Power Electronics Converter Modelling for High Frequency Applications using Black-Box Approach

End Semester Evaluation for BTP 2024-25

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Outline

Flow of the Presentation

- Motivation for the Project
- Modelling in PSCAD
- Control in PSCAD
- Frequency Scanning
- Black-Box Modelling
- Simulation Results
- Conclusion

Motivation for the Project

Challenges with Changing Modeling Paradigm

Traditional Methods

- Requirement of complete information of components inside a Power Electronics Converter
- Time-Domain Simulations
- Long Computational Times

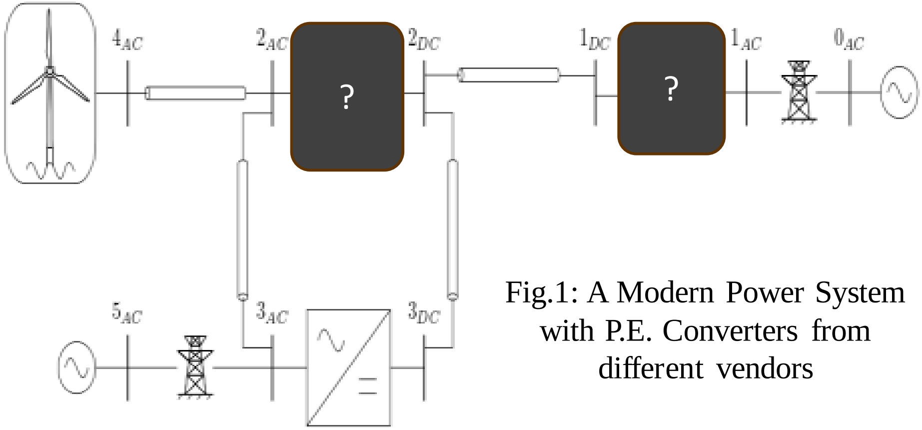


Fig.1: A Modern Power System with P.E. Converters from different vendors

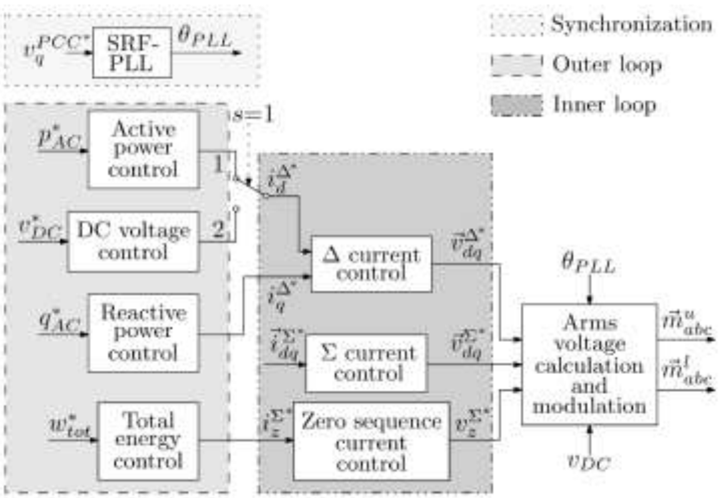


Fig. 2: Block diagram of closed-loop control.

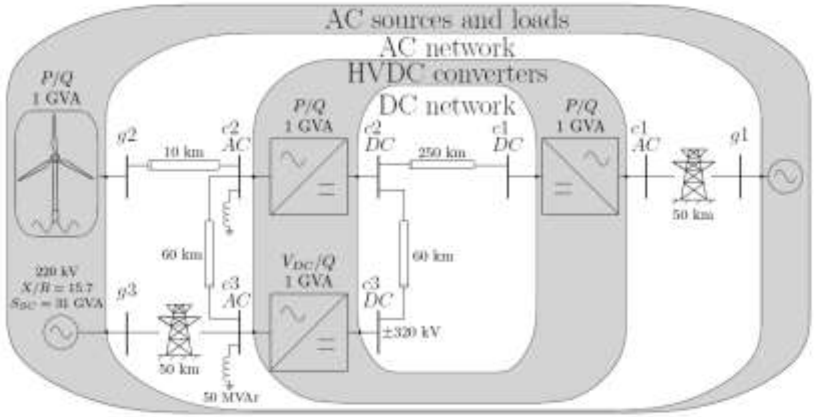
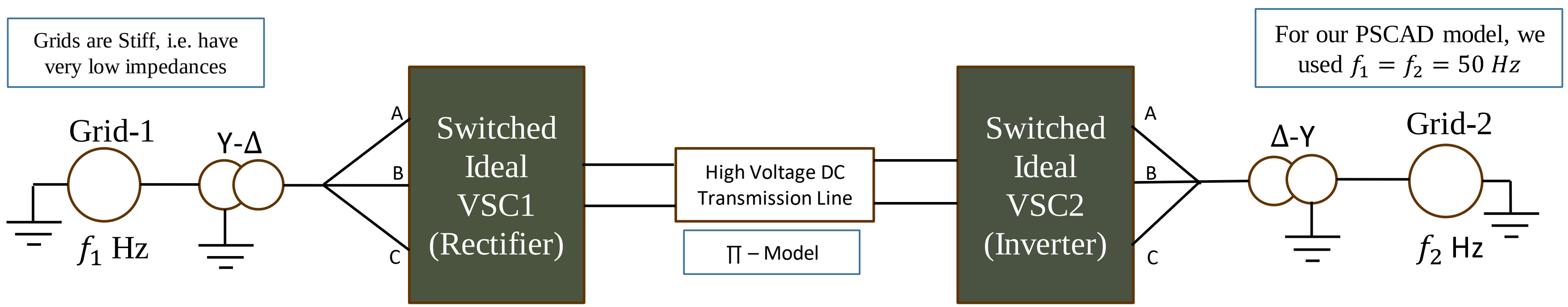


Fig. 3: Segmented power system for hybrid modeling (white and black model).

Modelling in PSCAD

Two-terminal HVDC system



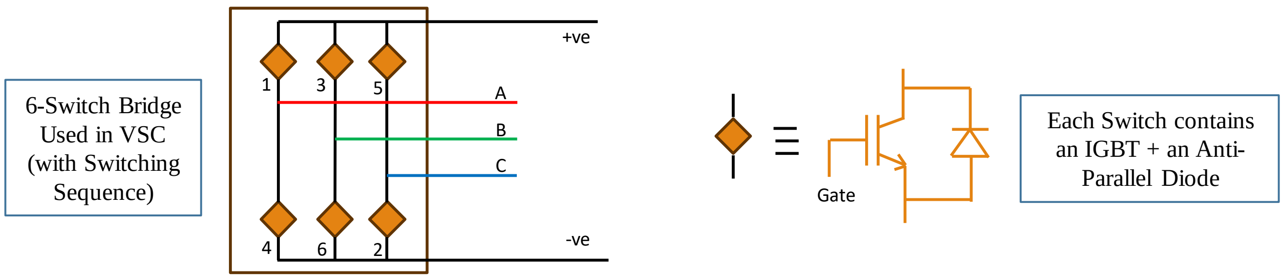


Fig. 4: Two-terminal high voltage direct current (HVDC) system modelled in PSCAD simulator.

Control in PSCAD

Active/Reactive Power Control in Closed-Loop

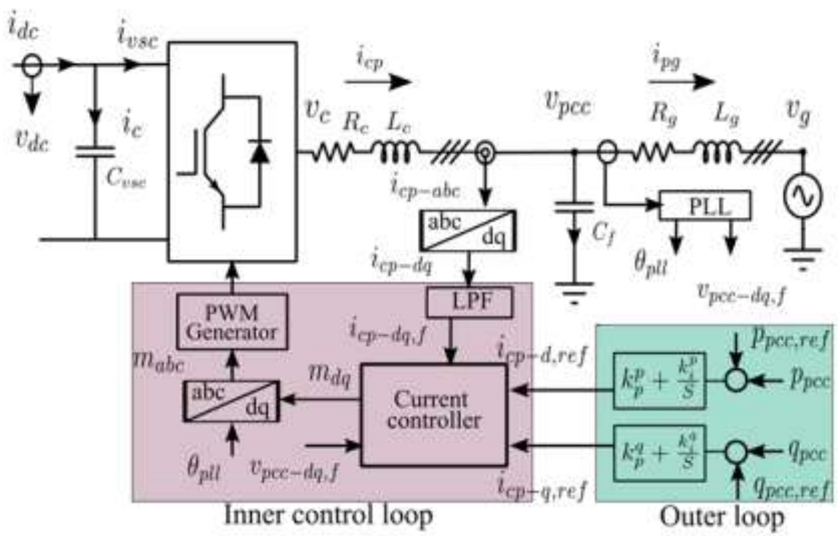


Fig. 5: Schematic diagram of converter with closed-loop control in dq-frame.

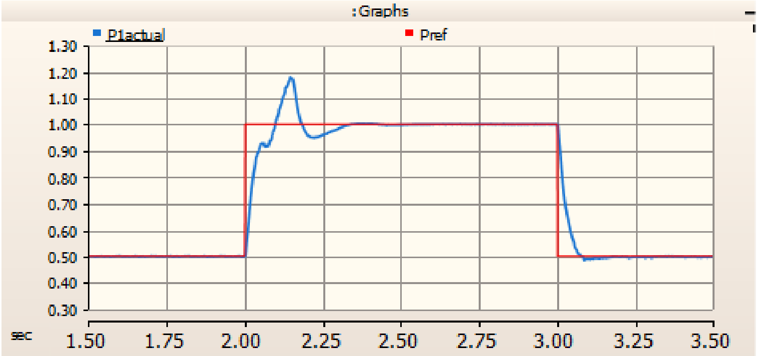


Fig. 6: Active power response.

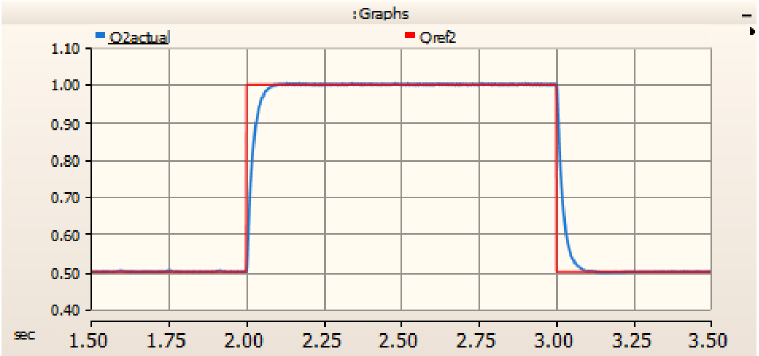


Fig. 7: Reactive power response

Frequency Scanning

Introduction

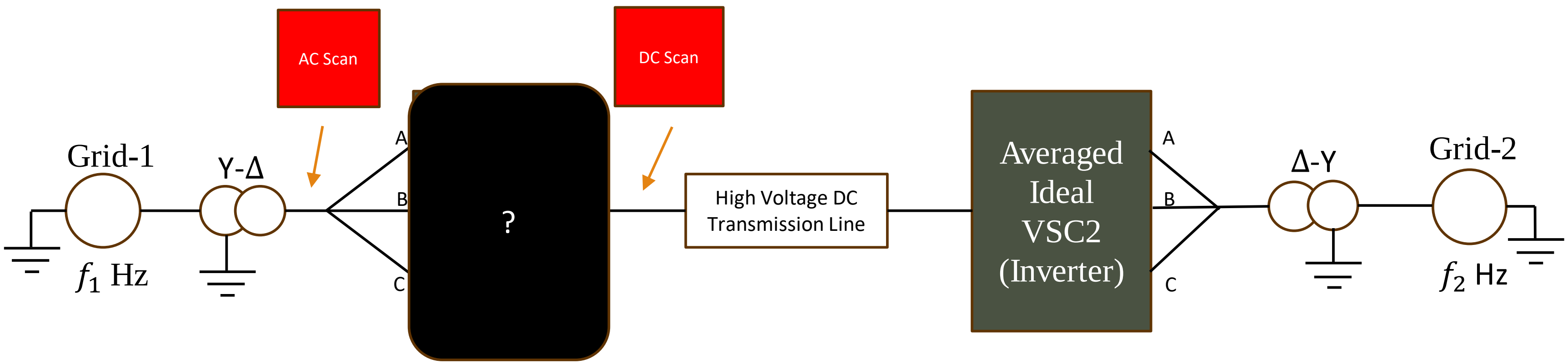


Fig. 8: Two-terminal high voltage direct current (HVDC) system modelled in PSCAD simulator.

- Frequency scanning techniques (FST) are data-driven methods used to study how a system responds to sinusoidal signals over a range of frequencies.
- These are particularly helpful in identifying resonances, assessing system stability and evaluating dynamic behaviour.
- We perform frequency sweep over the defined range of frequencies and output the response at each frequency using a bode plot.

Frequency Scanning

Creating a Black-Box Model

- Black-box modeling is an approach in system identification and control engineering where the internal structure and parameters of the system are unknown or ignored, and the focus is solely on the input-output relationships.

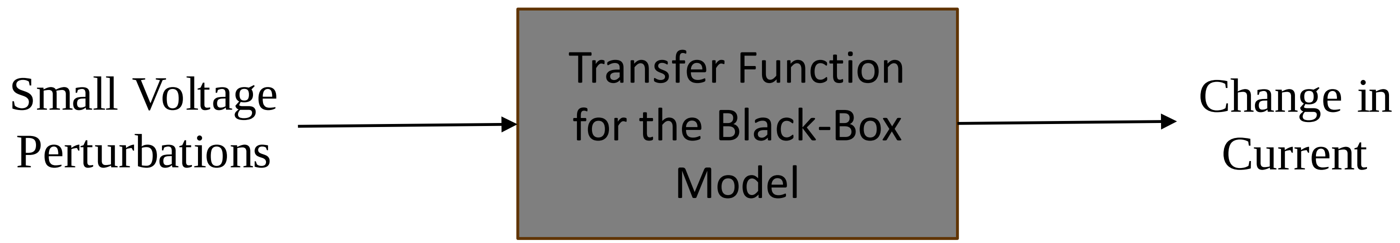
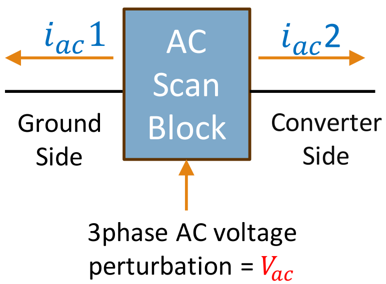


Fig. 9: Implementation of black-box model.

- All sinusoidal perturbations are run sequentially.
- The transfer function is nothing but an admittance value.
- Admittance values for all frequencies are then plotted on a bode plot.

Frequency Scanning

Creating Transfer Functions



$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \frac{2}{3} \begin{bmatrix} cos\theta & sin\theta \\ -sin\theta & cos\theta \end{bmatrix} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

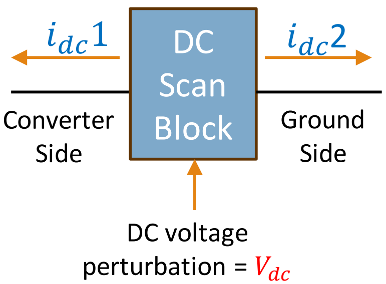
Clarke and Park Transformation:
abc-dq0 frame transformation for AC Currents & Voltage

$$Y_{dd}1 = \frac{\Delta i_{ac}^{d}1}{V_{ac}^{d}} \quad Y_{dq}1 = \frac{\Delta i_{ac}^{d}1}{V_{ac}^{q}}$$

$$Y_{qd}1 = \frac{\Delta i_{ac}^{q}1}{V_{ac}^{d}} \quad Y_{qq}1 = \frac{\Delta i_{ac}^{q}1}{V_{ac}^{q}}$$

Ground-Side Admittances

Steady-State



$$Y_{dc}1 = \frac{\Delta i_{dc}1}{V_{dc}}$$

Converter-Side Admittance

$$Y_{dc}2 = \frac{\Delta i_{dc}2}{V_{dc}}$$

Ground-Side Admittance

$$Y_{dd}2 = \frac{\Delta i_{ac}^{d}2}{V_{ac}^{d}} \quad Y_{dq}2 = \frac{\Delta i_{ac}^{d}2}{V_{ac}^{q}}$$

$$Y_{qd}2 = \frac{\Delta i_{ac}^{q}2}{V_{ac}^{d}} \quad Y_{qq}2 = \frac{\Delta i_{ac}^{q}2}{V_{ac}^{q}}$$

Converter-Side Admittances

Bode Plots of Frequency Scanning

AC Scanning

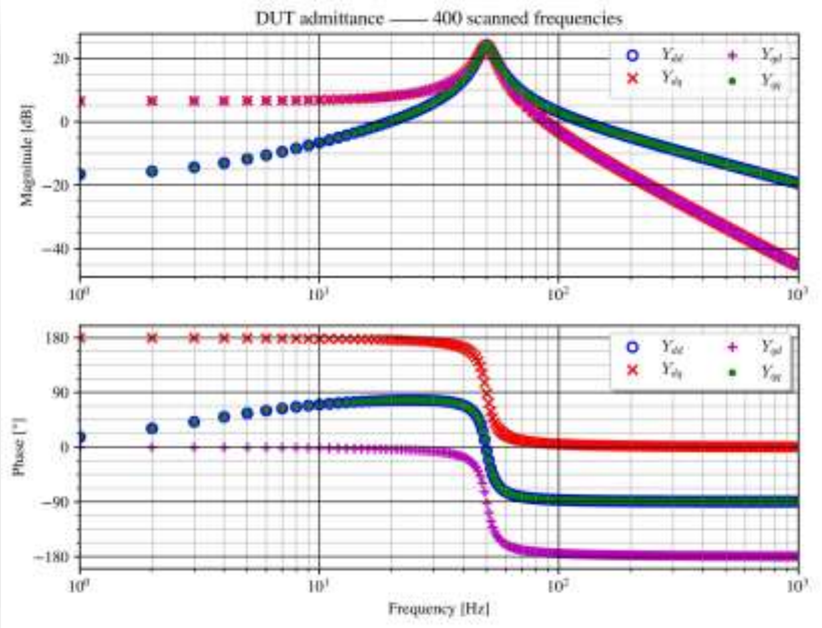


Fig. 10: Ground-Side Admittances for Scanned Frequencies in 1 – 1000 Hz.

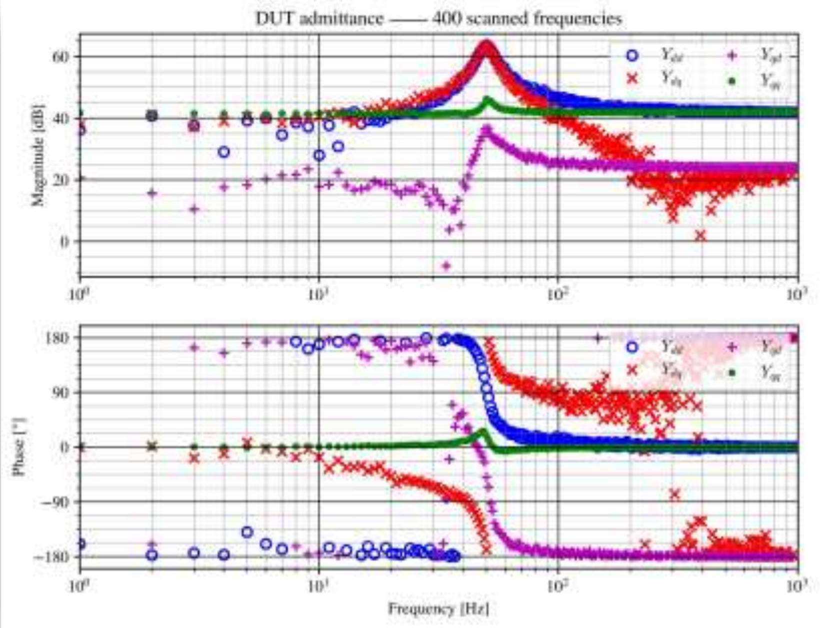


Fig. 11: Converter-Side Admittances for Scanned Frequencies in 1 – 1000 Hz.

Bode Plots of Frequency Scanning

DC Scanning

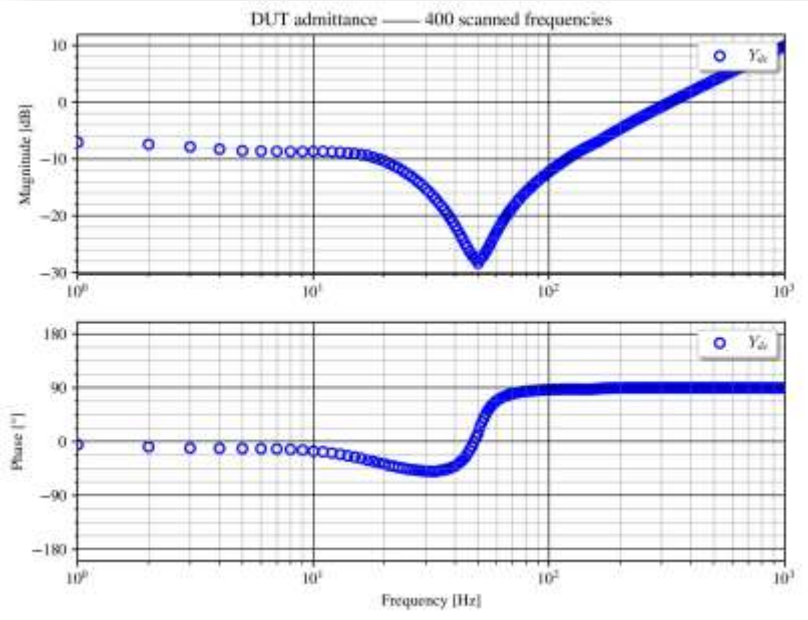


Fig. 12: Ground-Side Admittances for 400 Scanned Frequencies in 1 – 1000 Hz.

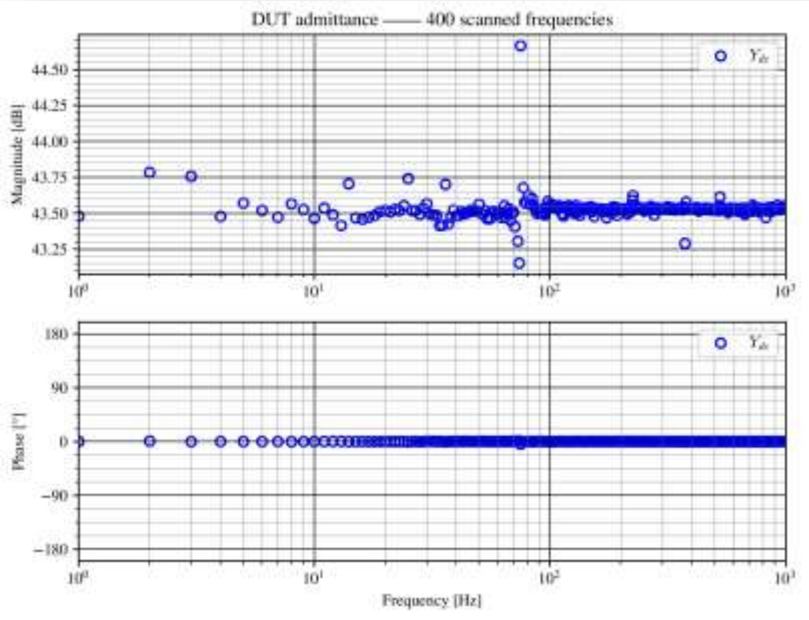


Fig. 13: Converter-Side Admittances for 400 Scanned Frequencies in 1 – 1000 Hz.

Conclusion

Conclusion of BTP Project

- Fortunate to have got the opportunity to work on P.E. and Control Systems which have so wide applications in the current world scenario
- 4-5 months of Research, Analysis, and Hardwork
- Teamwork with my fellow peers
- Learning about other domains
- Inspired to contribute further to the topic
- Motivated to innovate something that helps others
- Lastly, but above all grateful to have Lokesh sir as my supervisor

Conclusion

Future Works

Stability Analysis using GNC & Participation Factor Analysis

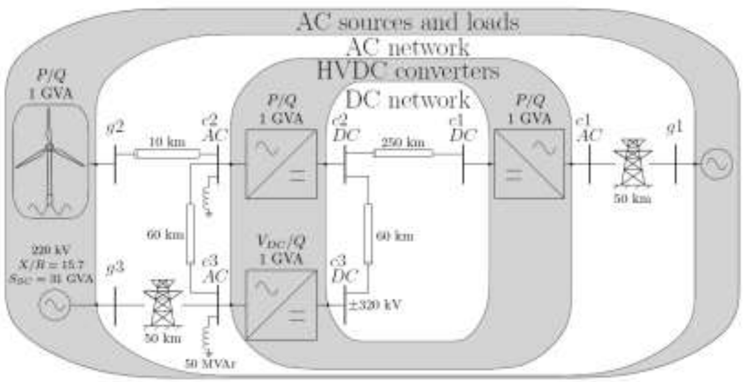


Fig. 14: Segmented power system for generalized Nyquist and bus participation analysis.

- Node Subsystem

- Edge Subsystem

$$GNC: \; L = Y_{edge}^{-1} Y_{node}$$

$$EVD \; of \; (Y_{edge} + Y_{node})^{-1}$$
$$PFs: \; \partial\lambda_n / \delta Z_{ij}(j\omega)$$

- We build node and edge matrices of Admittances for each subsystem using Frequency Scanning.
- Then we build a transfer function and use Generalised Nyquist Criterion to assess the system's stability.
- We can also perform Eigen Value Decomposition to analyse Participation Factors.

Questions

Thanks for your attention!

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