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# Constant Terminal Voltage

Working Group Meeting 3
19th June 2014

# Overview

- Options
- Study results
- Theoretical Analysis
- Summary

# Options

- Option 1 – Constant Terminal Voltage controlled to 1 p.u with full Transformer Tapping
- Option 2 - Adjustable Terminal Voltage with a limited Transformer Tapping Range
- Option 3 – Limited Transformer Tapping Range only

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# Advantages / Disadvantages

| Option | Advantages | Disadvantages |
|---|---|---|
| 1 | i) Generator Terminal voltage continuously controlled to 1p.u<br>ii) Maintains current Dynamic Reserve provision post fault.<br>iii) Maintains Stability margin | i) Potentially more expensive than other options (eg Transformer required with wider tapping range).<br>ii) References to BCA – Loss of Transparency<br>iii) Does not fully address Derogation issue |
| 2 | i) Potentially cheaper Generator Transformer with lower tapping range.<br>ii) Preserves the total reactive capability (ie operating envelope still maintained) | i) Less dynamic MVAr reserve provision post fault.<br>ii) Lower Stability Margin<br>iii) More complex to define minimum requirements of Generator transformer tapping range and Generating Unit target voltage range.<br>iv) Wider System implications would need to be understood eg would more reactive compensation equipment be required on the System or would enhanced excitation performance requirements be necessary. |
| 3 | i) Potentially cheaper Transformer with lower tapping range | i) As per option 2 in particular iv) which is likely to result in potentially greater costs to both NGET and Generators |

# Summary from Previous Meeting

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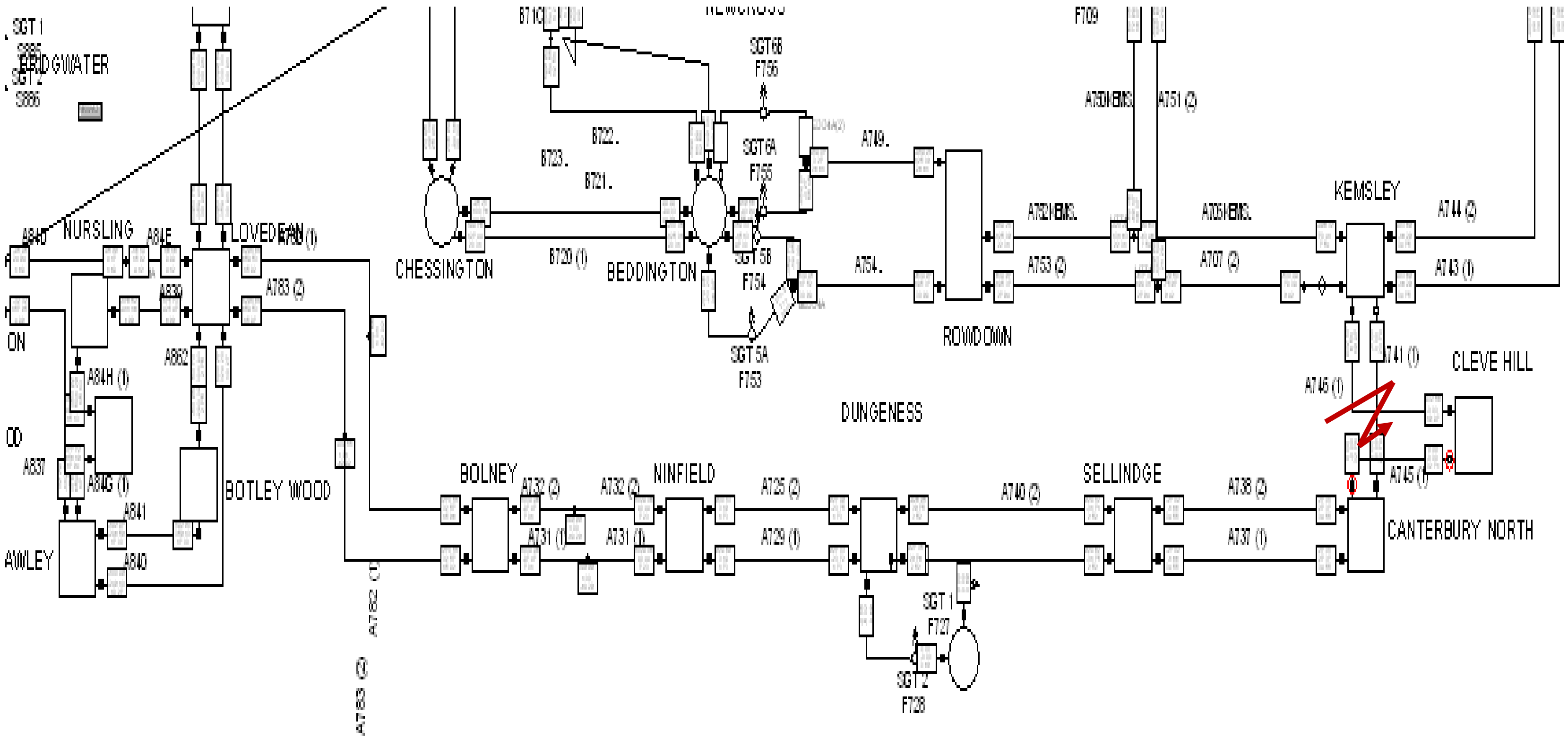
- Each option does have an effect on the terminal voltage of the Generator and the System Operators ability to control system voltage
- Impact on Excitation voltage and MVAr reserves
- Whilst impact on a machine basis is small this would be more significant across the total System
- National Grid's preferred approach is Option 1 Constant Terminal Voltage controlled to 1 p.u with full Transformer Tapping. Applies to new plant with relaxations permitted for existing plant who are unable to meet the current GB requirements

# Multi Machine Study



# Study Statistics

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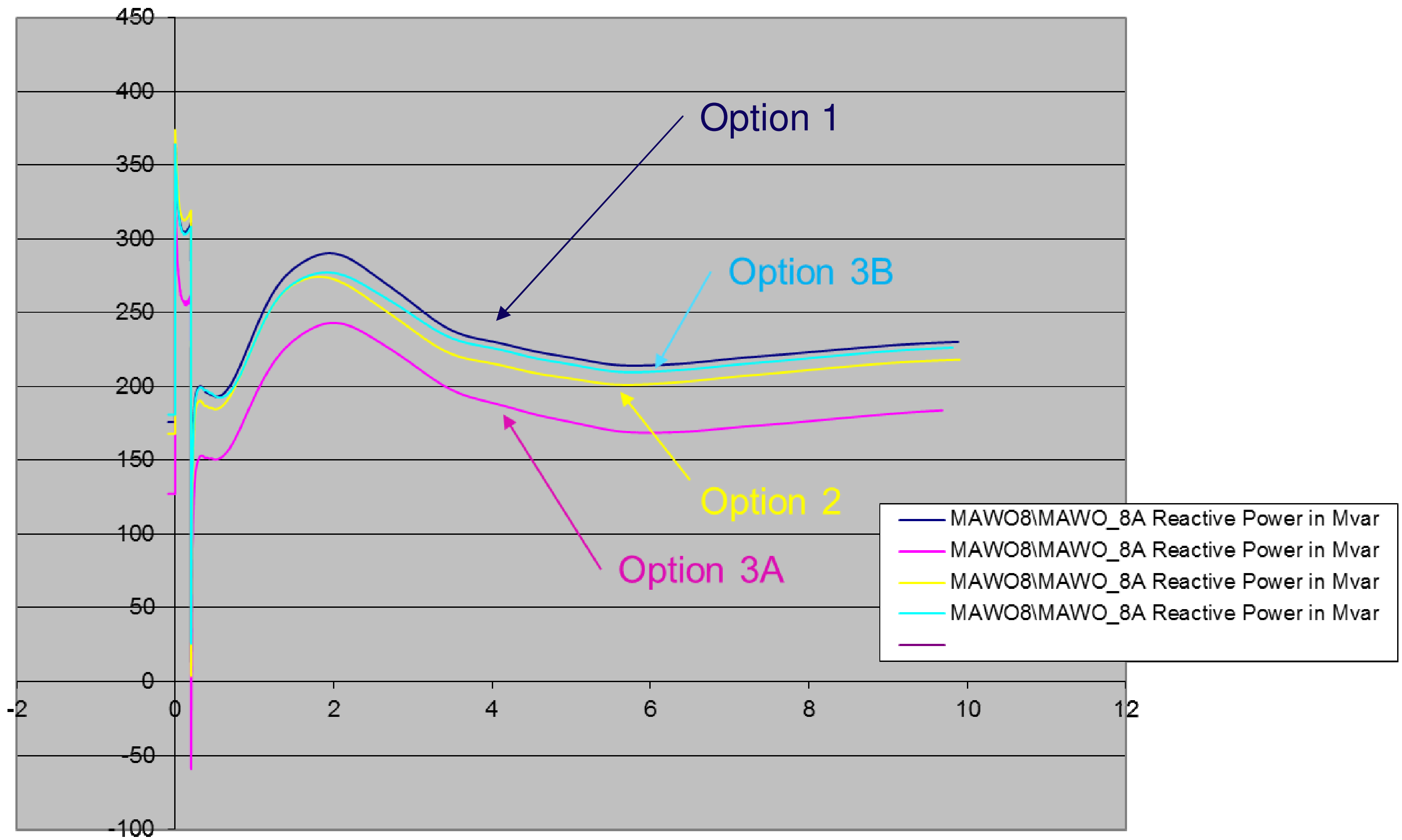
- Winter Peak 2014 Study
- Peak Demand = 54.4GW
- MVAr Demand = 14.8 MVAr
- Double circuit fault applied to Canterbury – Kemsley, Canterbury - Cleeve Hill
- Test Station – Marchwood - run at maximum reactive output - full lag (0.85 PF lag).
- Generator limits not modelled

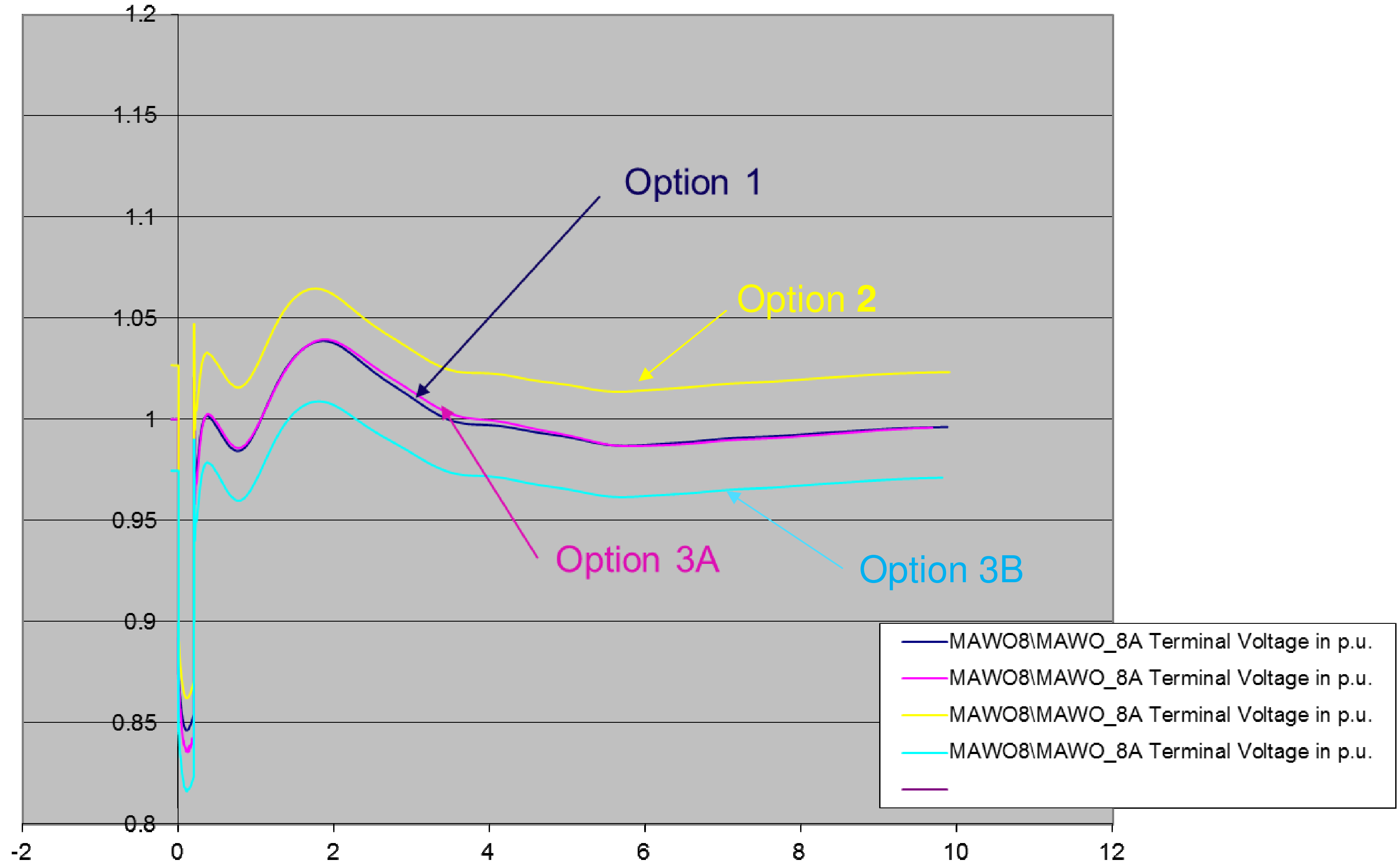
## Options – Test Generator - Marchwood

- Option 1 - Full Generator tapping range (±13 taps) – 1.25% tap step size on transformer voltage rating
- Option 2 - Limited tapping range (±6 taps) and terminal voltage adjusted to 1.0118 p.u – 1.25% tap step size on transformer voltage rating
- Option 3A – Limited tapping range (±6 taps) and terminal voltage adjusted to 1.0 p.u – 1.25% tap step size on transformer voltage rating
- Option 3B – limited tapping range and 1.0 p.u voltage (±6 taps) – 2.5% tap step size on transformer rating

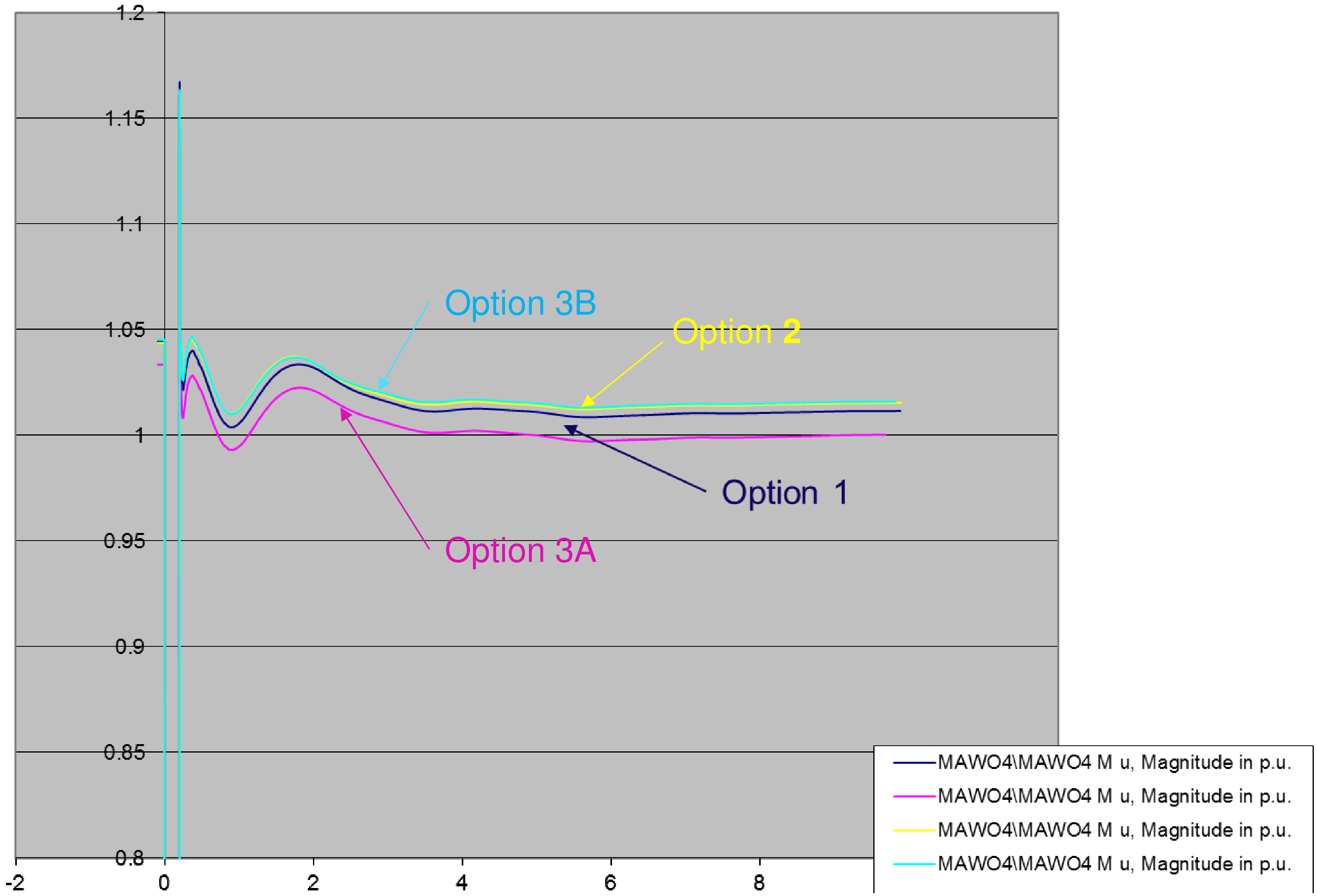
# Reactive Power Output - Marchwood



# Marchwood – Terminal Voltage



# 400kV Voltage - Marchwood



# 400kV Voltage - Bolney

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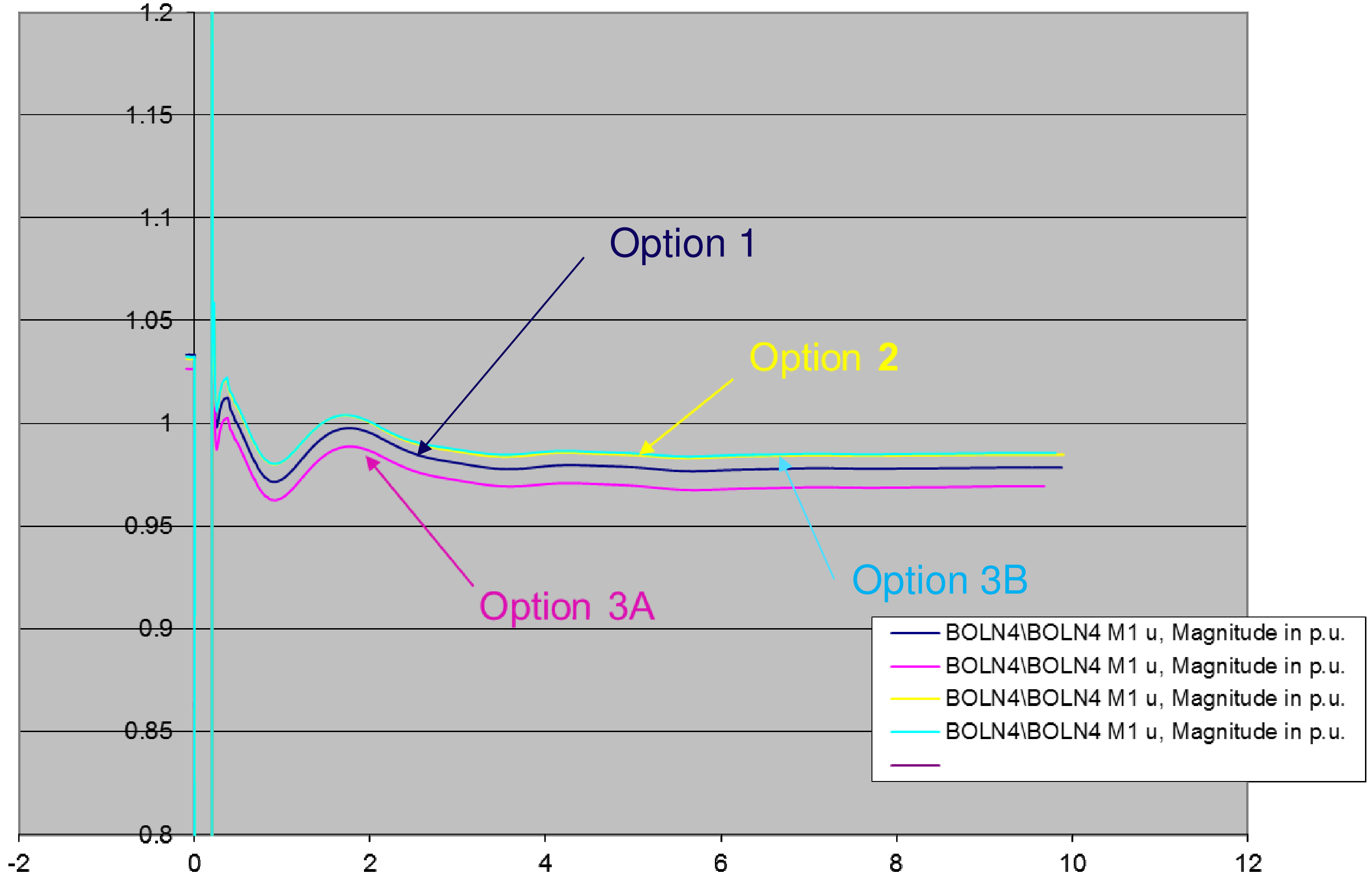

# 400kV Voltage - Canterbury

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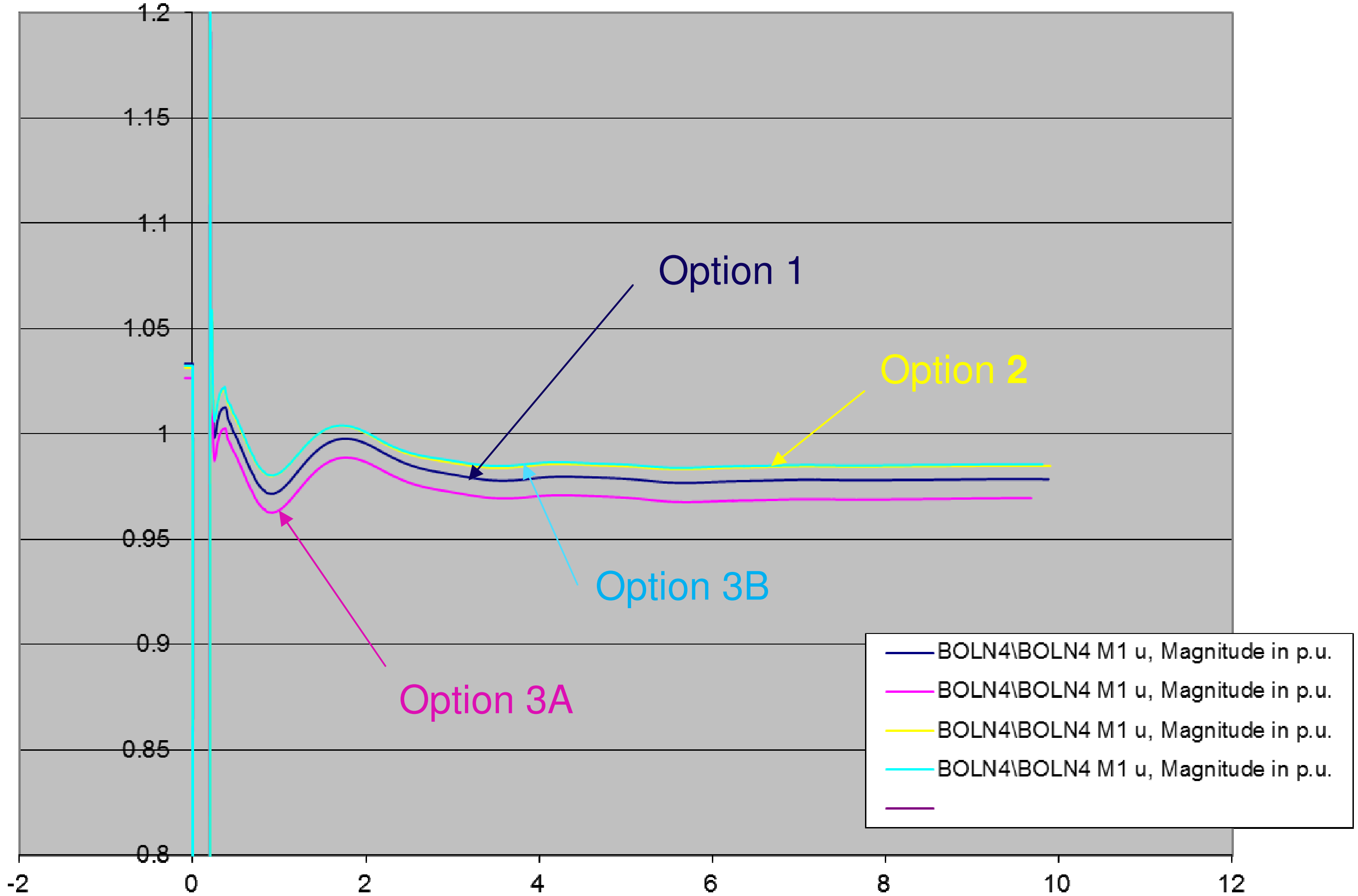

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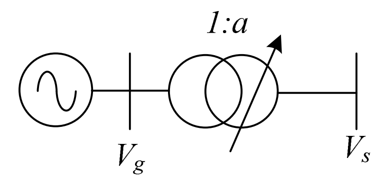
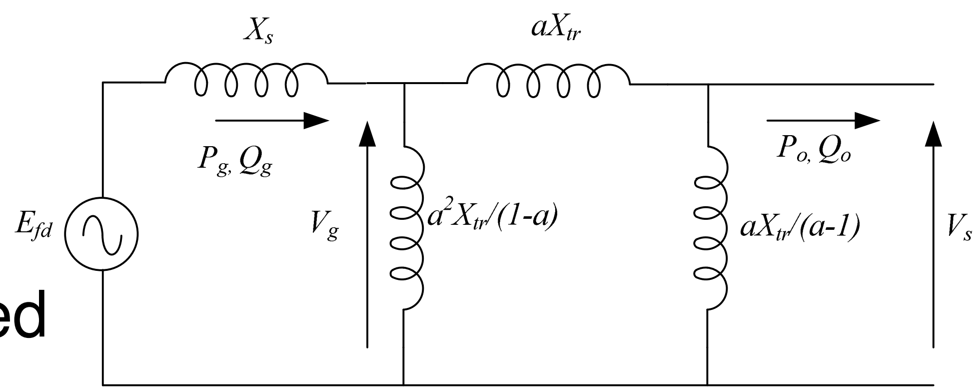
# Theoretical Analysis

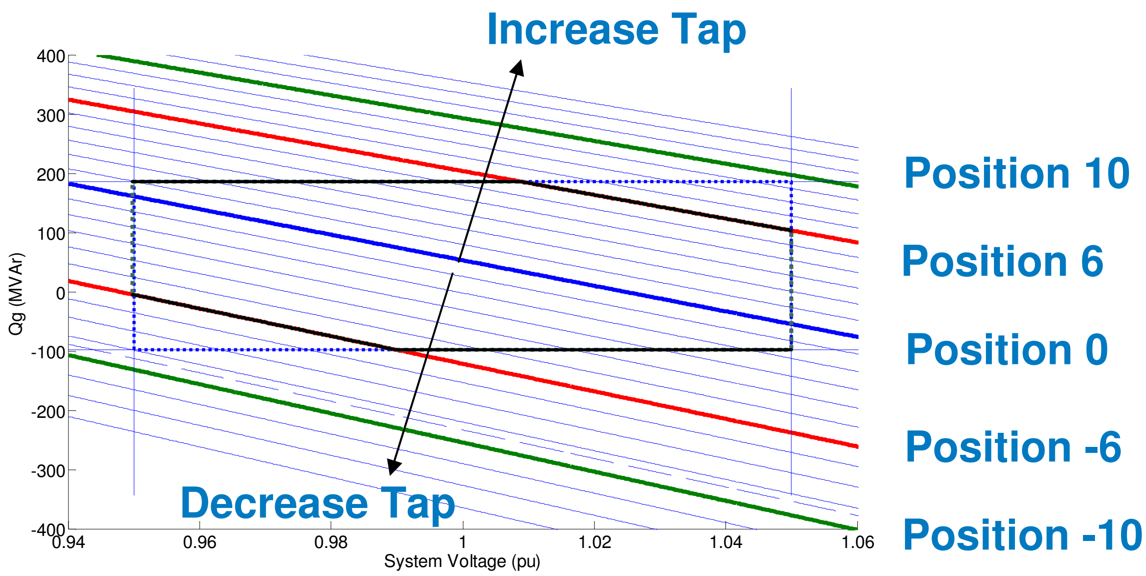
- Single line diagram
- Equivalent circuit
- Data from a typical Generator Transformer
- Copper losses neglected
- Generator not modelled



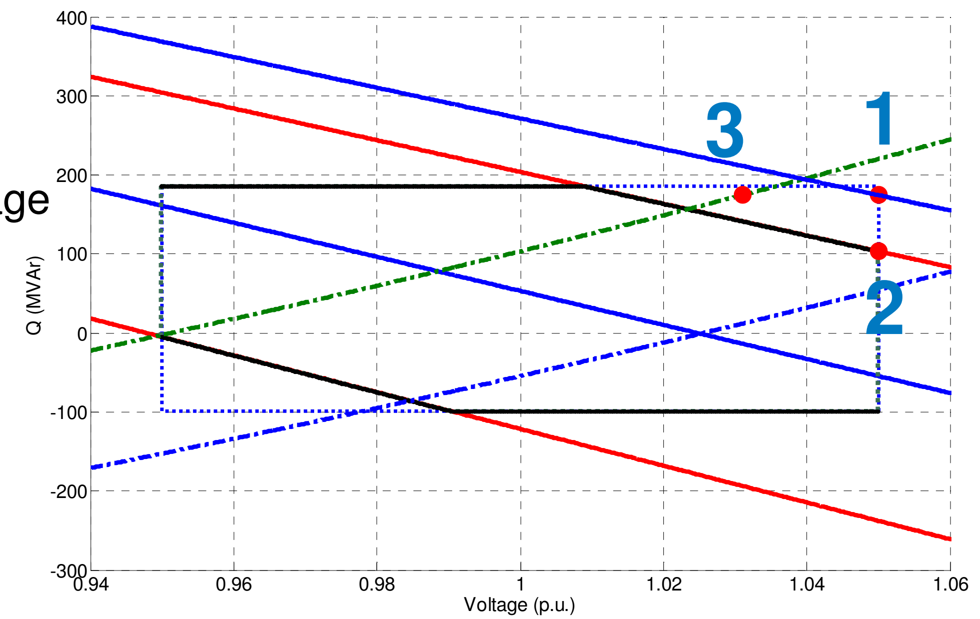
# Machine MVAr Output

$$Q_g = \frac{V_g^2}{X_{tr}} - \sqrt{\left(\frac{V_g V_s}{aX_{tr}}\right)^2 - \frac{P_g}{a}}$$



# Setting the terminal voltage

- Point 1:
  - 1.05pu Voltage at the GEP
  - 1.0pu Generator Terminal Voltage
  - Tap position 9




- Point 2:
  - Change to tap position 6

- Point 3:
  - Increase the machine terminal to 1.031pu

$$V_g = \sqrt{\frac{1}{2}\left(\frac{V_s}{a}\right)^2 + X_{tr}Q_g + \sqrt{\frac{1}{4}\left(\frac{V_s}{a}\right)^4 + X_{tr}Q_g\left(\frac{V_s}{a}\right)^2 - \left(X_{tr}P_g\right)^2}}$$

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# Response to a step change in voltage

- Reactive power output

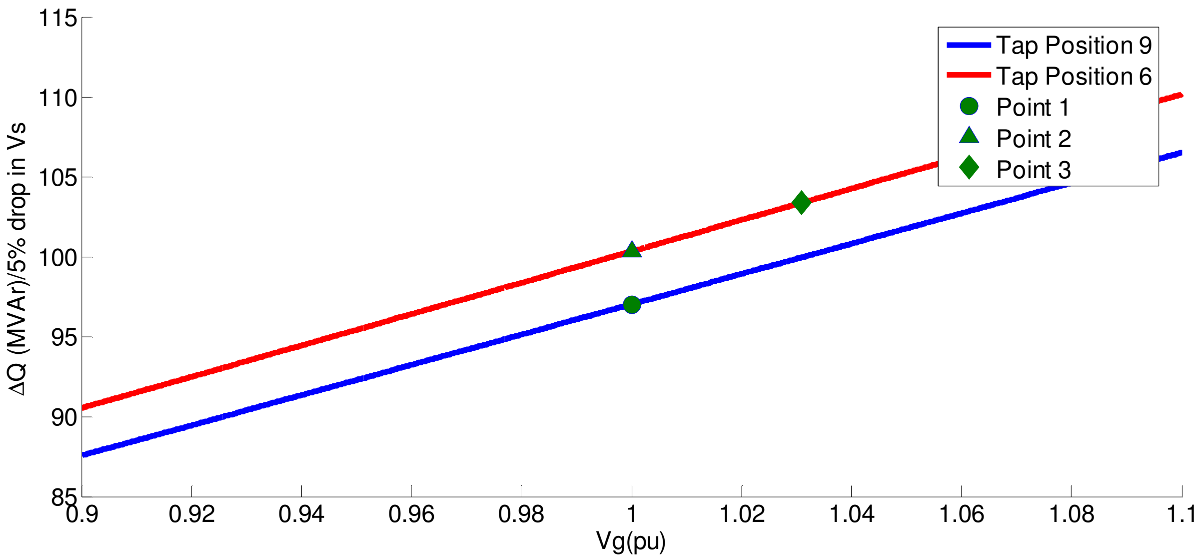
$$Q_g = \frac{V_g^2}{X_{tr}} - \sqrt{\left(\frac{V_g V_s}{aX_{tr}}\right)^2 - \frac{P_g}{a}}$$

- Rate of change of reactive power output for a step change in voltage at the Grid Entry Point

$$\frac{\partial Q_g}{\partial V_s} = -\frac{\left(\frac{V_g}{aX_{tr}}\right)^2 V_s}{\sqrt{\left(\frac{V_g V_s}{aX_{tr}}\right)^2 - \frac{P_g}{a}}}$$

# Response to a step change in voltage

- Point 1, 2, and 3 correspond to the same initial operating points as per previous slide
- Diagram shows increase in reactive power injected in response to a 5% step drop in voltage at the Grid Entry Point.
- Results seem to suggest an improvement which is not evident from study work



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## Summary

- Results of multi machine studies (South Coast) show an second order effect but difficult to draw exact conclusions
- Theoretical analysis suggests that an improvement in performance could be obtained if terminal voltage contributes to the HV voltage
- This needs to be re-assessed in Digsilent / Power Factory to confirm the theory
- Further feedback from working group required

# Discussion