TRANSPOWER

Rules aren’t made to be broken, but let's test the status quo

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Outline

The assets

The status quo (switching policy)

Testing the status quo

Results and analysis

Outcomes – the new status quo

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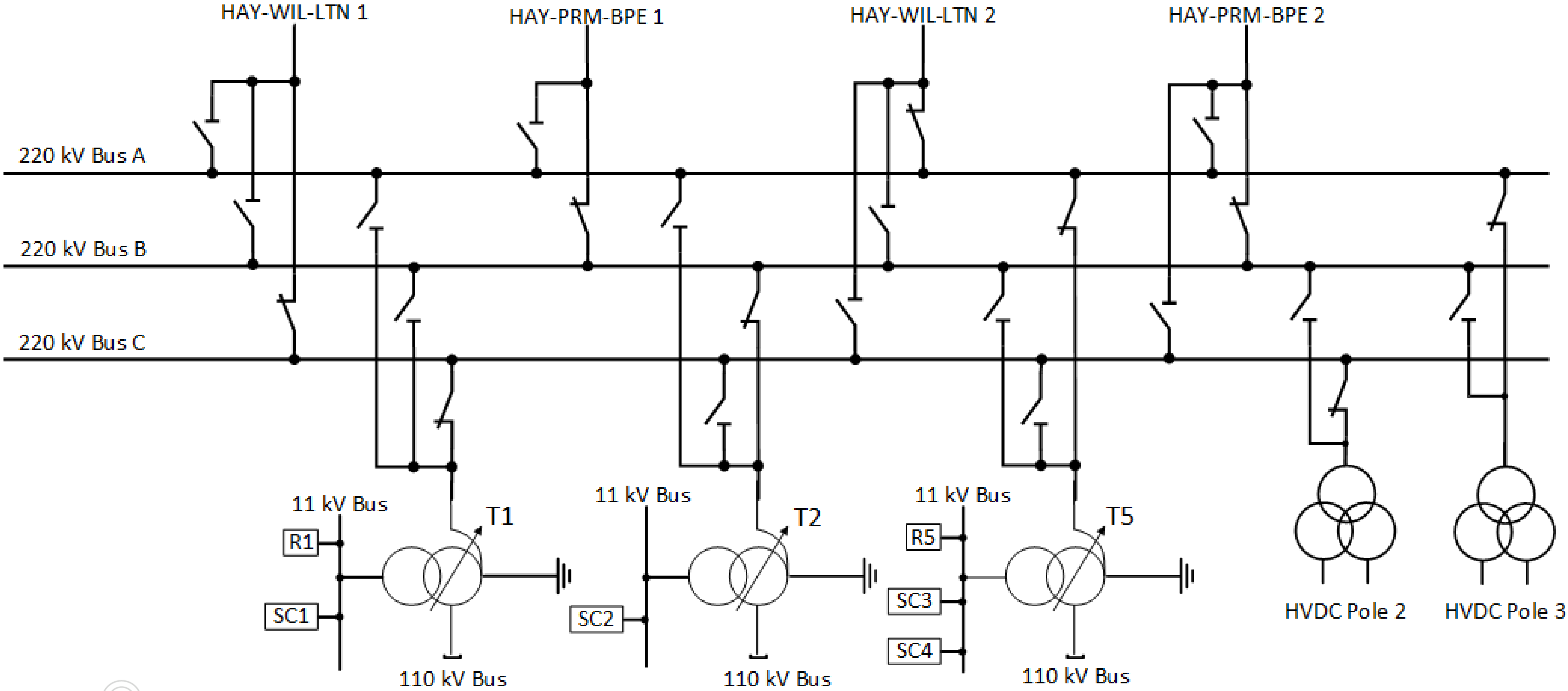
Haywards 220 kV Bus - simplified



Haywards interconnector transformers

T5

220/110/11 kV

200/233/243 MVA

YNa0d3

Transpower policy

- TP.OG 41.07

"Operation of power transformers"

- TP.OG 48.02

"HVDC: Bipole Operating Policy"

2.2 Appendix B - Transformers that have Livening Problems

Note - *Highlighted units in blue are transformers that are planned to be replaced or de-commissioned in the next 12 months*

2.2.1 Transformers with On Load Tap Changers

The following **transformers** with on load tap changers have a previous history of livening problems and therefore have a higher risk of tripping or, tripping other in service **transformers** if they are not livened in accordance with **Sections 6.2 and 6.4**.

Station	Transformer	Tap to be selected for livening	Transformer nominal ratio	Notes
Haywards	T1	1	220/110 kV	Magnetising inrush may trip HVDC link
	T2	1	220/110 kV	
	T5	1	220/110 kV	

6. DISTURBANCES AND TRIPPINGS AFFECTING THE HVDC LINK

6.1 Energising of large transformers

The energising of large transformers can result in high inrush currents and voltage disturbances due to saturation of the transformer core. In particular the energising of the 220/110/11 kV interconnecting transformers at Haywards can cause a significant voltage disturbance which may lead to customer complaints and commutation failures. To minimise the disturbance, the interconnecting transformers must be energised using a separated HAY 220 kV bus section and connected just to BPE via BPE-PRM-HAY 2 (or BPE-PRM-HAY 1). This bus section would usually be Bus B.

Note: *The energising of the BEN and HAY Pole 2 and Pole 3 converter transformers is almost unnoticeable because of the pre-insertion resistors fitted to their circuit breakers.*

Why do we have this policy – documentation

What the policy says:

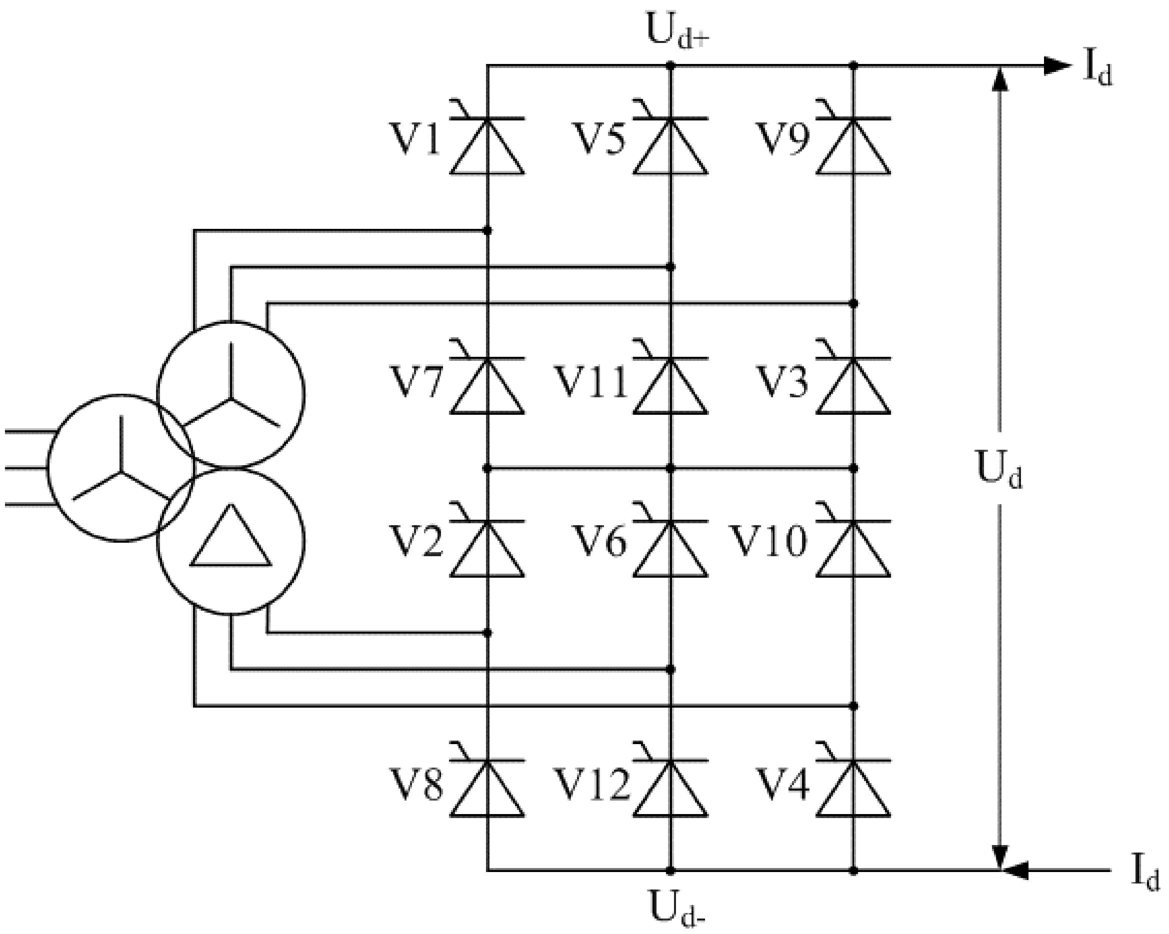
- "…can cause a significant voltage disturbance which may lead to customer complaints and commutation failures…"

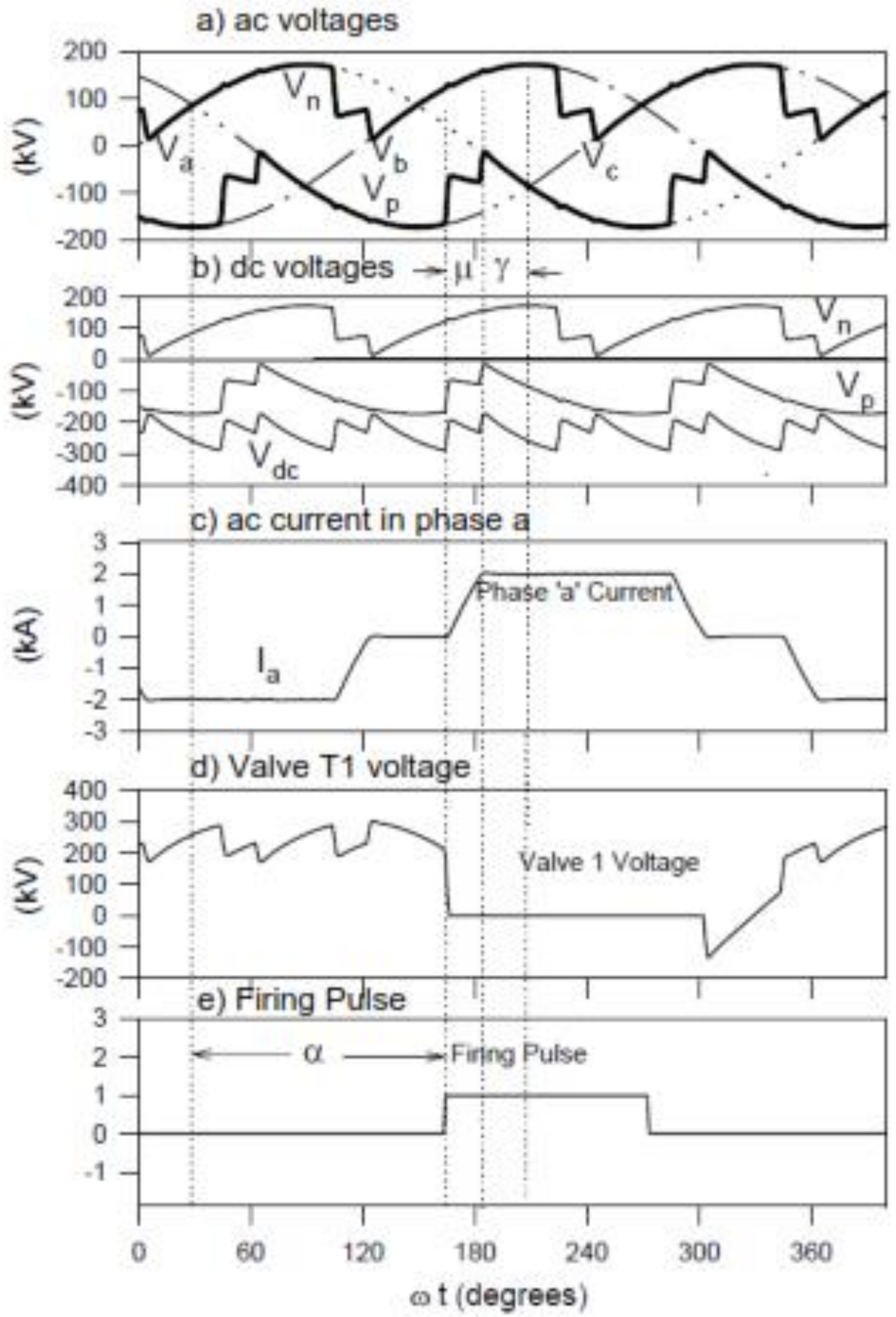
What a SCADA note says:

- "After Pole 2 was commissioned, there were two incidents where Pole 2 tripped when a HAY interconnector was energised… the event charge for a Pole 2/Pole 3 trip can be high …"

How does a transformer trip a Pole?

- Line Commutated Converter





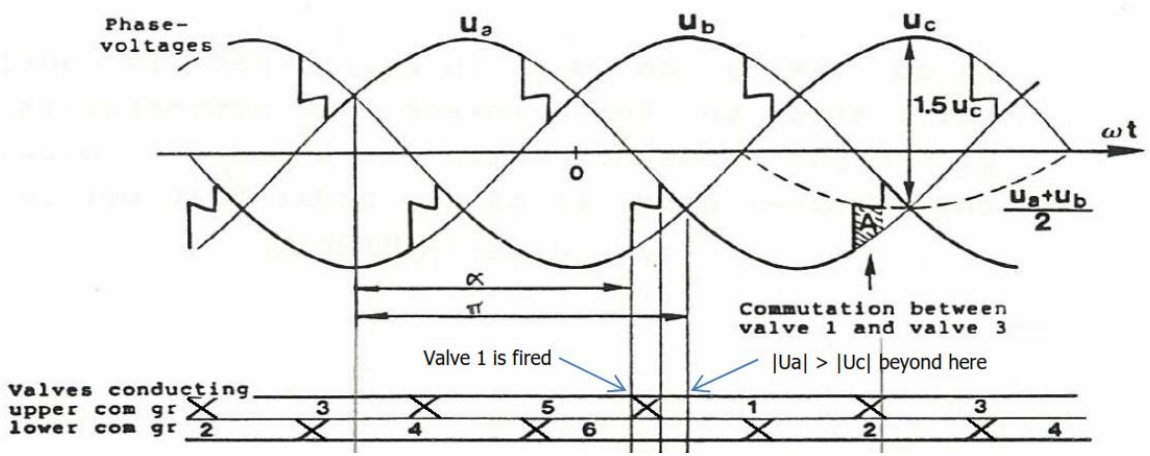
How does a transformer trip a Pole?

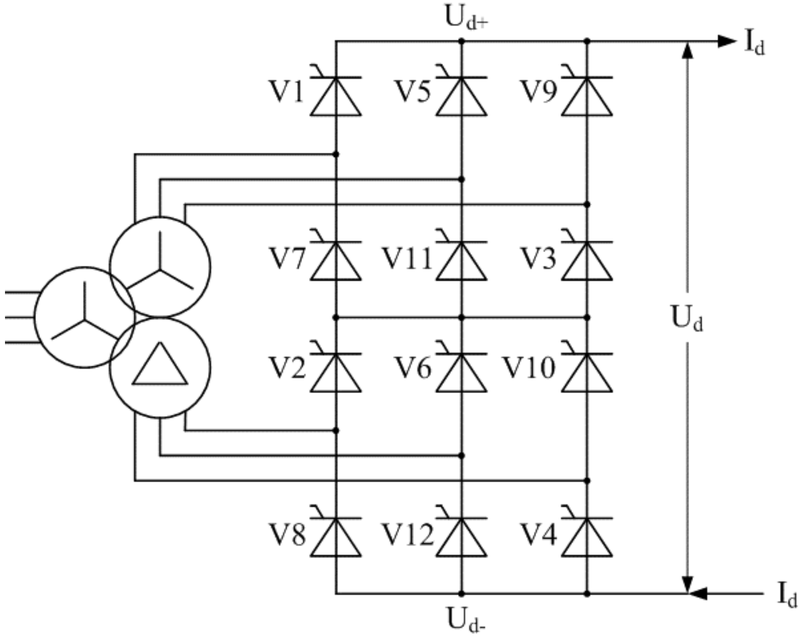
Variables:

- Firing angle, α
- Overlap angle, μ
- Extinction angle, γ

$$\gamma = 180° - (\alpha + \mu)$$

A valve has only a short period (γ) of reverse "recovery" voltage before it must support forward voltage again. Maintaining an adequate extinction angle 'γ' is therefore critical for the thyristors.





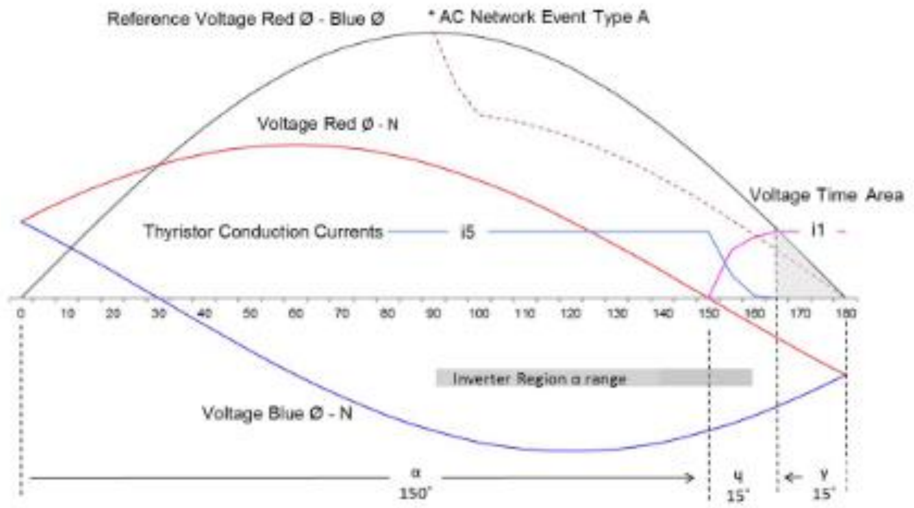
How does a transformer trip a Pole?

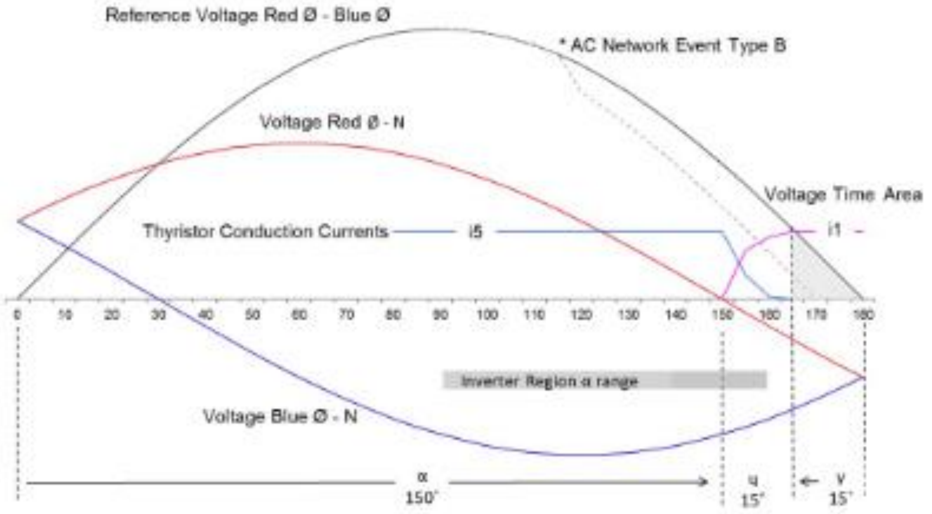
- Inrush current causes reduction in AC bus voltage
- Increase in overlap angle (μ)
- Decrease in extinction angle

$$\gamma = 180° \; - (\alpha + \mu)$$

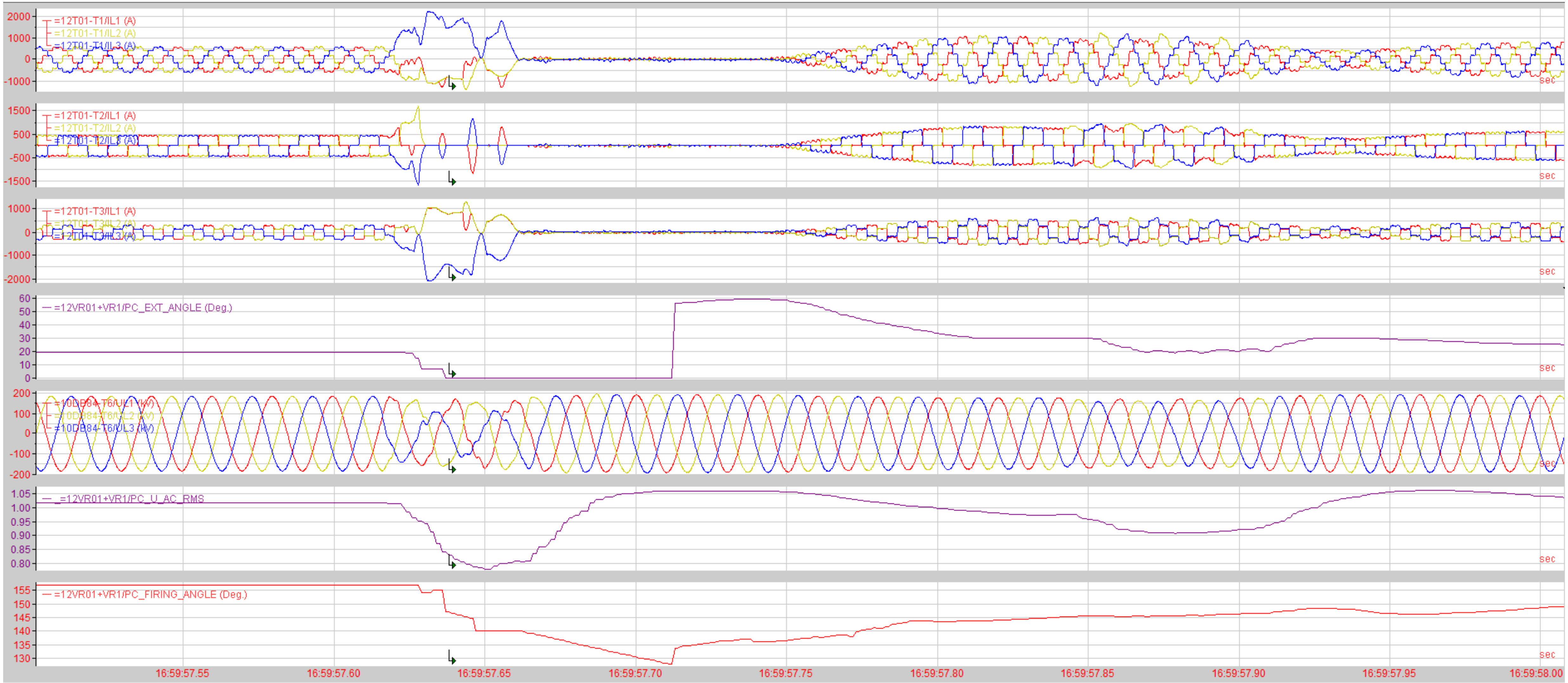
- Thyristor re-ignited
- Commutation failure

Commutation failures happen at the inverter station only.





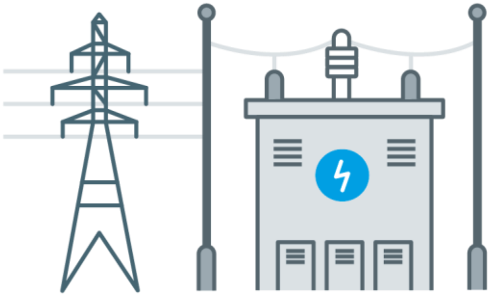
Commutation Fault



Challenges with the energisation policy

Time and cost associated

Risk to assets



Risk to personnel

Risk to power system

Why do we think we can test the status quo?

Challenging procedures is not reason enough!

Energisation policy pre-dates 2006

Then

- Pole 1 Mercury Arc Valves
- Original 1990's control system
- Limited transient event recording

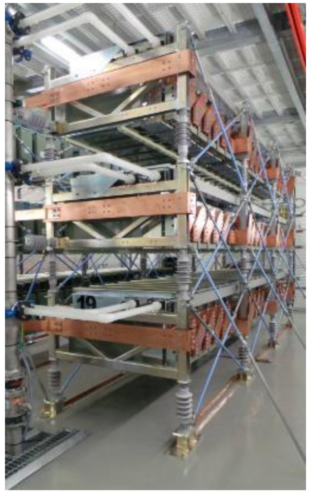
Now

- 2013 Pole 3 installation and Control system upgrade
- 2020 Pole 2 Valve Base Electronics Upgrade
- Haywards STATCOM
- System modelling

= A far more resilient, stable and responsive system

Then…

Now…



= A far more resilient, stable and responsive system

The assets

The status quo (switching policy)

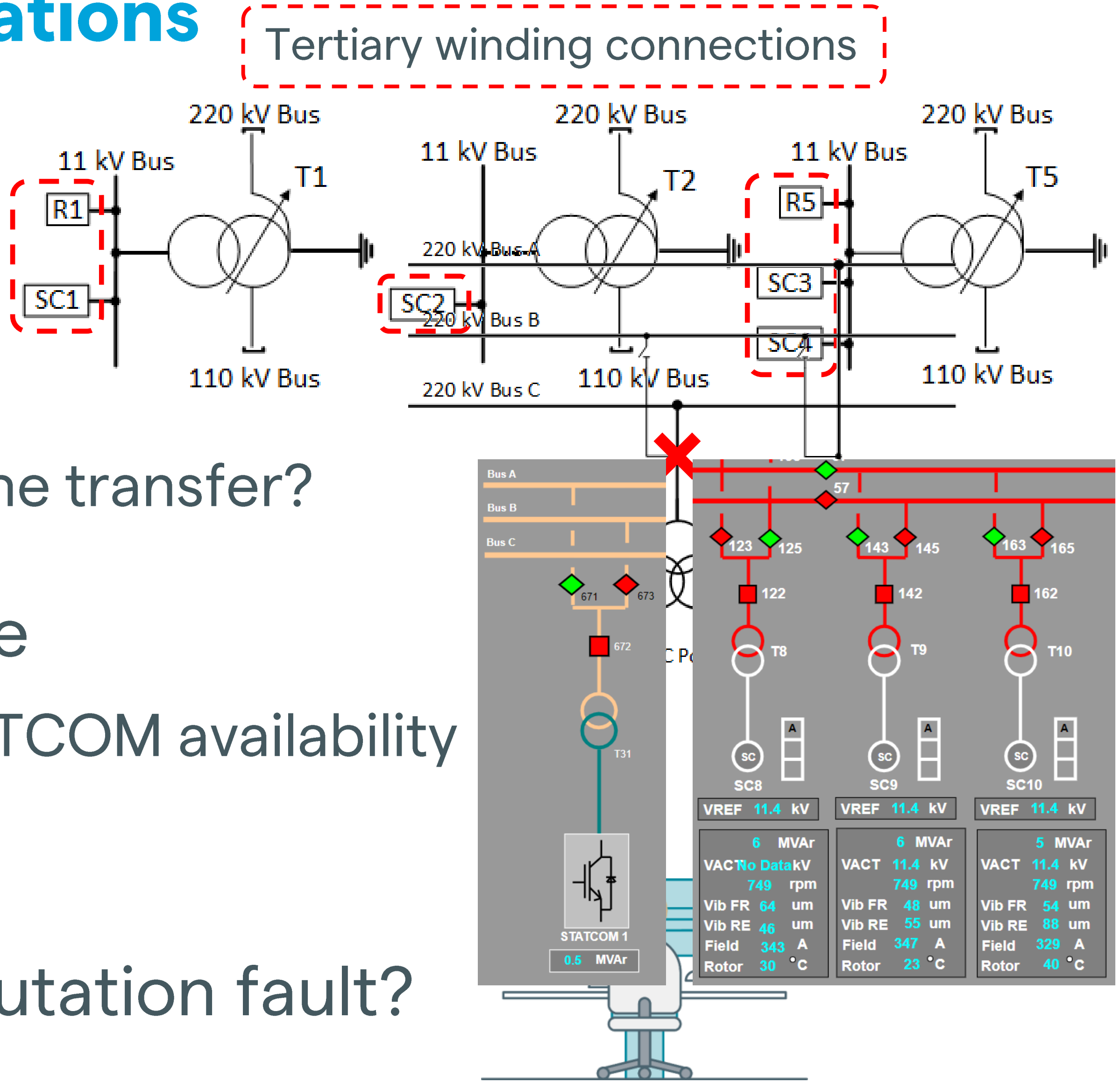
Testing the status quo

Results and analysis

Outcomes – the new status quo

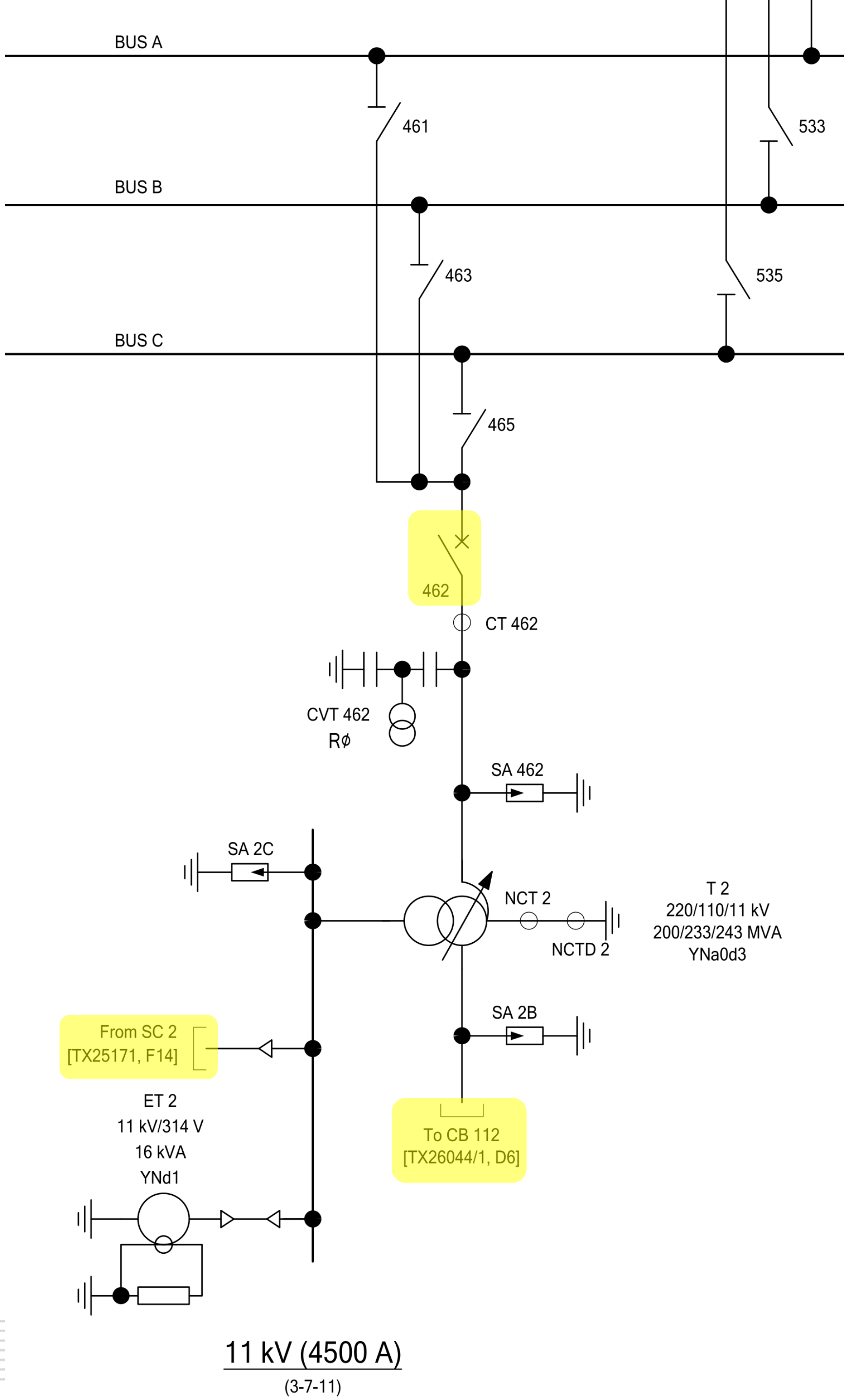
Testing Constraints/Considerations

- Transformer outage impact
- HVDC transfer
  - If Pole 2 trips, can Pole 3 handle the transfer?
- Voltage support available onsite
  - Synchronous condenser and STATCOM availability
- Risk to the HVDC link
  - How close is Pole 2 to commutation fault?



Test Procedure

1. Stop Synchronous Condenser C2 and open breaker.
2. De-energise T2.
3. Close breaker to energise T2.
4. HVDC Engineers confirm proceed/cease.
5. Repeat ten times
6. Return to service.



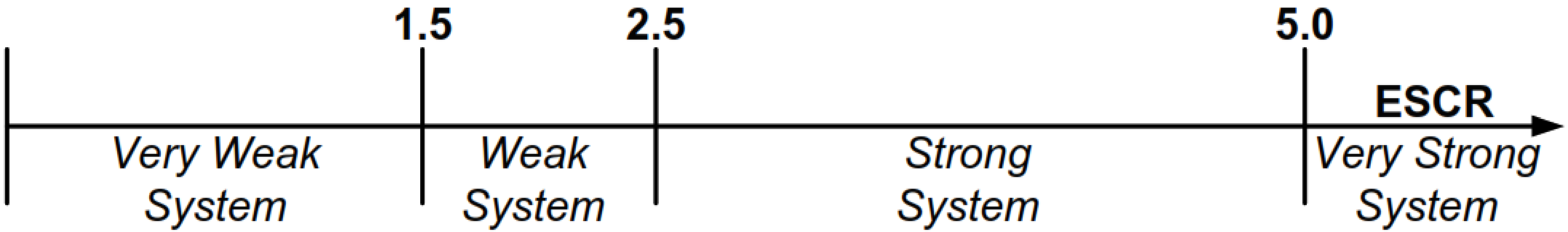
AC System strength and LCC converters

Short Circuit Ratio - Strength of AC system (short circuit MVA Ssc), relative to HVDC power transfer (PDC)

$$SCR = \frac{S_{3phsc}}{P_{DC}}$$

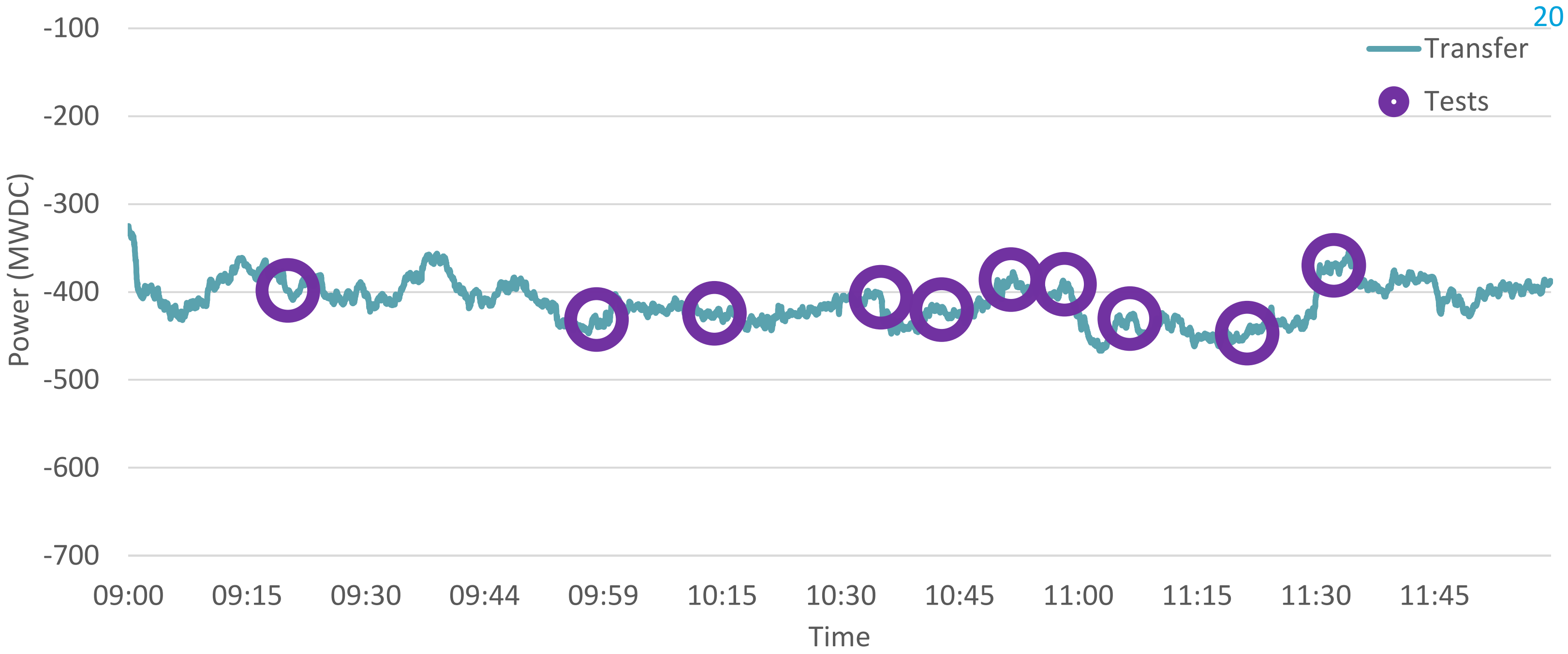
Effective Short Circuit Ratio - Effect of HVDC equipment (AC filters) connected to the AC side

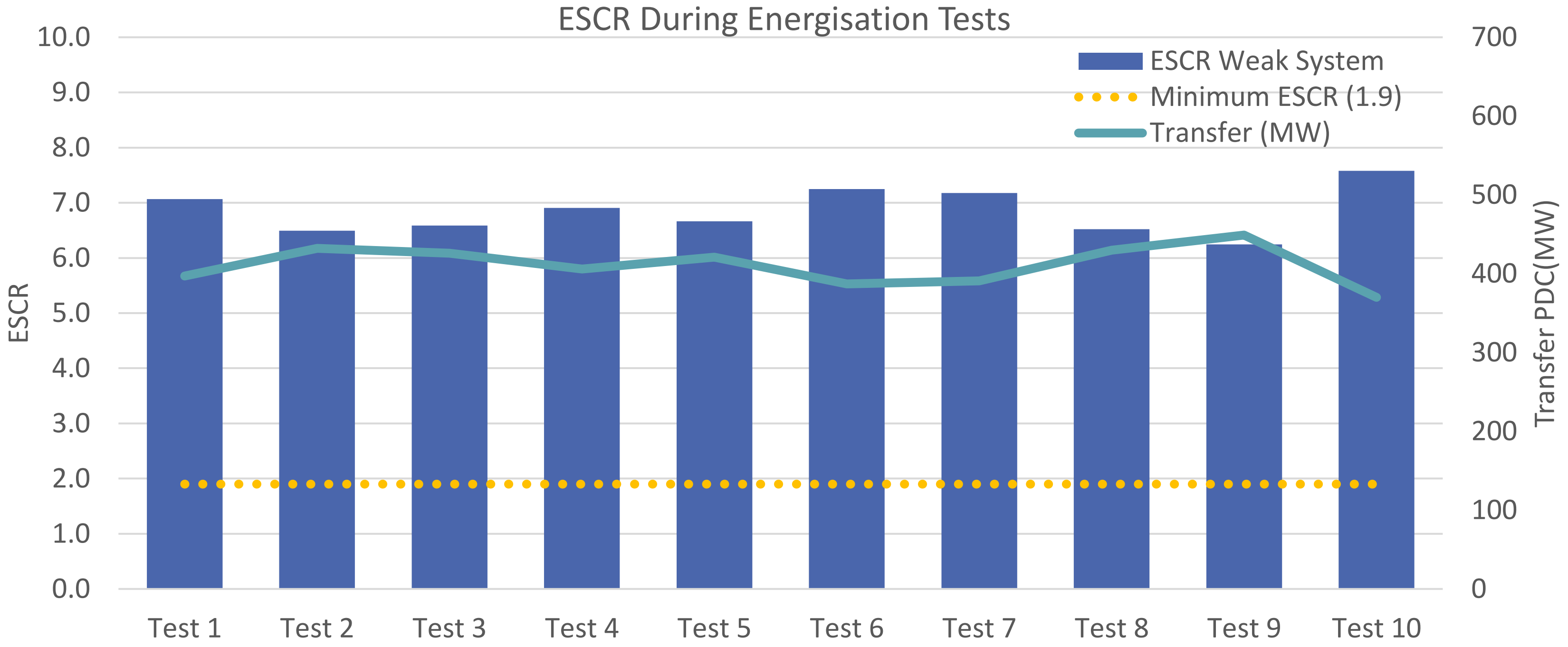
$$ESCR = \frac{S_{3phsc} - Q_{filters}}{P_{DC}}$$



HVDC transfer and ESCR during energisation tests

- Less than ±700 MW transfer
- 7 Synchronous condensers in service
- HVDC operating in Northflow (power flow from Benmore to Haywards)





The assets

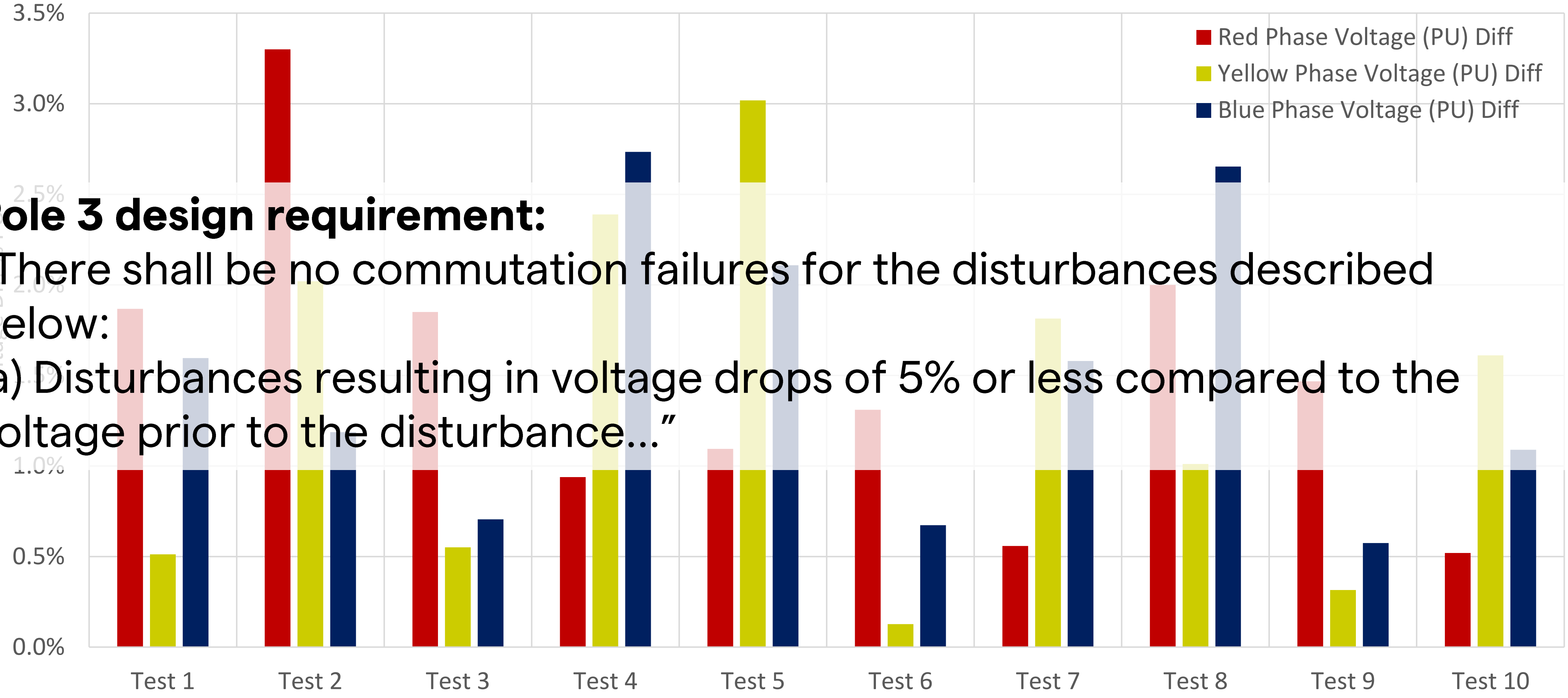
The status quo (switching policy)

Testing the status quo

Results and analysis

Outcomes – the new status quo

Voltage Impact

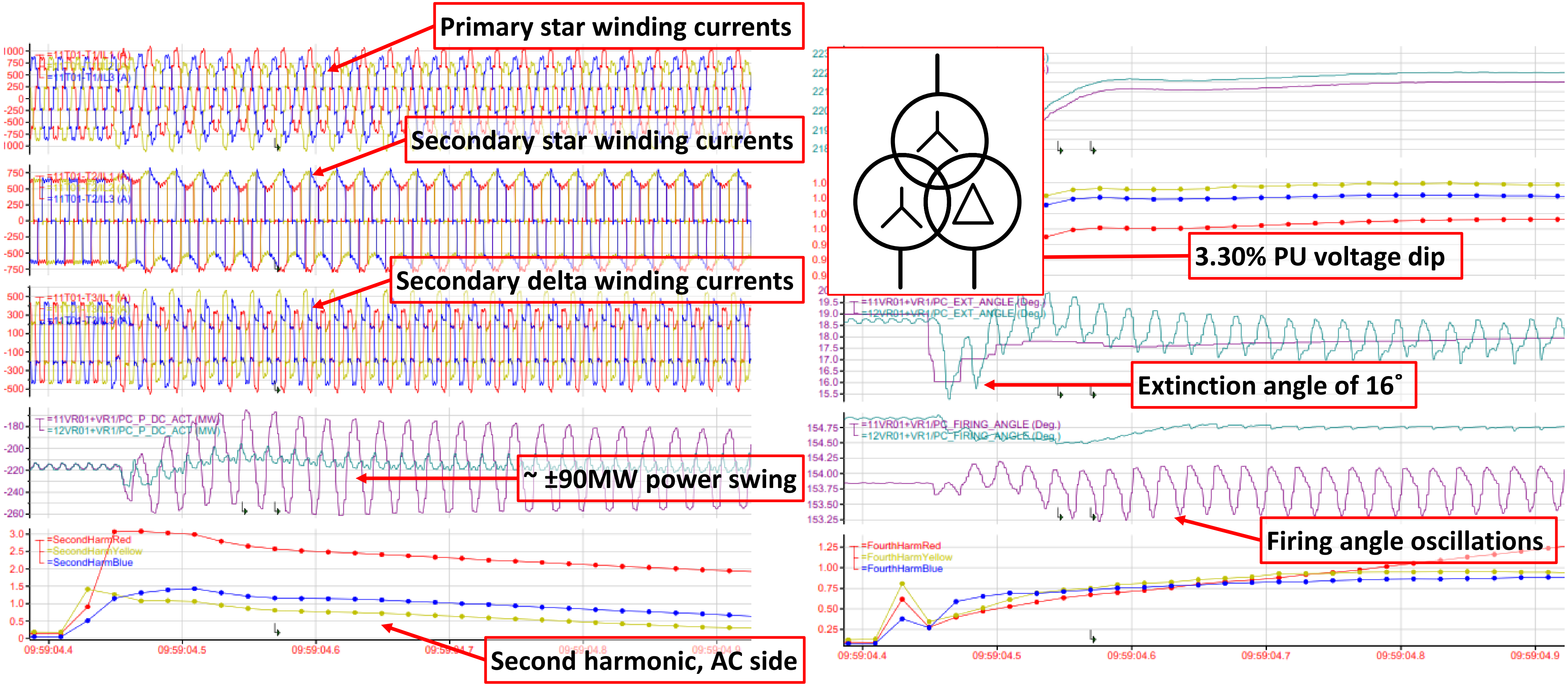


Pole 3 design requirement:

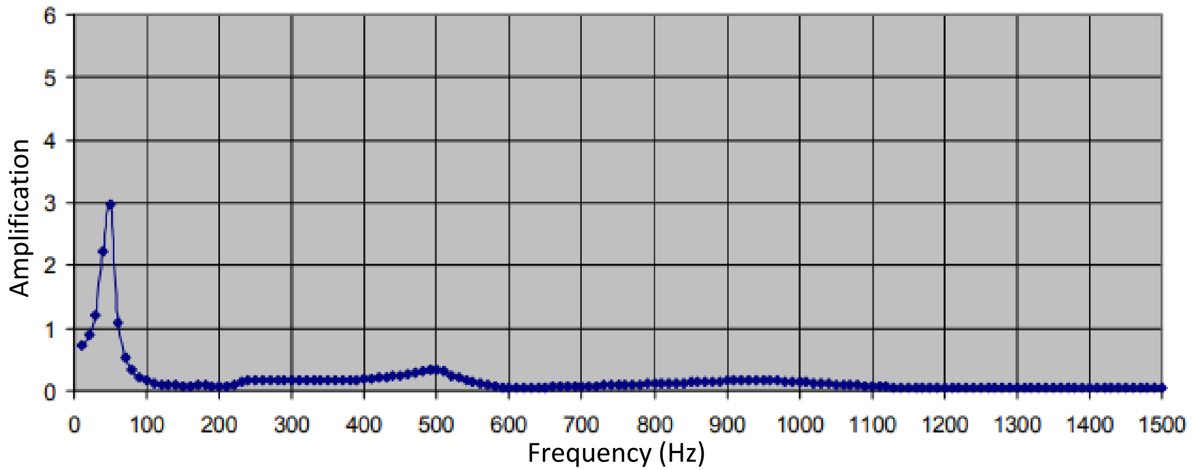
"There shall be no commutation failures for the disturbances described below:

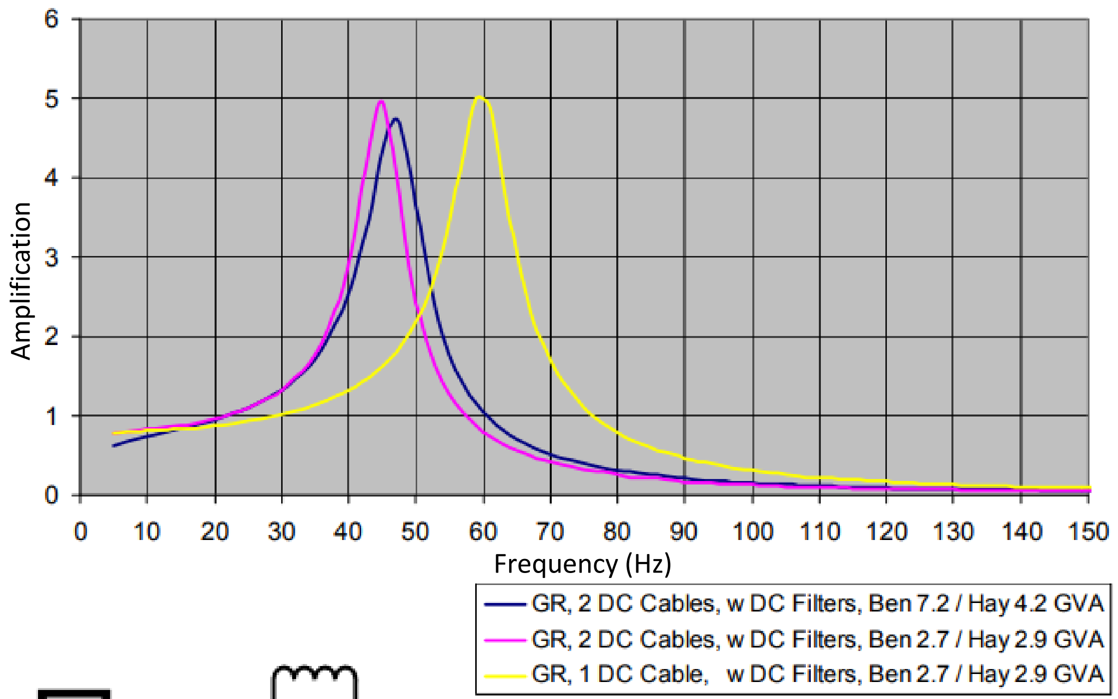
(a) Disturbances resulting in voltage drops of 5% or less compared to the voltage prior to the disturbance…"

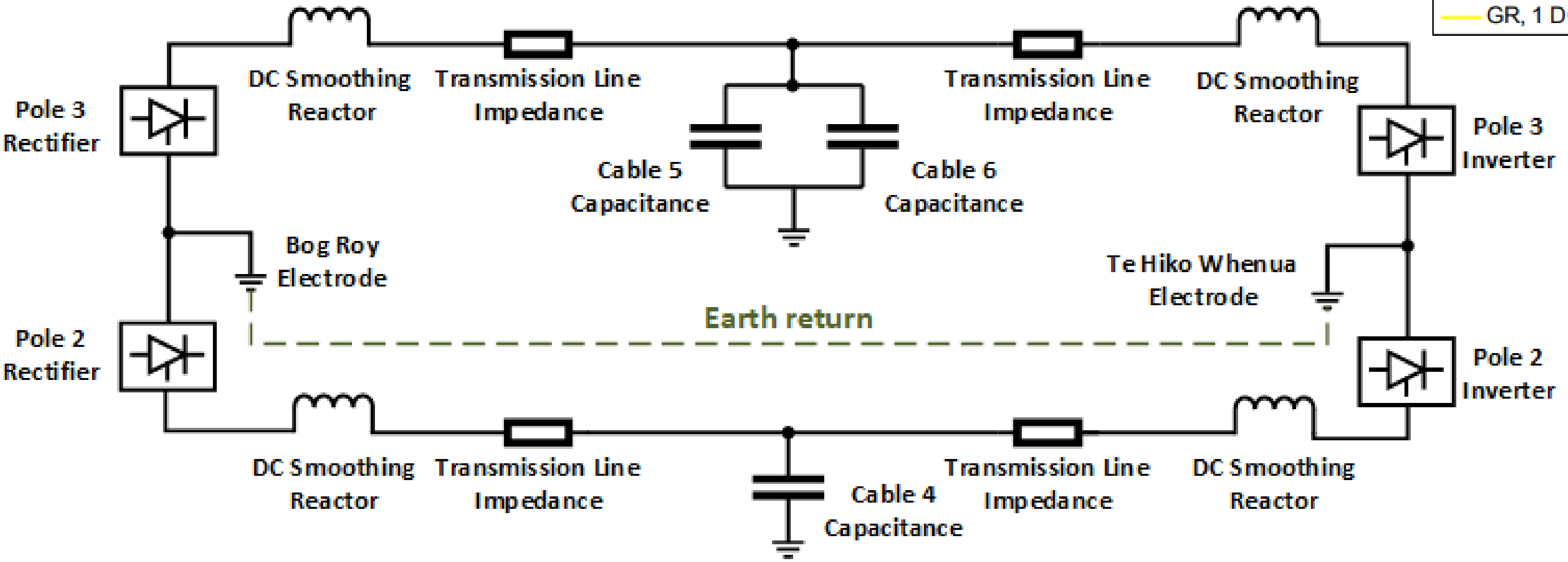
The unforeseen - 50Hz oscillations on Pole 3



50 Hz resonance

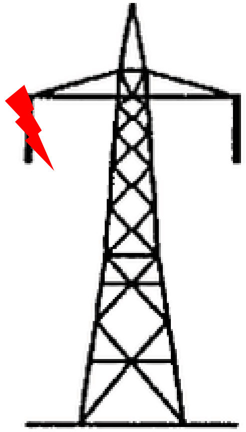




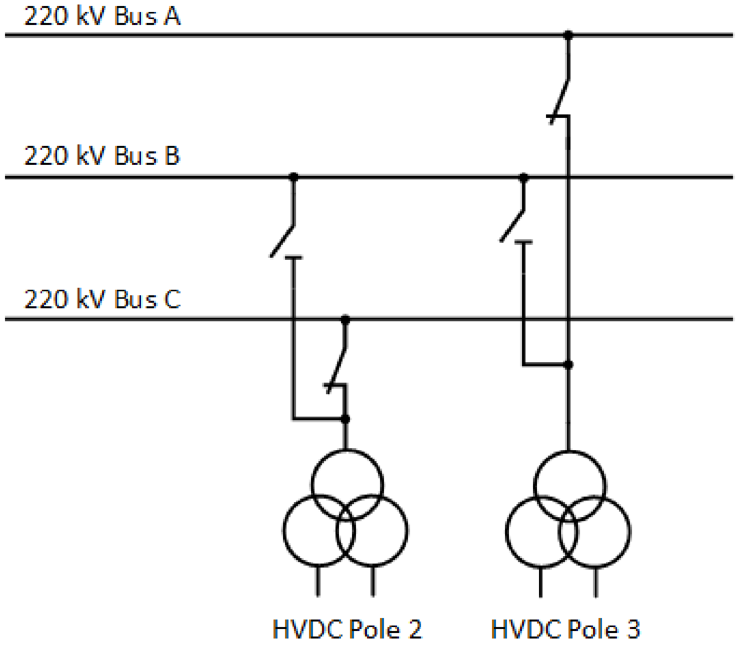


Measuring severity against other events

- DC overhead line fault



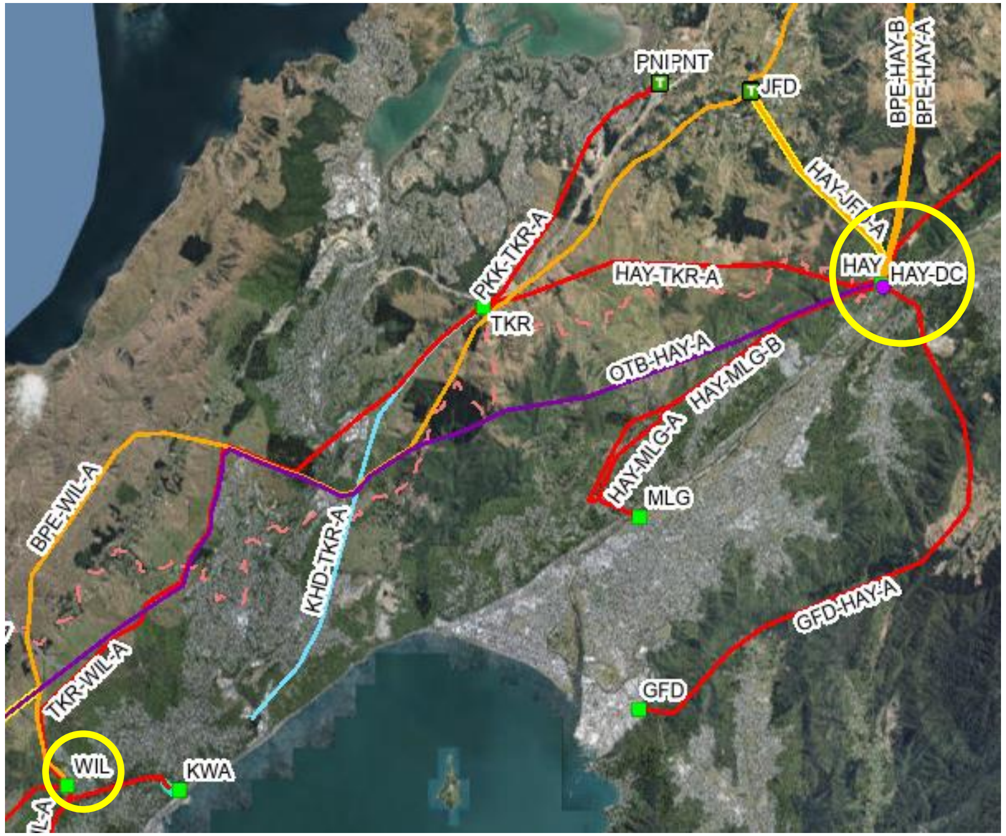
- Pole 2 converter transformer energisation

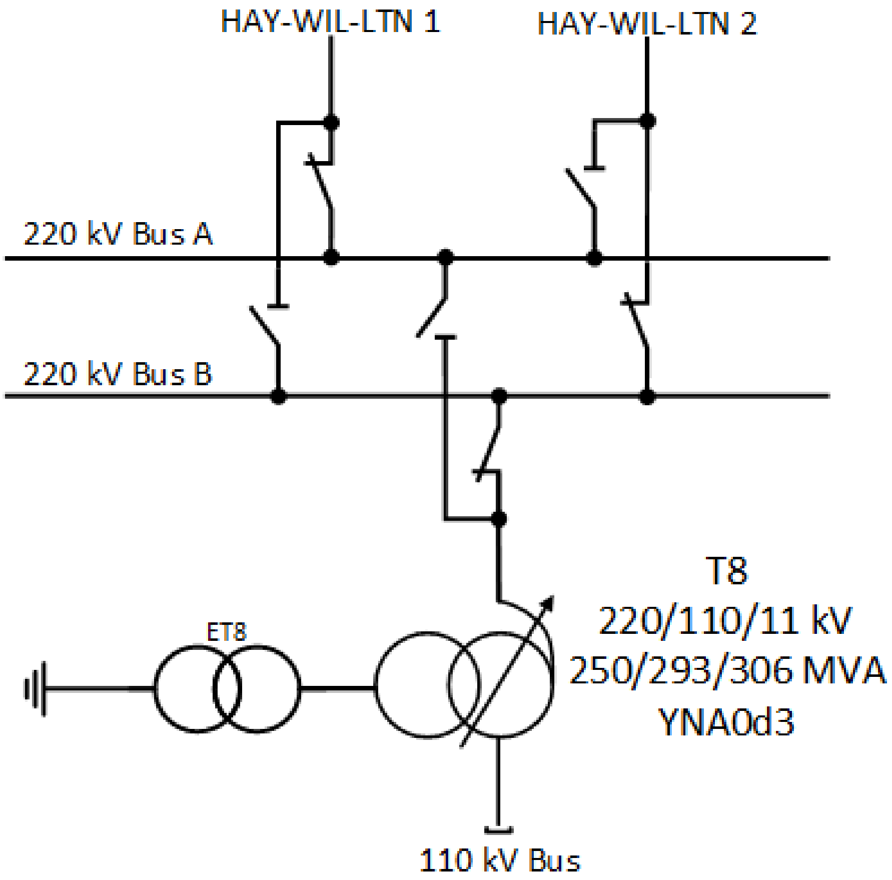


- Wilton T8…

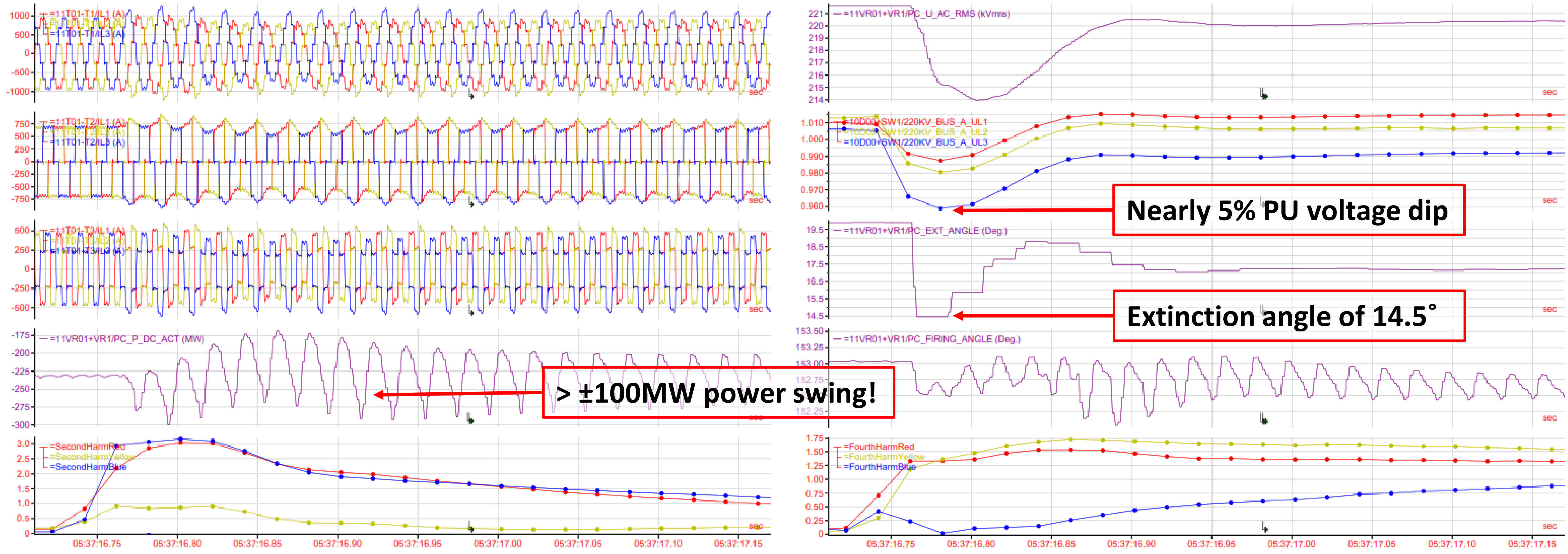
Wilton T8

- Electrically, very close to Haywards
- Larger transformer than the Haywards interconnector transformers
- No switching policy

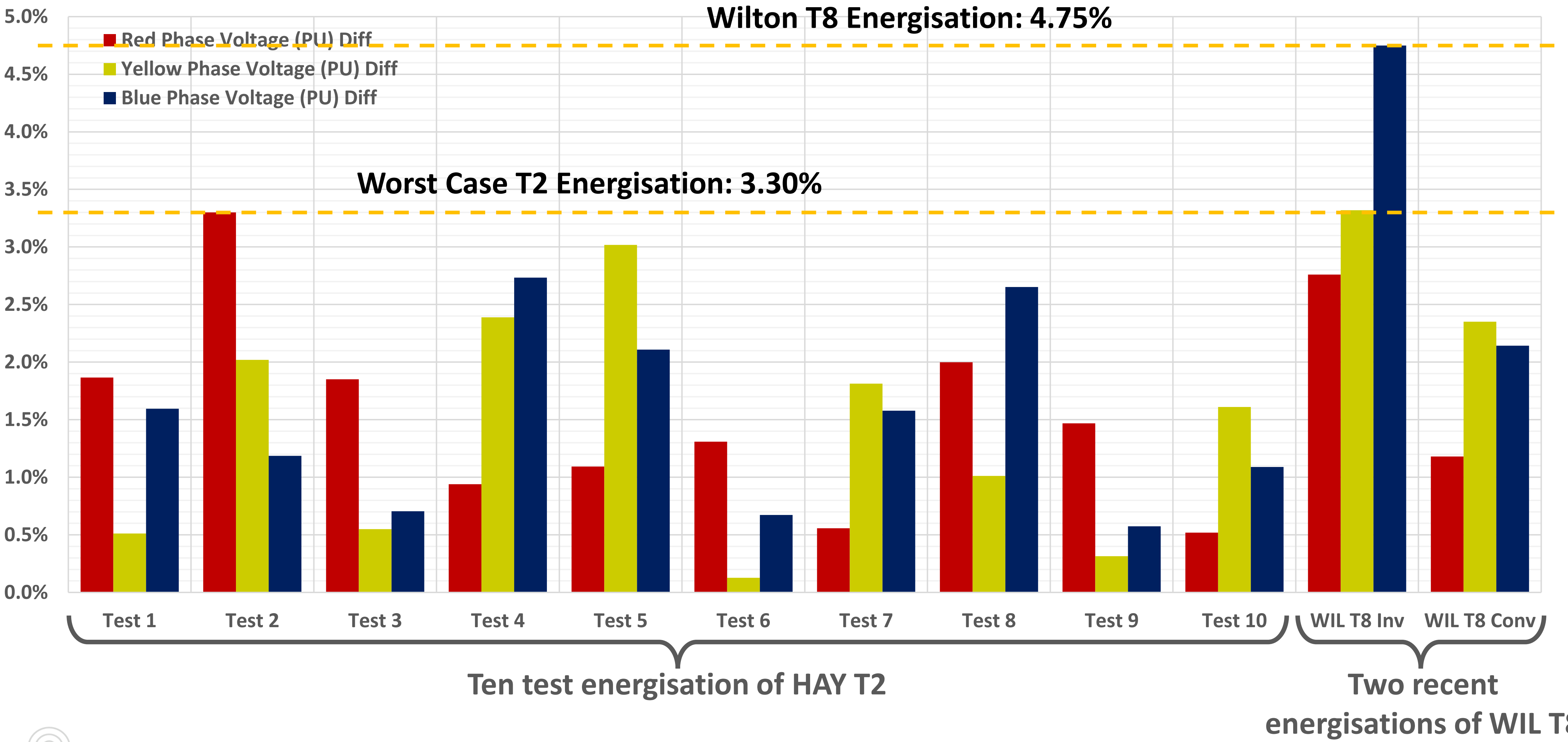




Wilton T8 energisation, as seen at Haywards



Voltage impact



The assets

The status quo (switching policy)

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Results and analysis

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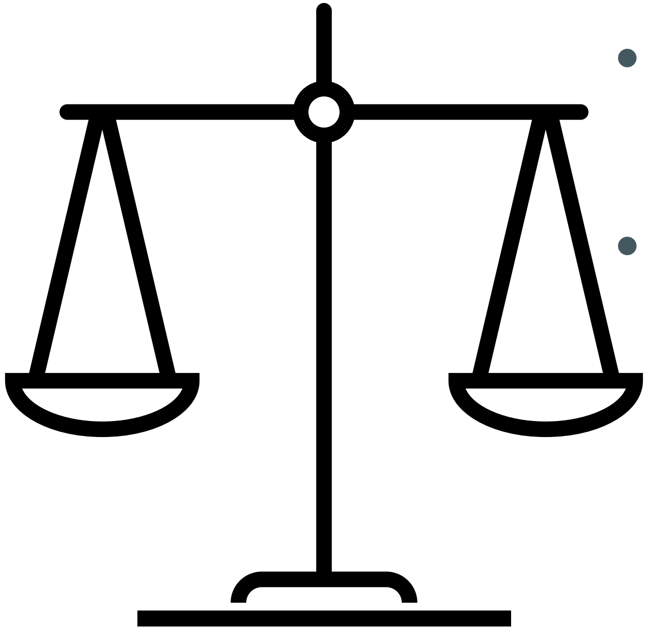
Weighing up the risks

The current policy

- Switching procedure risks
- Time and cost
- Apparent reduction of HVDC risk



Changing the policy

- Apparent risk to the HVDC link
- Efficiency
- Reduced switching risk
- Consistency

New policy…

6. DISTURBANCES AND TRIPPINGS AFFECTING THE HVDC LINK

6.1 Energising of large transformers

The energising of large transformers can result in high inrush currents and voltage disturbances due to saturation of the transformer core. In particular the energising of the 220/110/11 kV interconnecting transformers at Haywards can cause a significant voltage disturbance which may lead to commutation failures.

If the following system conditions are met, it is acceptable to energise these transformers directly off the Haywards 220kV bus:

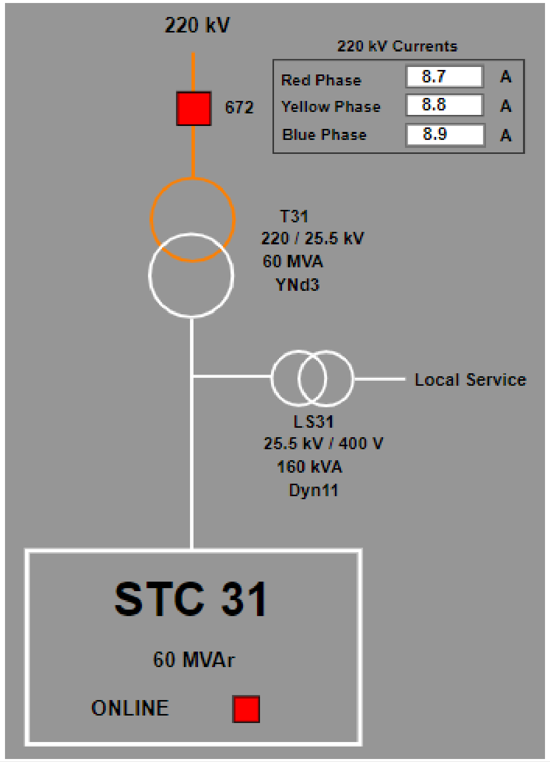
- At least 5x HAY synchronous condensers in service
- HAY STC31 in service
- HAY 220kV bus not split

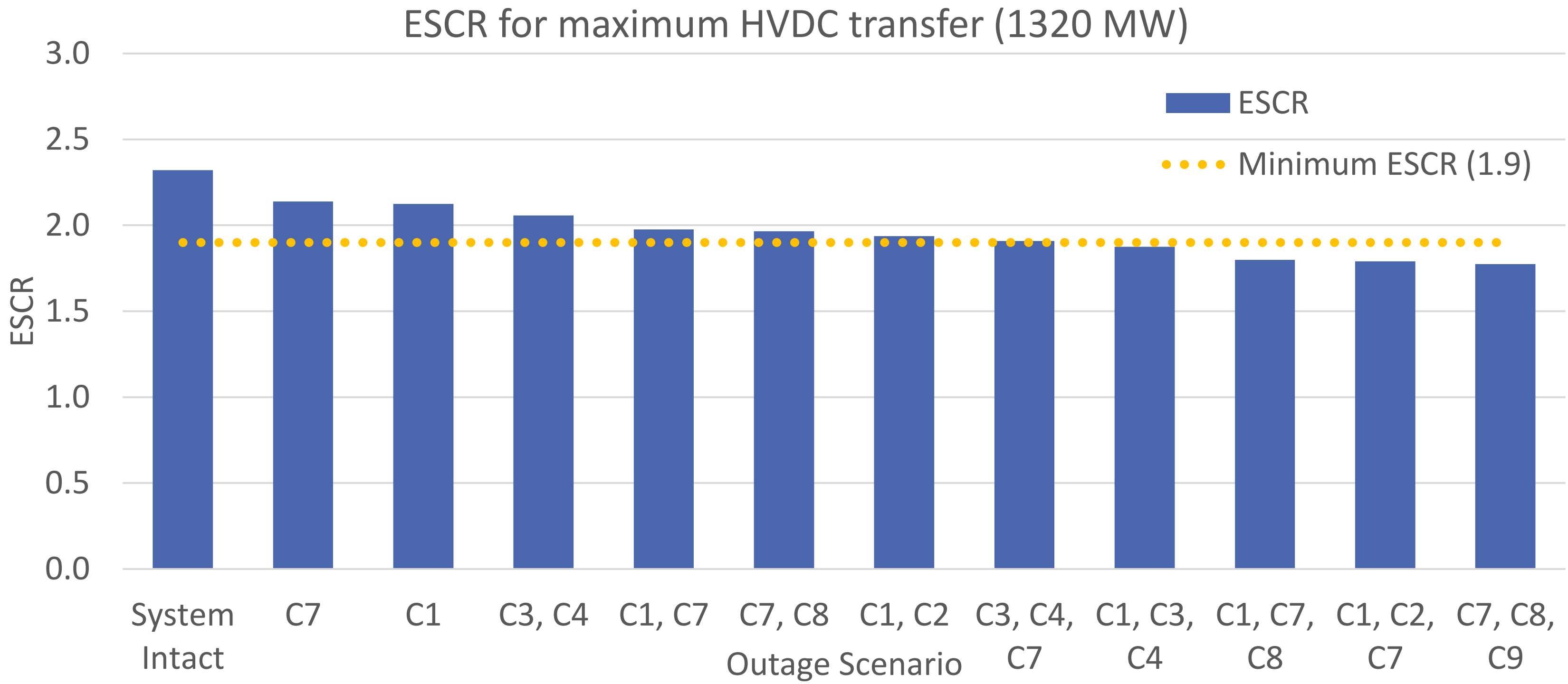
If any of these conditions are not met, the interconnecting transformers should be energised using a separated HAY 220 kV bus section which is only connected to BPE via BPE-PRM-HAY 2 (or BPE-PRM-HAY 1) to minimise the disturbance. This bus section would usually be Bus B.

Note: *The energising of the BEN and HAY Pole 3 converter transformers is almost unnoticeable because of point on wave switching and pre-insertion resistors fitted to their circuit breakers. The energising of the BEN and HAY Pole 2 converter transformers can cause voltage disturbances as only pre-insertion resistors are fitted to their circuit breakers.*

New policy caveats

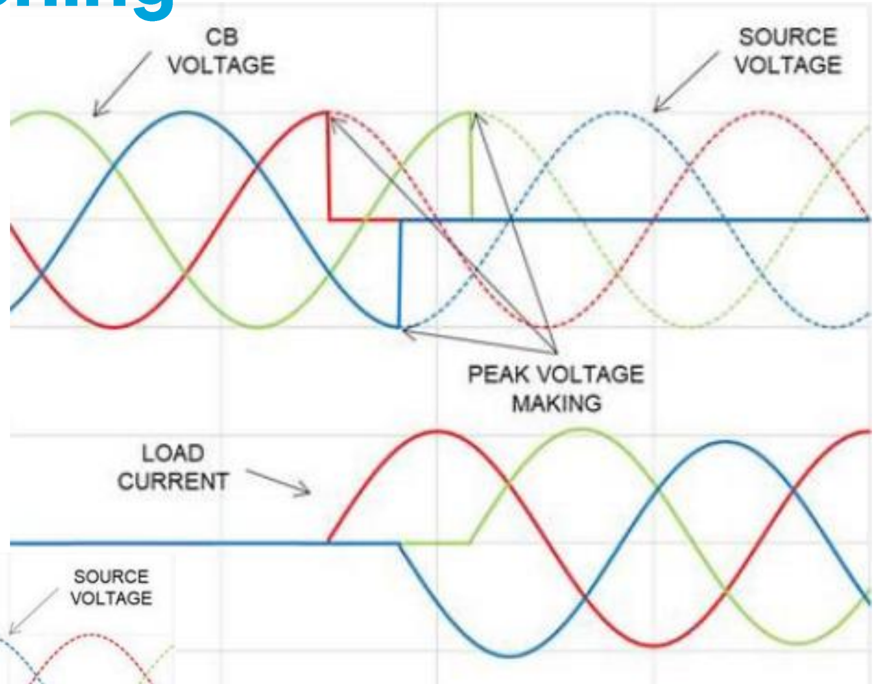
- 220 kV bus splits
- STC31 availability
- Condenser Availability



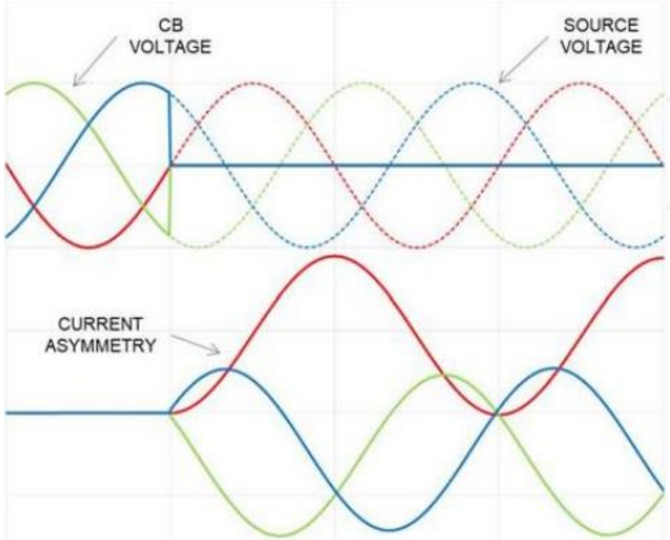


Future mitigation - Point on wave switching

- Pole 2 converter transformers
- Haywards Interconnector Transformers
  - Circuit Breaker type
  - Breaker age
  - Cost vs Benefit
- Wilton T8 settings review



With



Without

Lessons Learnt

Always ask why we do it that way, and conversely, always record incidents, investigations, conclusions, and decisions.

Check all results/response, not just the variables that you are concerned about.

It is much easier to implement a new rule than removing an existing rule, especially an old rule.

Summary

Reviewed existing policy (the ‘status quo’) and associated challenges

Found flaws in the reasoning behind the status quo

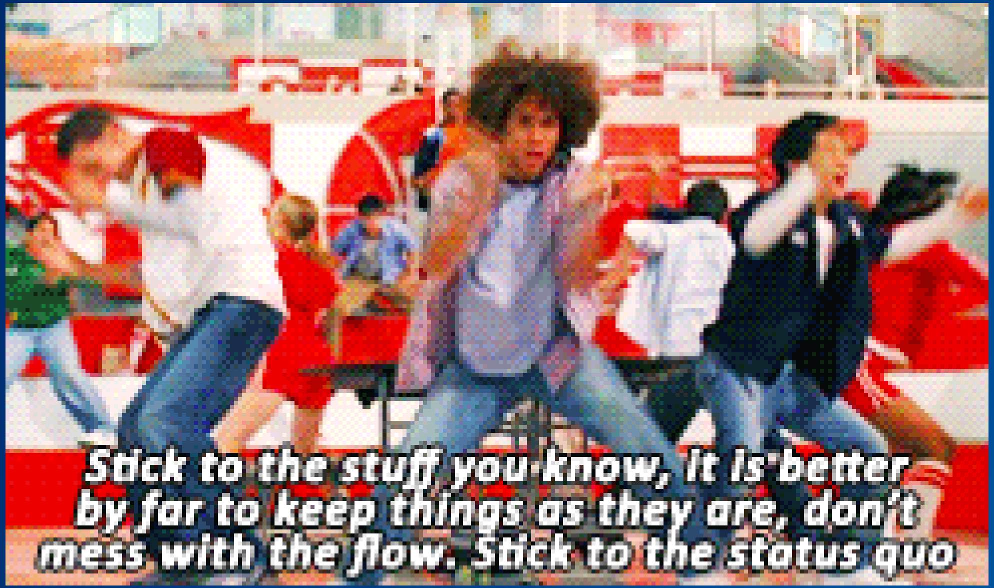
Tested the counter theory

Established the actual risks (predicted and unforeseen) associated with energization

Compared the risk with business as usual

Rewrote the policy!

Questions?


Stick to the stuff you know, it is better
by far to keep things as they are, don't
mess with the flow. Stick to the status quo

Thank you

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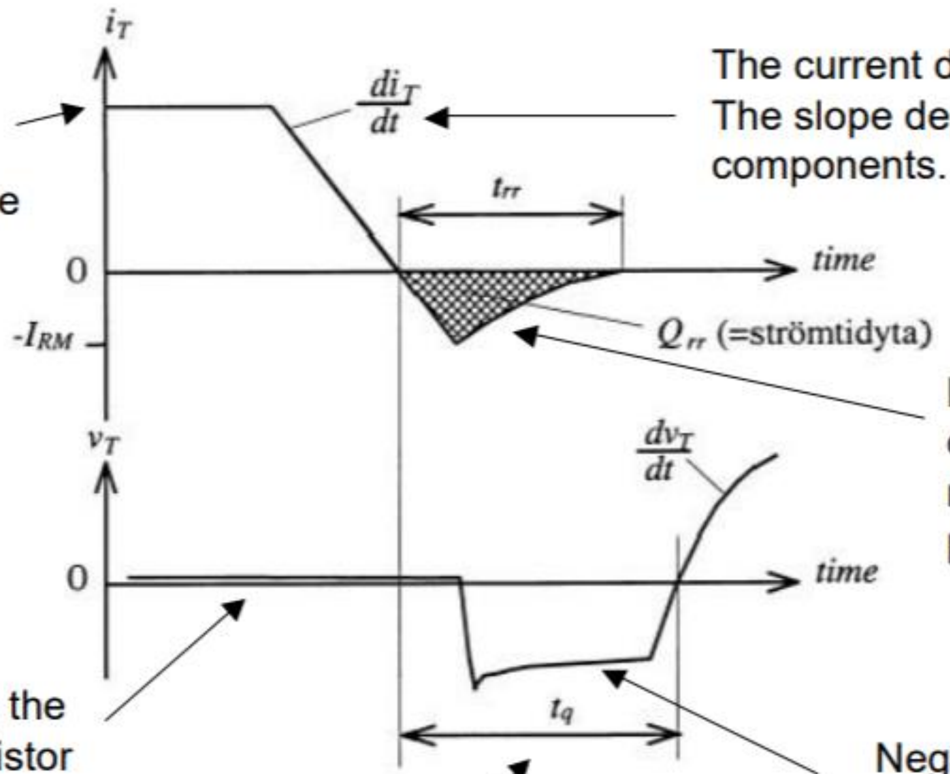
Extinction of the Avalanche Current in the Thyristor



Current in the conducting thyristor before the extinction starts.

The current derivative during extinction. The slope depends on external components.

During this time the charges created during the avalanche, re-combine due to the reversed polarity.

Voltage across the conducting thyristor

t_q is an important parameter for a thyristor.

Negative voltage due to that the following thyristor is fired and connects its phase voltage to the common cathode side.