts of the network
  - Drax / Eggborough – worst case
  - Seabank
- Standard fault clearance times applied plus longer duration faults to cater for issues such as backup protection
- Analysis of high impedance faults
- Effect on voltage profile observed.
- Test machines in lagging region of operation
- Studies run in Digsilent Power Factor Factory

Drax – Keadby – Thorpe Marsh, Drax – Thorpe Marsh - Double Circuit Winter Peak

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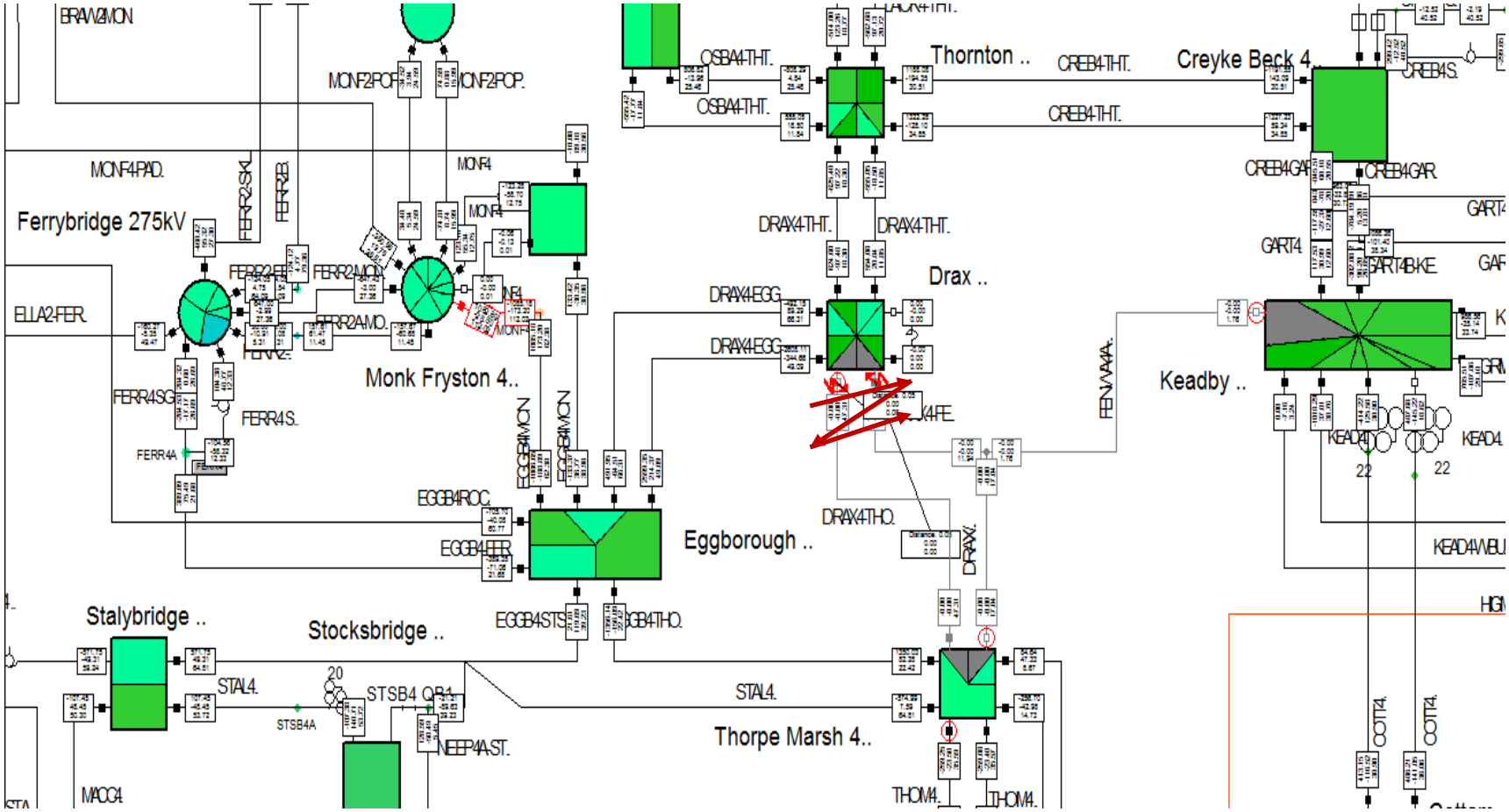
- Solid three phase fault applied on Drax – Keadby – Thorpe Marsh, Drax – Thorpe Marsh double circuit adjacent to Drax. – Worst Case.
- All six Drax machines running
- Drax machines running in the lagging mode pre fault
- Circuit breaker X705 at Drax stuck to model the effect of greater generation loss.
- All breakers on Drax – Keady – Thorpe Marsh, Drax – Thorpe Marsh opened within 140ms except X705 at Drax. X705 cleared by Backup protection which clears Main Bar 2 550ms after fault inception

Drax – Keadby – Thorpe Marsh, Drax – Thorpe Marsh - Double Circuit fault



Drax – Keadby – Thorpe Marsh,
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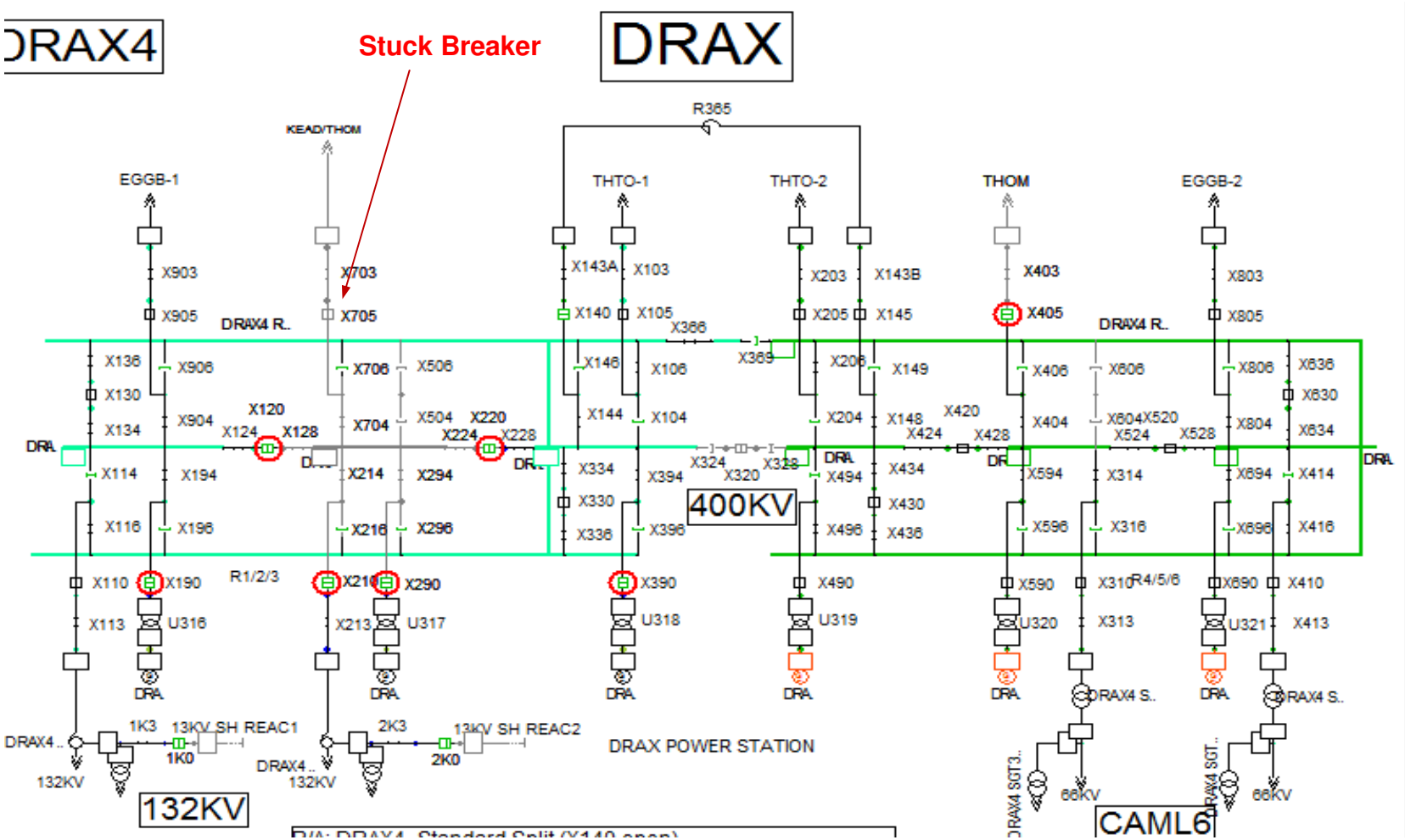
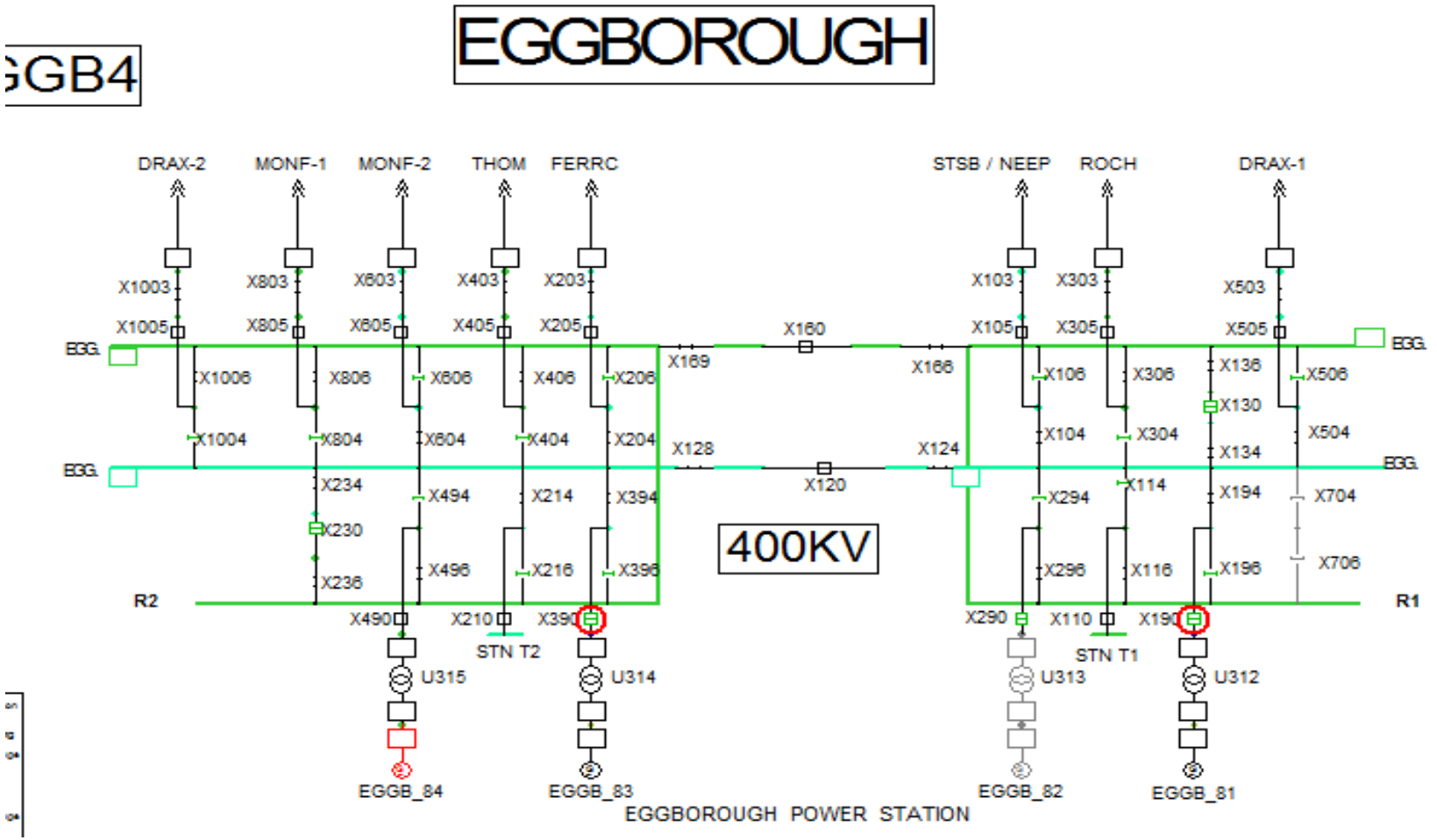


Drax – Keadby – Thorpe Marsh, Drax – Thorpe Marsh - Double Circuit fault



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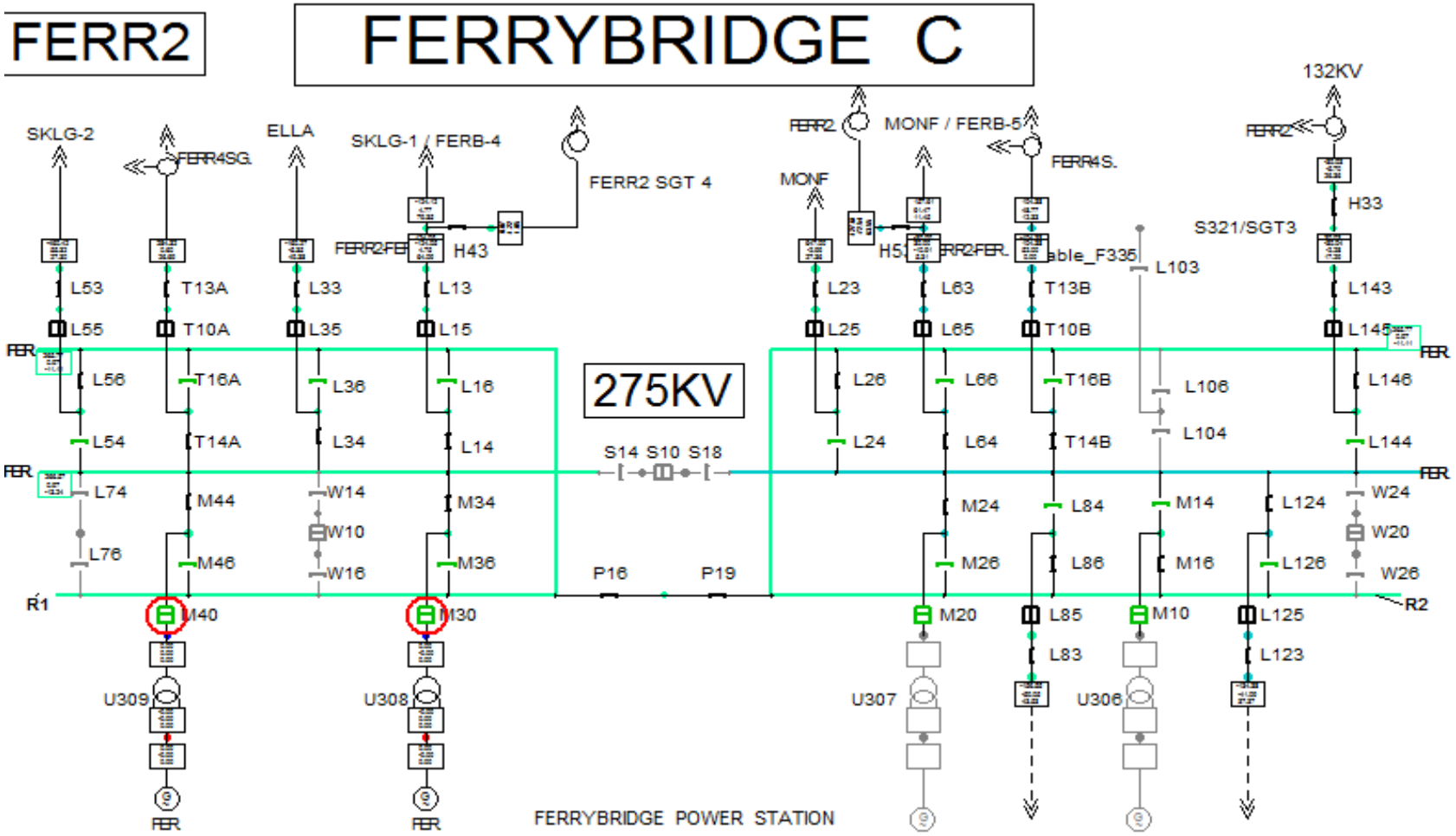

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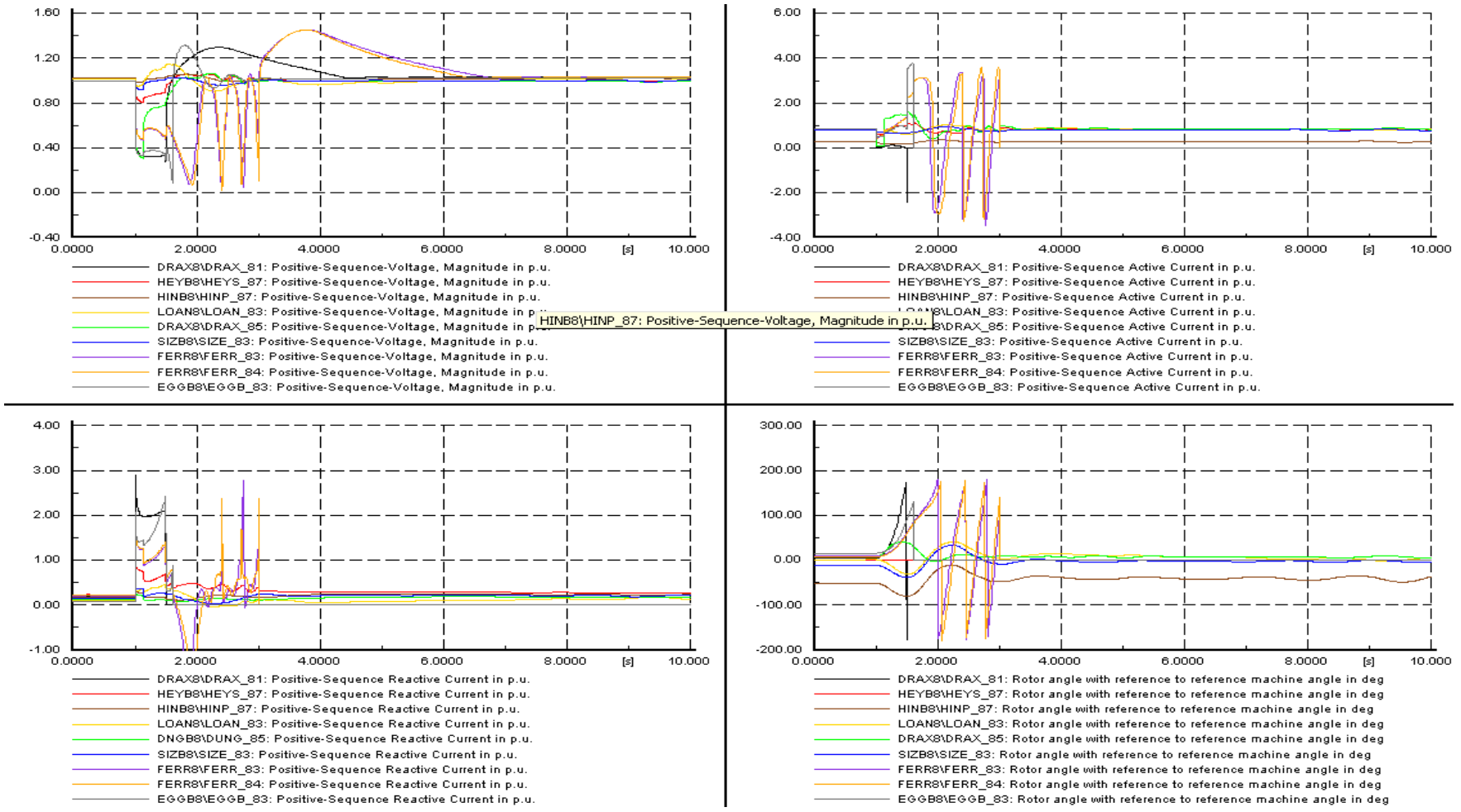

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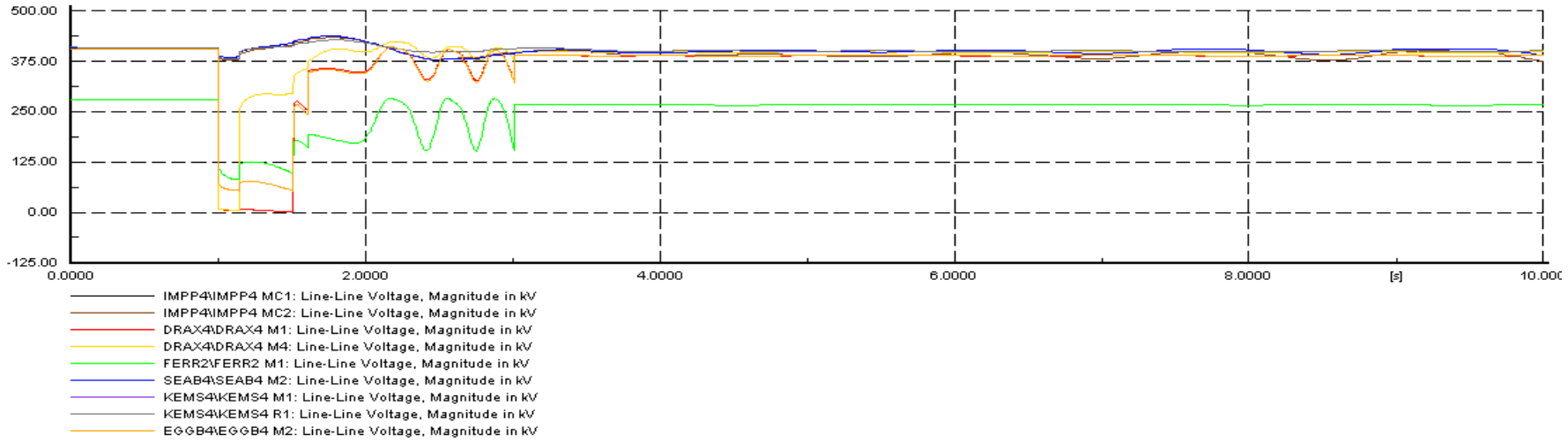

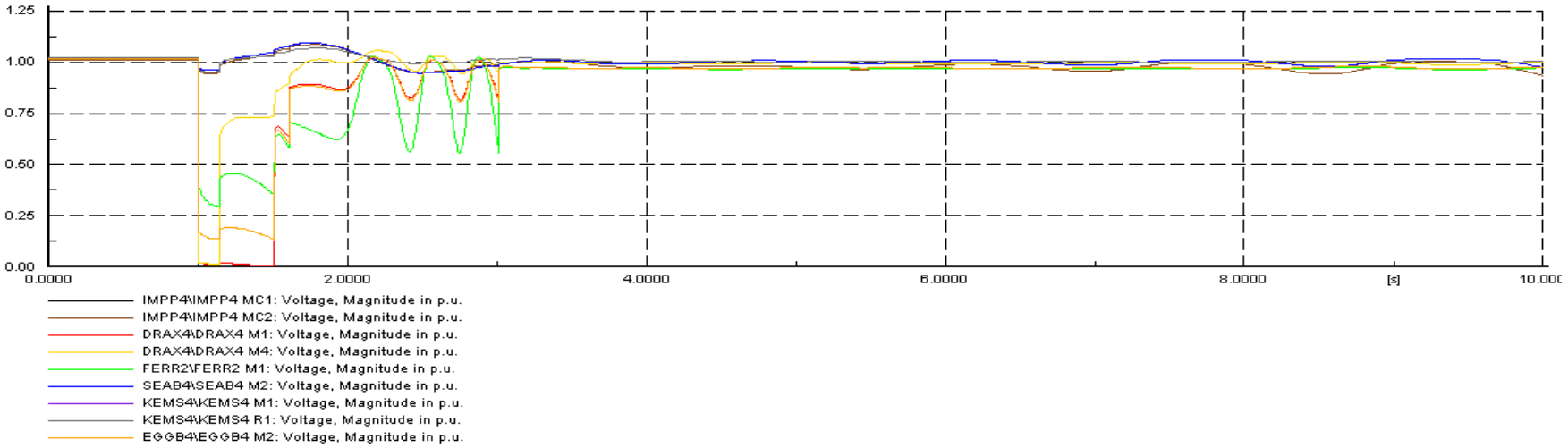

Drax / Eggborough - Summary

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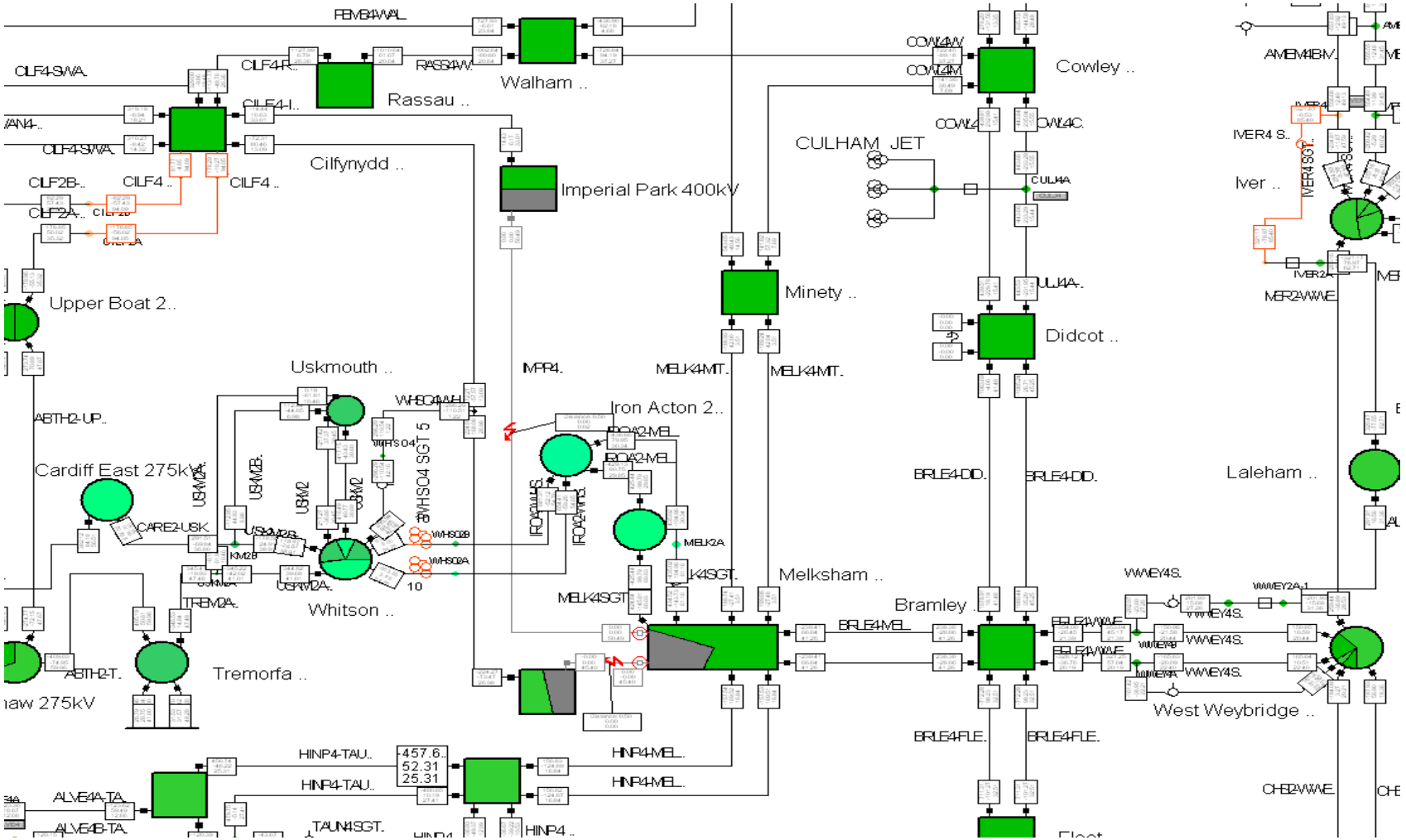
- Very severe fault case
- Loss of approximately 3500MW of Generation. Drax Unit 2 trips due to the stuck breaker
- Drax Units 1 & 3, Eggbrorough Units 1 & 3 and Ferrybridge Units 3 & 4 pole slip
- Generation loss exceeds contigency of 1800MW by 1700MW resulting in loss of low frequency demand disconnection scheme.
- Indicative Voltages observed at Drax Main Bar 1 (MB1) and Main Bar 2 (MB2) recorded at 0p.u for 140ms and MB1 - 0.71 p.u and MB2 - 0.02 p.u at 200ms.
- At 200ms the retained voltage at Eggborough was recorded as 0.68 p.u and the voltage at Ferrybridge was recorded at 0.51 p.u until clearance of the fault.
- For remote machines no significant issue observed

Seabank – Melksham,
Melksham – Imperial Park Disturbance - Winter Peak

- Disturbance applied to Seabank – Melksham, Seabank Imperial Park double circuit.
- Effect was to observe a zero retained voltage for 140ms adjacent to Seabank and then increase the retained voltage to 0.5p.u for both 500ms and 700ms.
- All Seabank machines running
- Seabank machines running in the lagging mode pre fault
- Circuit breaker X205 at Seabank and effect on adjacent Generation observed
- Study results are shown for the 500ms case.

Seabank – Melksham, Melksham – Imperial Park Disturbance



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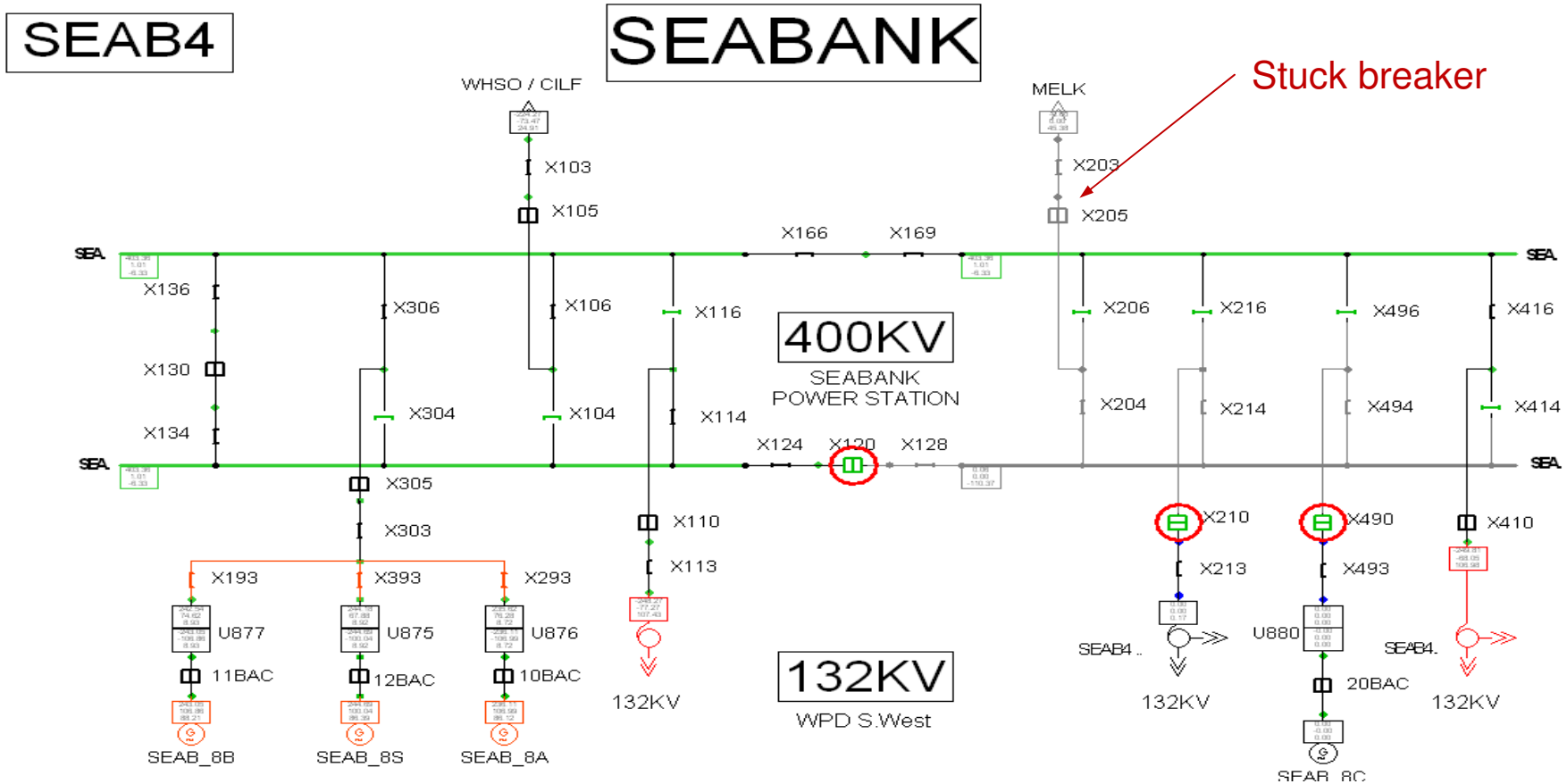
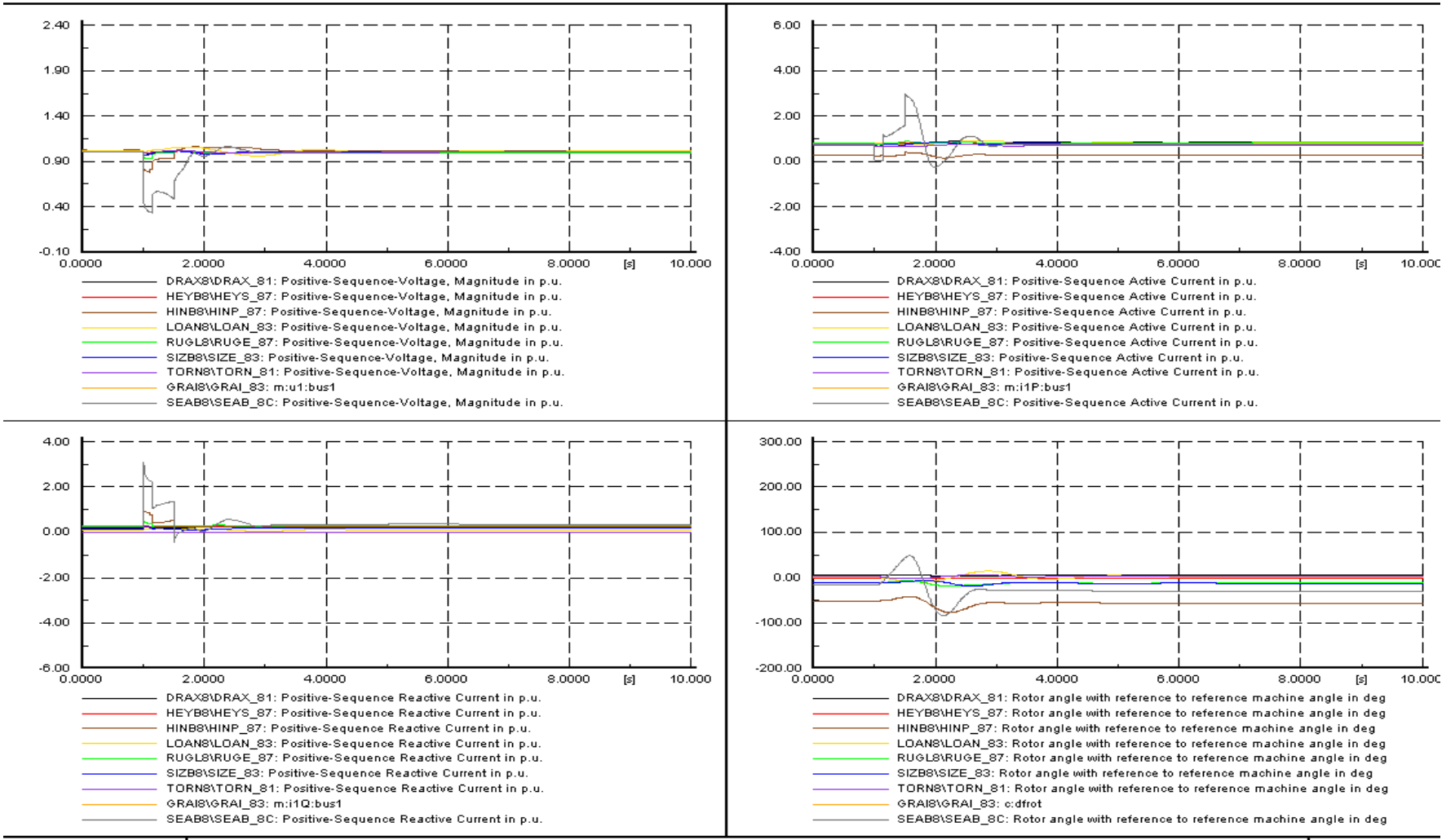


Seabank – Melksham, Melksham – Imperial Park Disturbance



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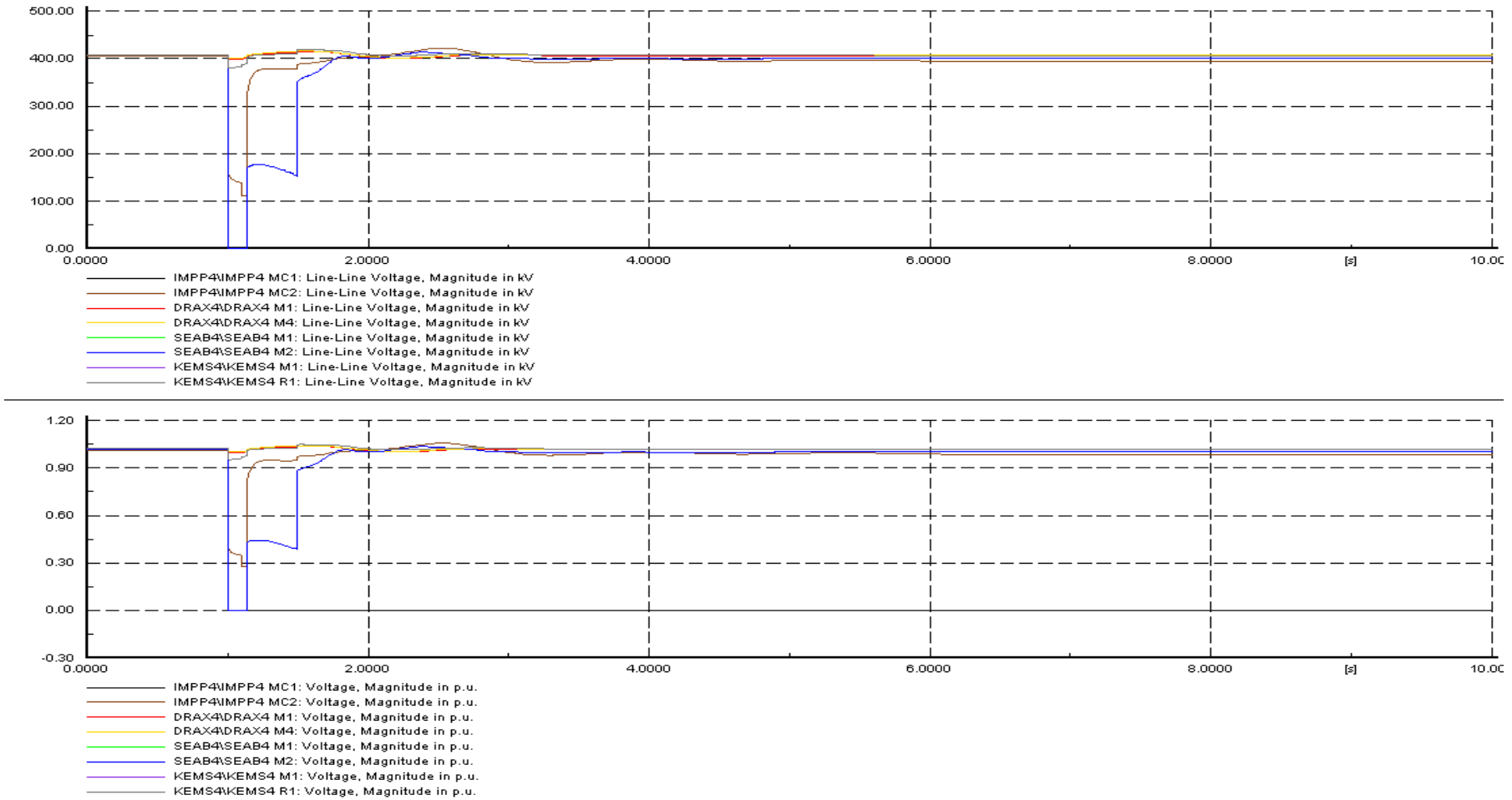

Seabank - Summary

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- For a zero retained voltage fault at Seabank for 140ms and a retained voltage of 0.5p.u for 410ms (total fault clearance time of 550ms) all the Seabank machines survived.
- For a zero retained voltage at Seabank for 140ms and a retained voltage of 0.5p.u for 560ms (total fault clearance time of 700ms) pole slipping was observed.
- For a low impedance, long duration fault (circa 500ms) and standard running arrangements under winter peak conditions, a fault on the Seabank - Melksham circuit this could leave 750MW of GGCT plant feeding down one circuit resulting in potential stability issues.
- Under worst case conditions, a maximum of about 1200MW could be lost at Seabank. This would not exceed the 1800MW loss catered for under the SQSS.

Additional Studies Sensitivities

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- To understand the effect on System Voltage a number of both multi and single machine studies were run at both Seabank and Drax / Eggbrough. The single machine study was important to ensure they were representative of the multi machine study
- In all cases, comparisons were made between the single machine and multi machine studies to gauge results.
- (1) Zero p.u retained voltage at the HV Generator terminals for 140ms with the Generator in the full leading mode and pre / post fault voltage set to 1.0p.u
- (2) 0.4p.u retained voltage at the HV Generator terminals for 270ms with the Generator in the full leading mode and pre / post fault voltage set to 1.0p.u
- (3) 0.5p.u retained voltage at the HV Generator terminals for 700ms with the Generator in the full leading mode and pre / post fault voltage set to 1.0p.u
- (4) 0.68p.u retained voltage at the HV Generator terminals for 1000ms with the Generator in the full leading mode and pre / post fault voltage set to 1.0p.u
- (5) 0.85p.u retained voltage at the HV Generator terminals for 10s with the Generator in the full leading mode and pre / post fault voltage set to 1.0p.u
- Both Seabank and Eggborough machines past all the tests.

Additional Studies Sensitivity Results (1)

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- Conditions (1) to (5) were run on all the Seabank and Eggborough machines both in the single and multi machine studies and a good comparison was achieved between the two.
- The single machine models used the same controllers and Generator Transformer models as the multi machine studies
- Further analysis was undertaken and the tests were repeated with various additional more onerous conditions to establish at what point pole slipping occurred.
- All studies were rerun on both machines (single and full system) for the following additional cases.
  - Tests (1) – (4) but returning to 0.9p.u – All passed
  - Tests (2) – (5) with additional 140ms at 0p.u – problems occurred on test (3)
  - Fault impedance was halved to further reduce the voltage – in some cases machines pole slipped and the fault impedance was then increased to determine the limit
- In addition to the above we also looked at the effect of increasing the impedance between the machine and system.

Additional Studies Sensitivity Results (2)

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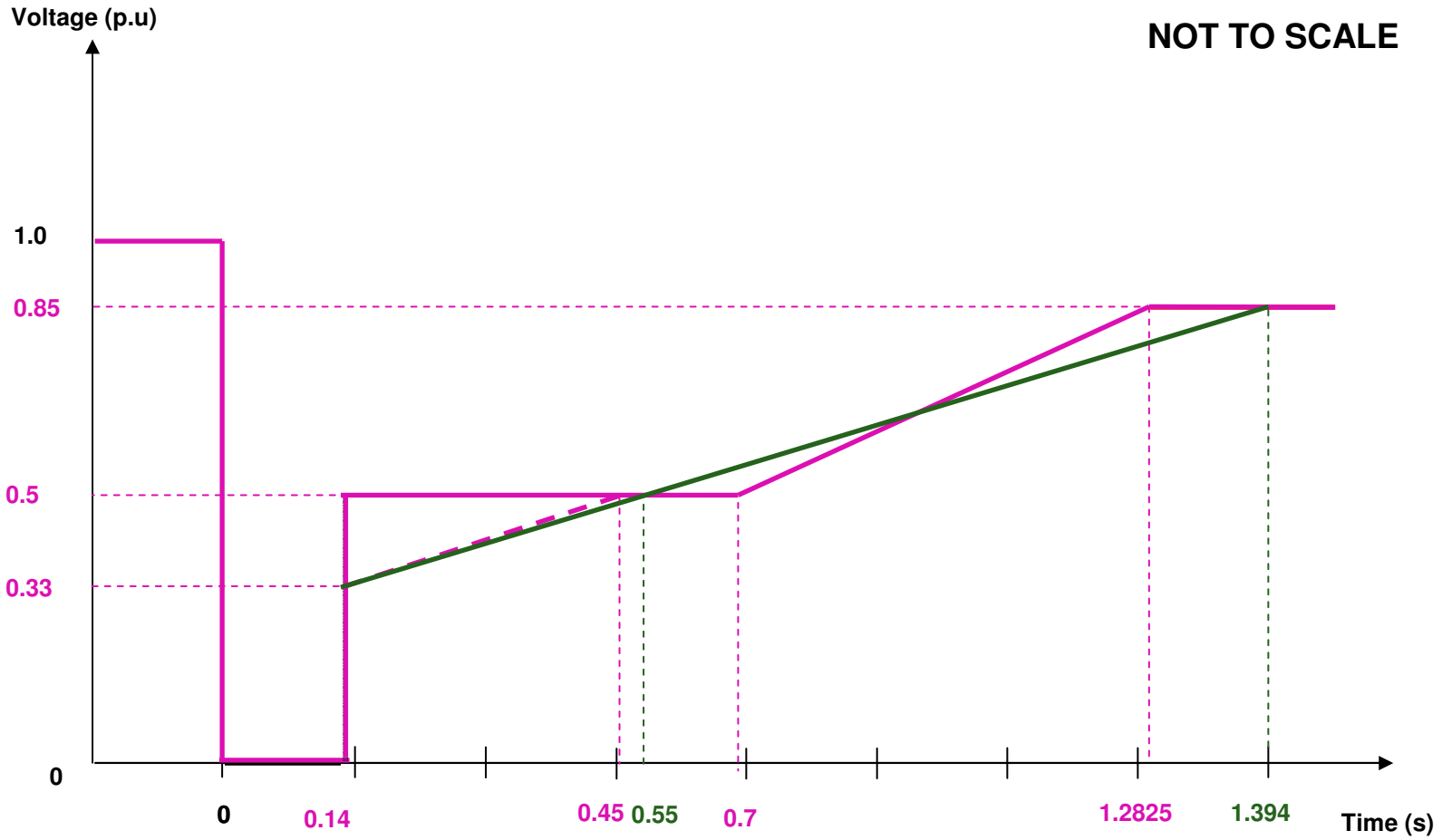
- Additional studies were assessed by adjusting the fault impedance to identify at what point the Generation under test would not pole slip.
  - 10s at 0.58p.u volts (Seabank) and 0.69p.u (Eggborough)
  - 1 second at 0.48 p.u (Seabank)
  - 270ms at 0.23p.u (Seabank) and 0.22p.u (Eggborough)

  Three tests resulted in pole slipping so additional impedance was added until a stable result was achieved
  - 1s at 0.42 to 0.51p.u (Eggborough)
  - 700ms at 0.42 to 0.47 (Seabank) and 0.39 to 0.45 p.u (Eggborough)
- Effect on auxiliaries needs to be assessed
- NGET can provide an equivalent single machine study for this purpose

ENTSO-E RfG - Voltage Duration Profile – Study Results



Summary

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- Significant additional study work completed
- Actions addressed as discussed at the last meeting
- Some further consideration needs to be given to the period between 550ms – 700ms for a retained voltage of 0.5p.u – reflected in additional voltage against time curve
- National Grid to undertake further sensitivity studies in respect of load models and pinch points on the System
- Input required from Generators and manufacturers in respect of station auxiliaries

Discussion