Control of Hybrid (High Voltage) AC/DC Grids

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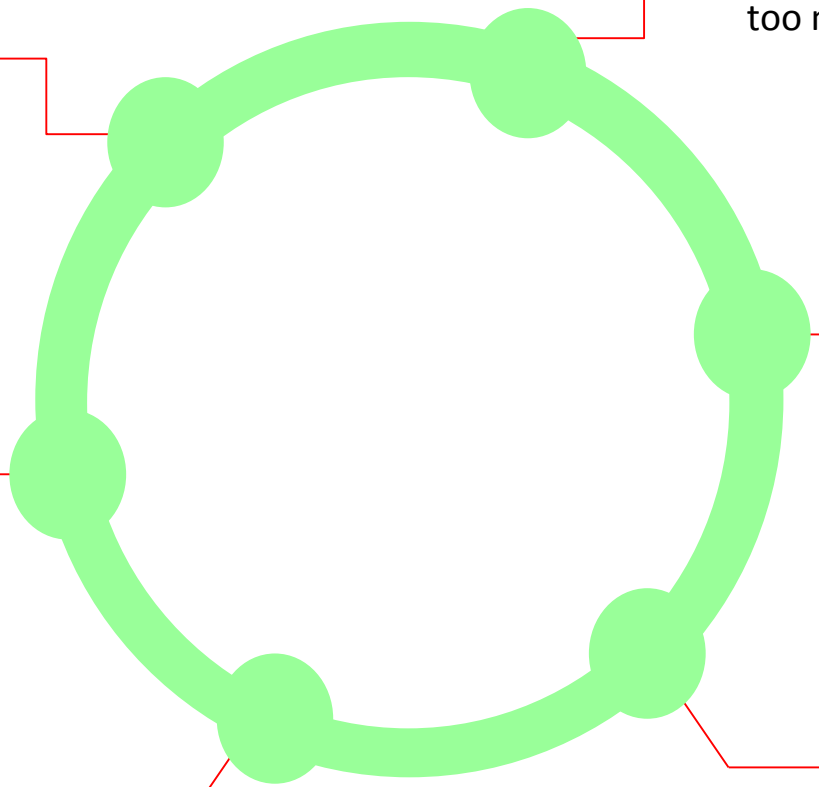
Direction of this Work (1)



Models to capture both AC/DC side dynamics without sacrificing too much computational time

Coordination and control

Further research on identification of AC-DC interactions

Controller design and synthesis (Extension to MTDC)

New phenomena and mitigation or control strategies

Influence of physical properties of grid on interactions and phenomena

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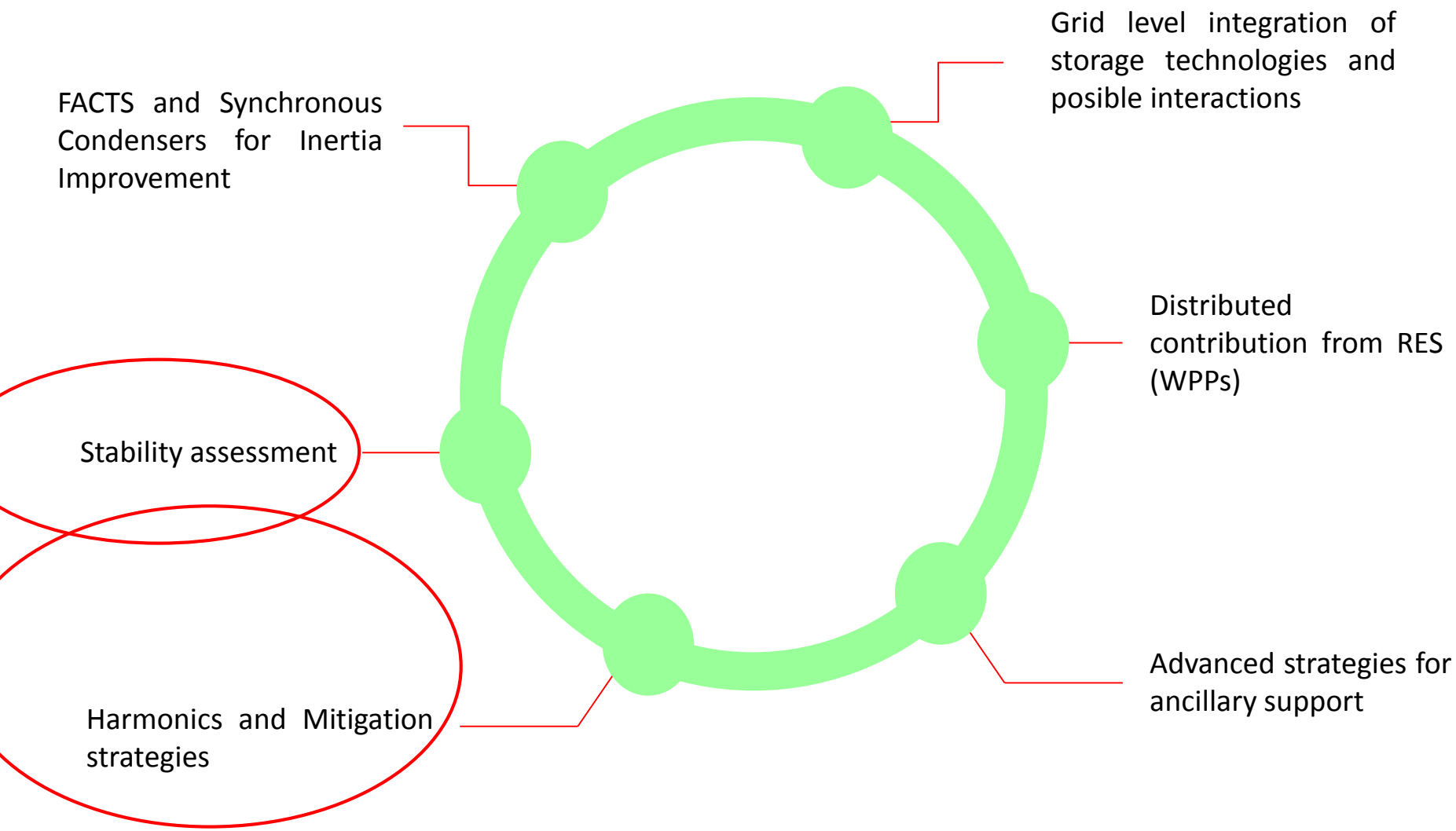
Direction of this Work (2)



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Harmonic Stability and Interaction

- Expected pervasiveness of PE converters and devices.
- Transmission system as an interconnection of devices.
- Global stability becomes the fundamental issue.
- Complicated when two distinct grids are involved.
- Understanding and insight into harmonic interaction and stability of combined **Meshed AC and MTDC** grids**.**

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Methodology for Analysis

- Impedance modelling.
- Classical frequency domain analysis.
- State space + frequency domain (large systems).

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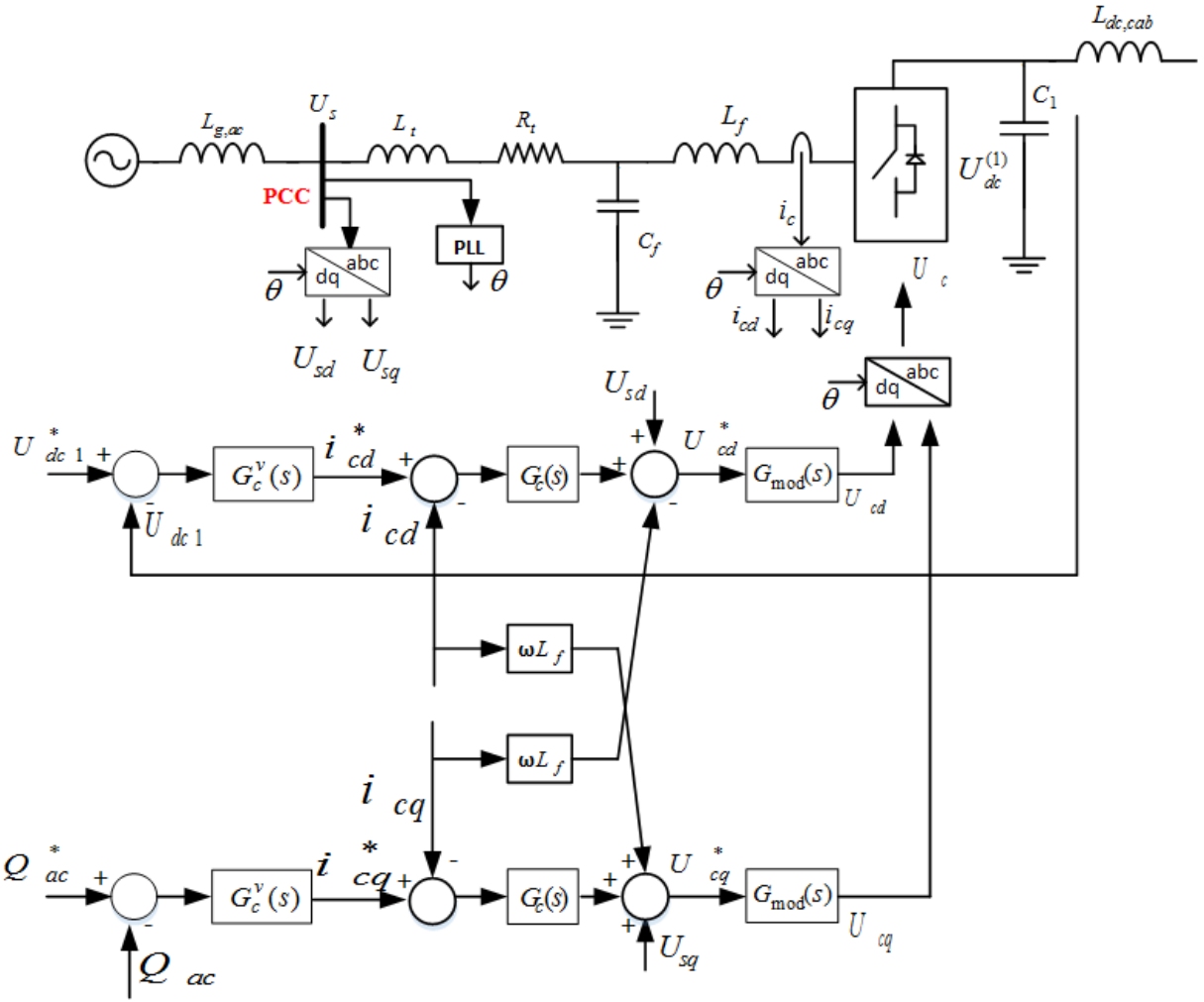
HVDC Control Basics

- Multi-loop control system



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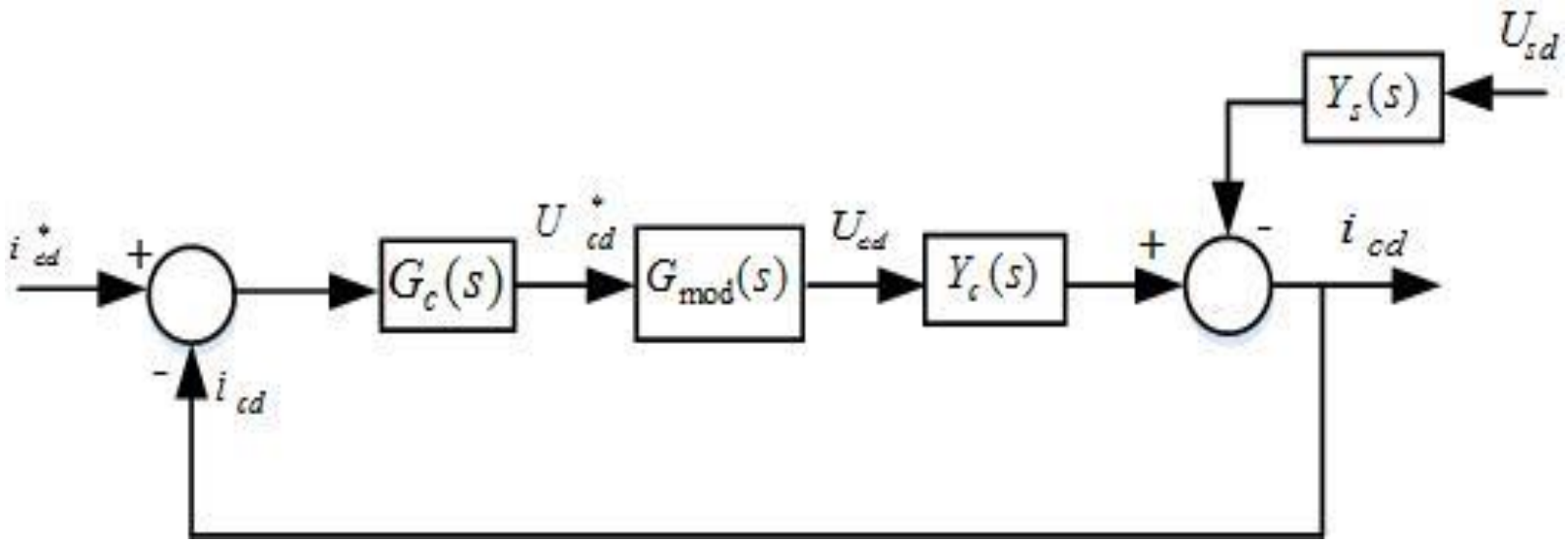
HVDC Control Basics

- Current controller as the fundamental control system.



- Interacts directly with the converter and AC grid.

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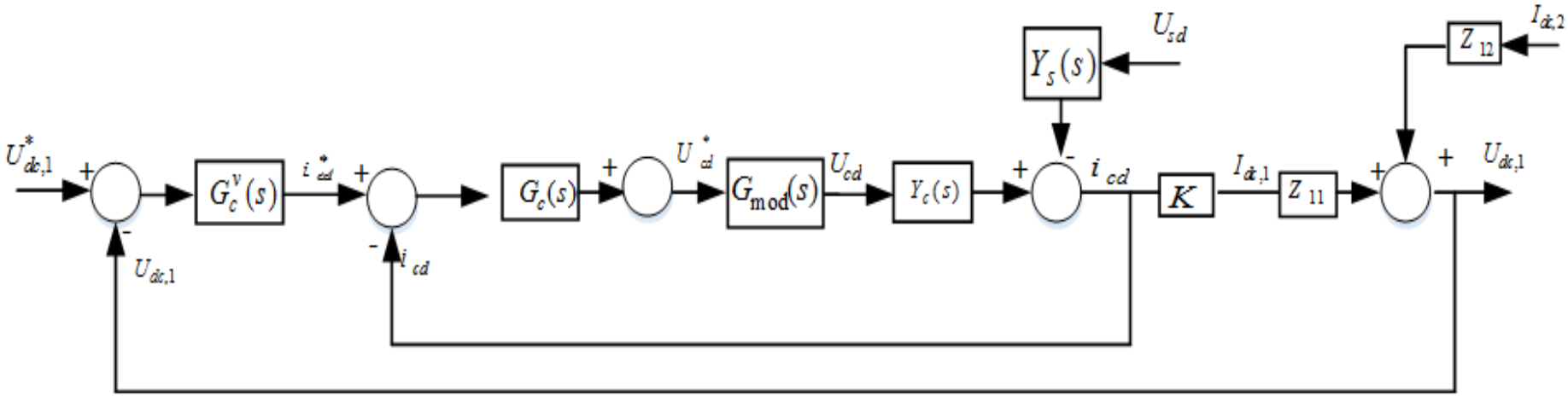
HVDC Control Basics (2)

- AC, DC voltage, power controller as an outer-loop.



- Controls the either the voltage of the AC bus, DC bus, or power injected.

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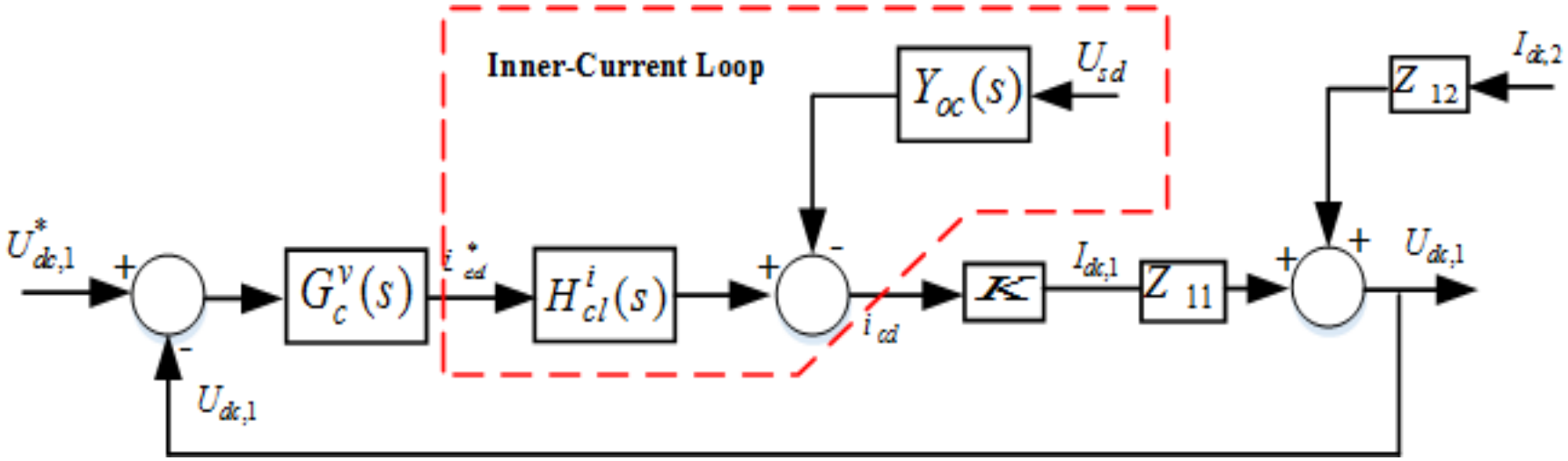
HVDC Control Basics (3)

- Reduced control system



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Rationale for Impedance Model

- Current controller can be viewed as dynamic impedance.
- Voltage controller can be viewed as dynamic admittance.
- **<u>Note:</u> Admittance and Impedance are used interchangeably.**
- Why not model the entire system as an impedance?
- Impedance plots are a good predictor of stability.

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Why Investigate Harmonics/Resonance?

- Global impedance (control inclusive) changes with any change at all.
- Changes affect the harmonic/resonance points.
- Control parameter particularly affect resonances.
- Shape of impedance functions over frequency.
- Possibility of resonance points moving to the LF region.
- Control system as a means to manipulate impedance.

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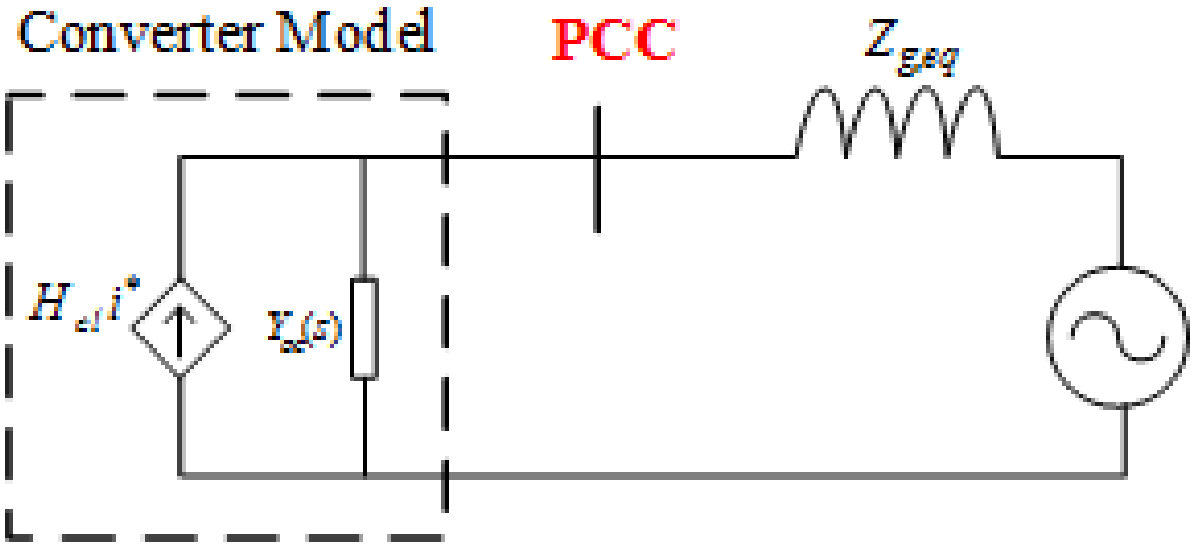
Impedance Modelling

- Inner-loop and AC grid dynamics:

$$i_{c,dq} = H_{cl}^{i} i_{c,dq}^{*} - Y_{oc} U_{s,dq}$$

$$Y_{oc} = \frac{Y_{ac}}{1 + H_{ol}^{i}}$$



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Impedance Modelling (2)

- Outer-loop, inner-loop, AC grid dynamics, DC grid dynamics:
  - $U_{dc1} = H_{cl}^{v} U_{dc1}^{*} - \frac{KY_{oc}H_1(s)}{1+H_{ol}^{v}} U_{s,dq} + Z_{ic} I_{dc2}$

$$Z_{ic} = \frac{Z_{dc,p}}{1 + H_{ol}^{v}}$$

$$Y_{oc}^{v} = \frac{Y_{oc}}{1 + H_{ol}^{v}}$$

- Notice we can actually construct the impedance of a system if we know the eigenvalues of the system.

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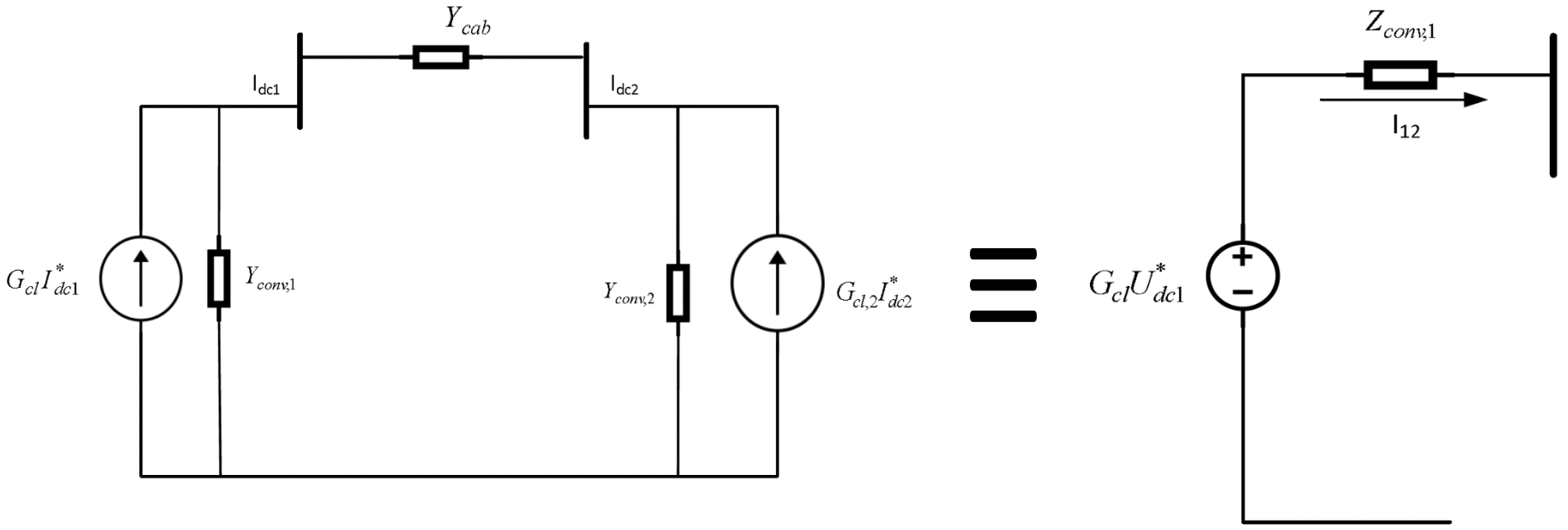
Extension to Meshed Grid



a. DC side current source bus circuit

b. DC side voltage source equivalent

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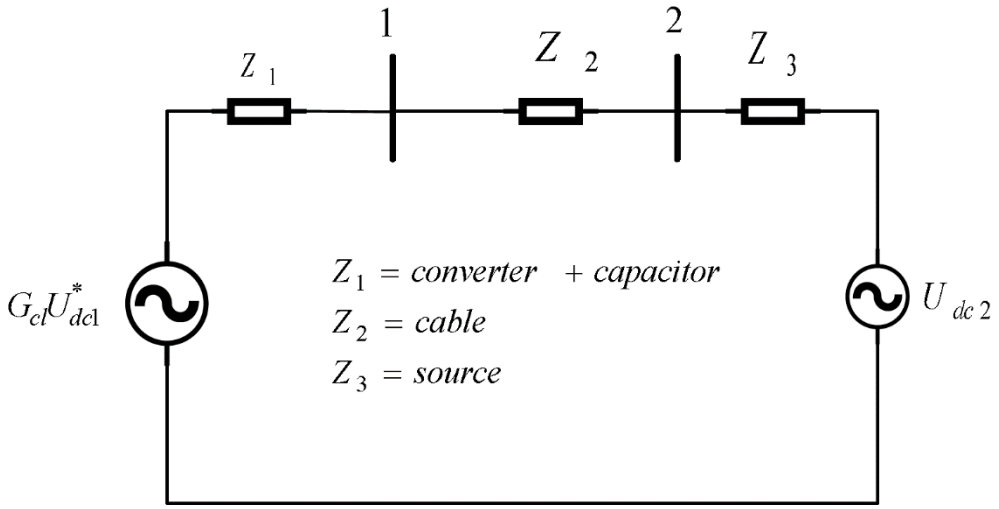
To have a matrix that describes the DC Side



a. DC side Z-bus circuit

- **All variables are in s-Domain**

$$Z_{bus,dc} = \begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix}$$

$$Z_{11} = \frac{Z_1 Z_2 + Z_1 Z_3}{Z_1 + Z_2 + Z_3}$$

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Then…

- The same is done for the AC grid.
- Thus, we can have a whole matrix that describes the network dynamics and control of an MTDC as a single matrix,
- And that of control and AC grid as a single matrix.
- Then, we select the buses that we are interested in with respect to the corresponding AC bus OR analyse the DC bus matrix distinctly for DC side analysis.
- Same applies for AC bus.

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Analysis

- Bode plot of open loop gains and influence of parameter sensitivity on frequency response.
- Bode plot of closed loop charateristic equations.
- Nyquist stability criterion.
- Routh-Hurwitz stability criterion

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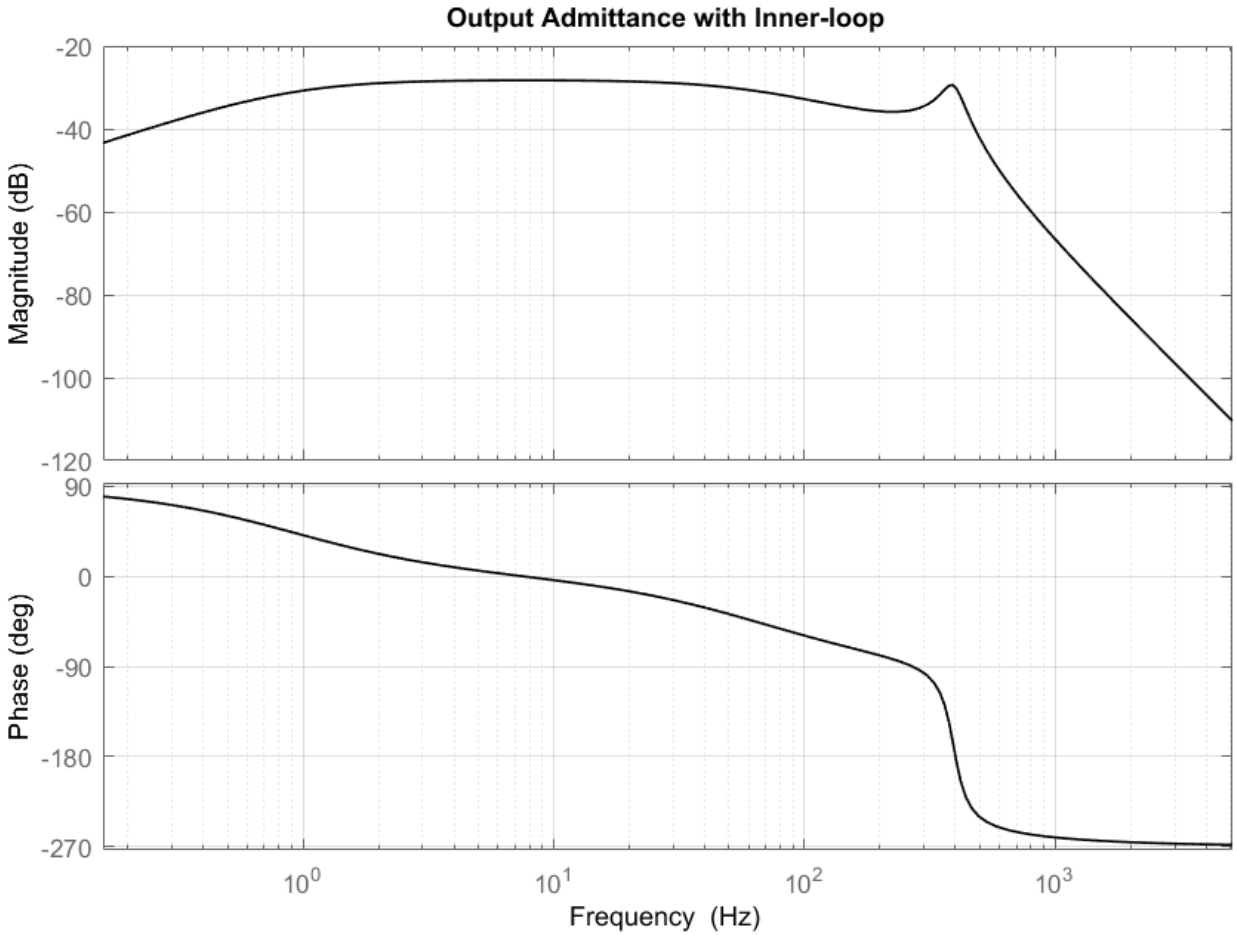
Results

- AC output admittance with base control data (Inner-loop)



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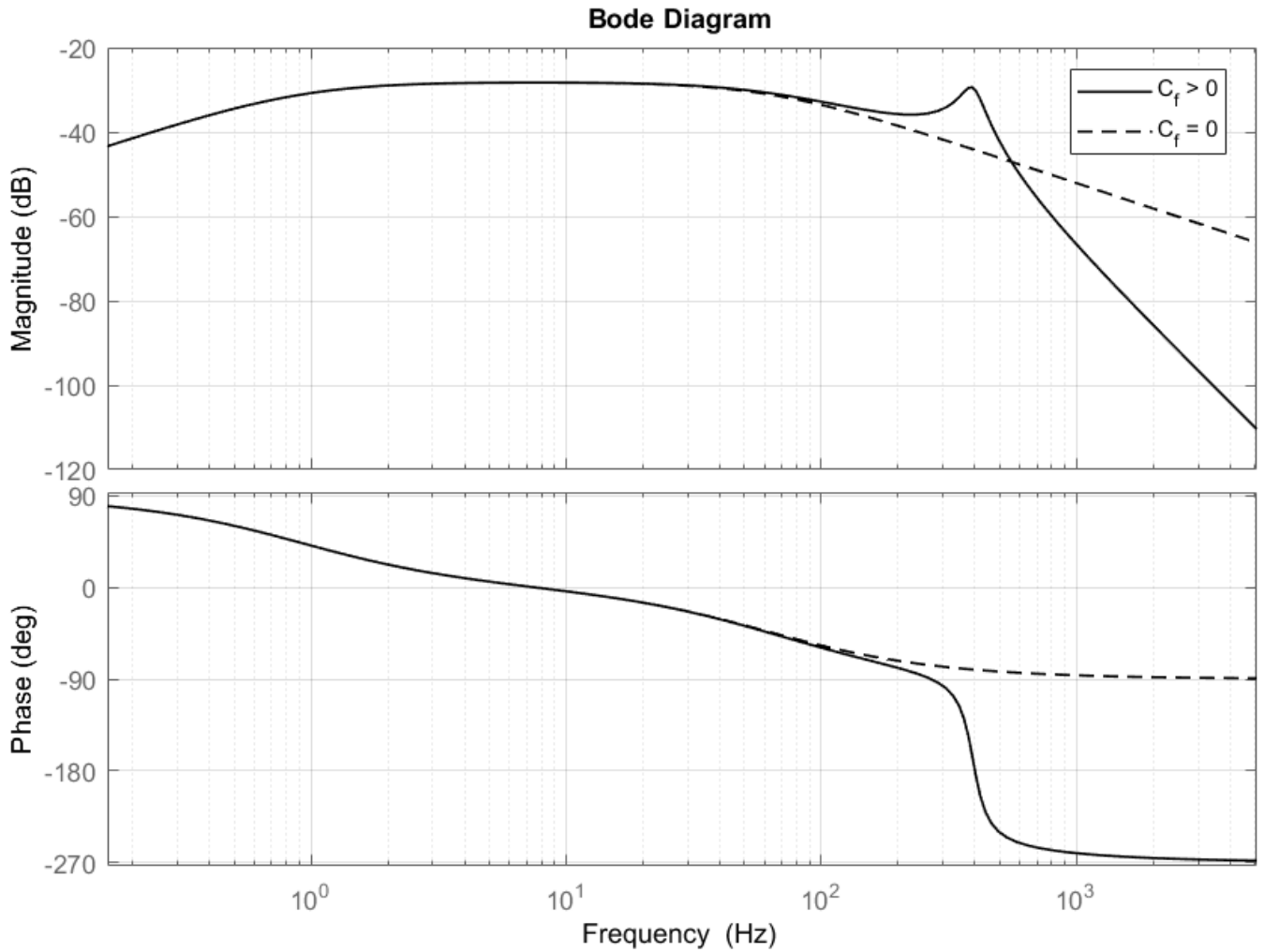

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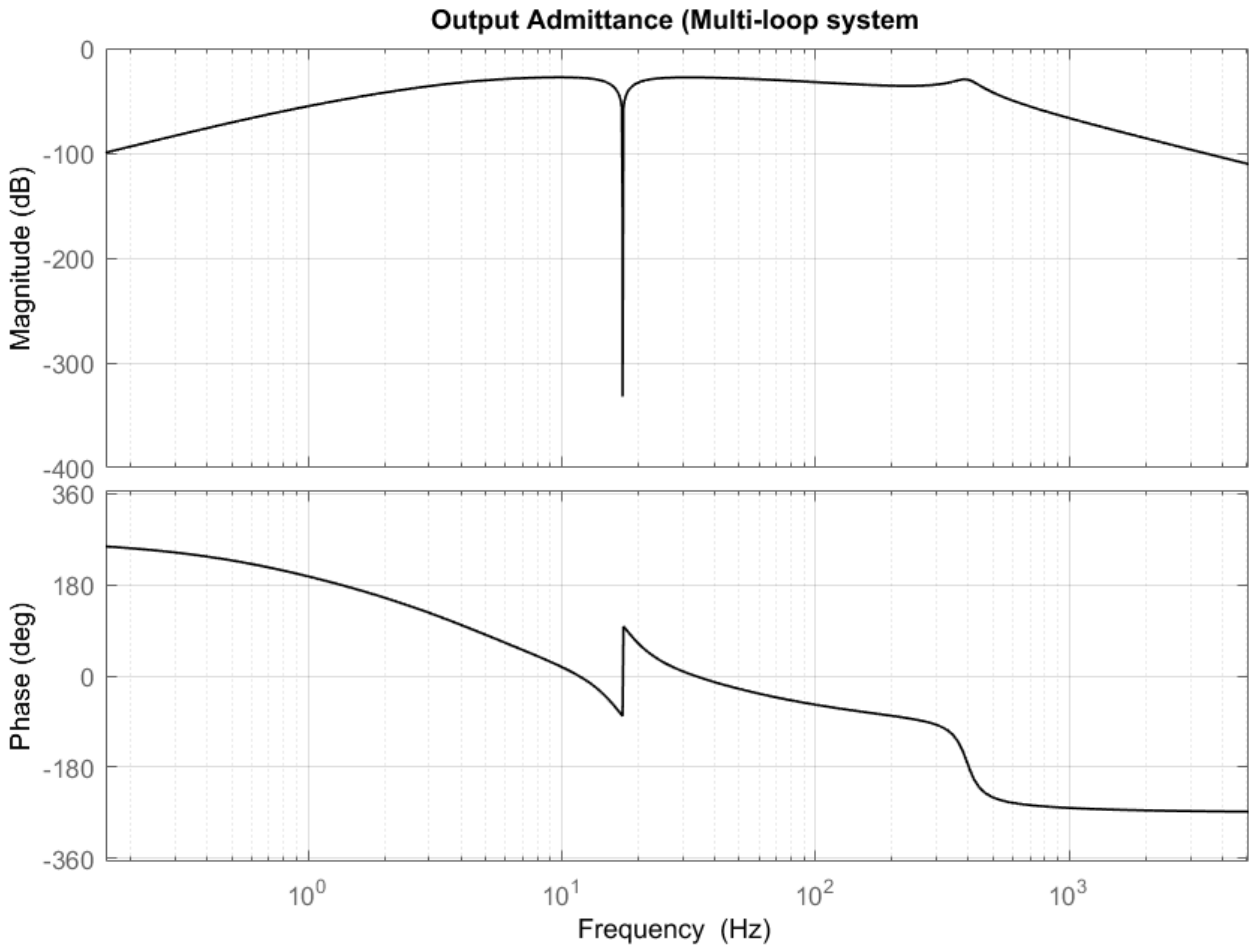
Results

- AC output admittance with base control data (outer-loop)



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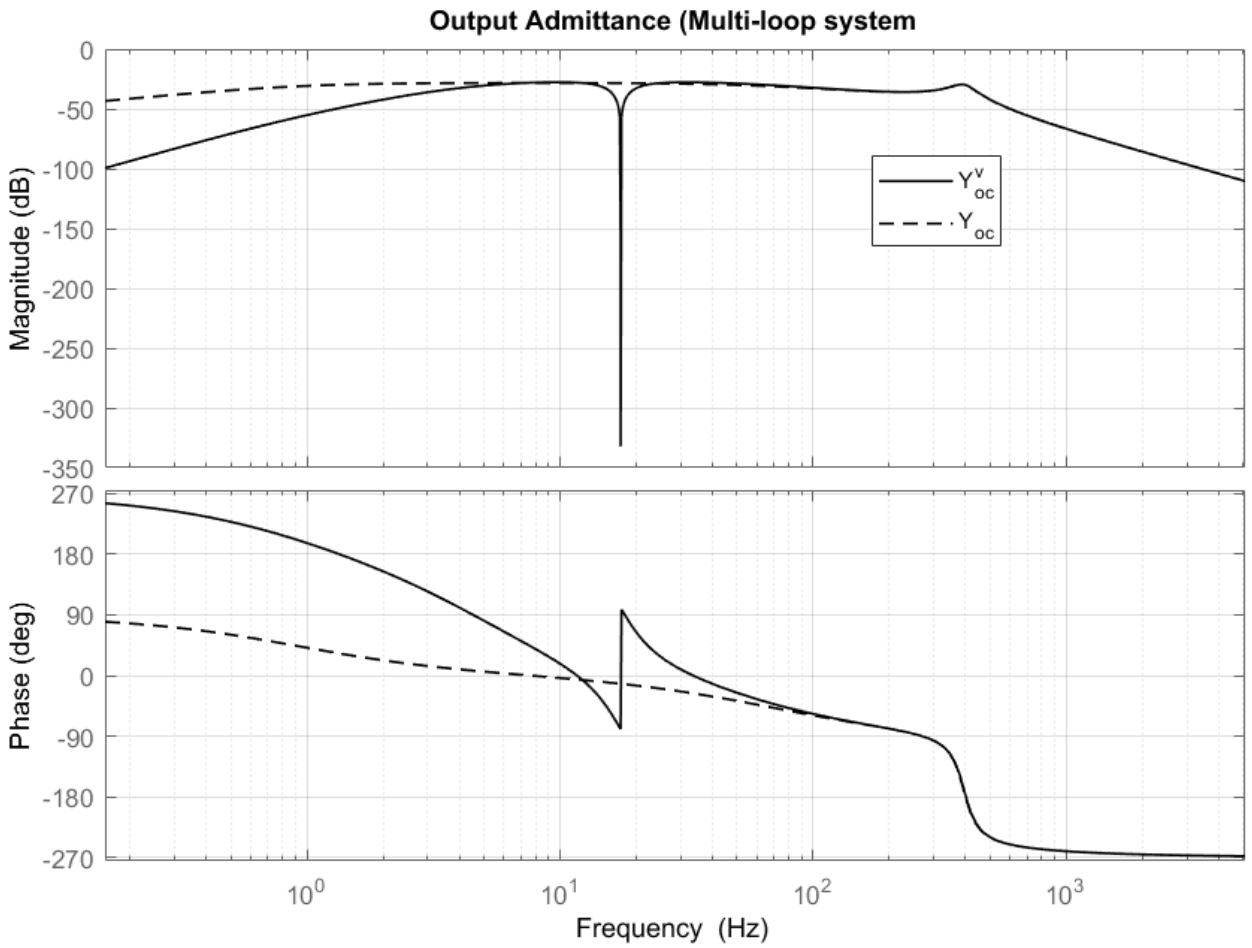
Results

- Impedance change from inner-loop to outer-loop



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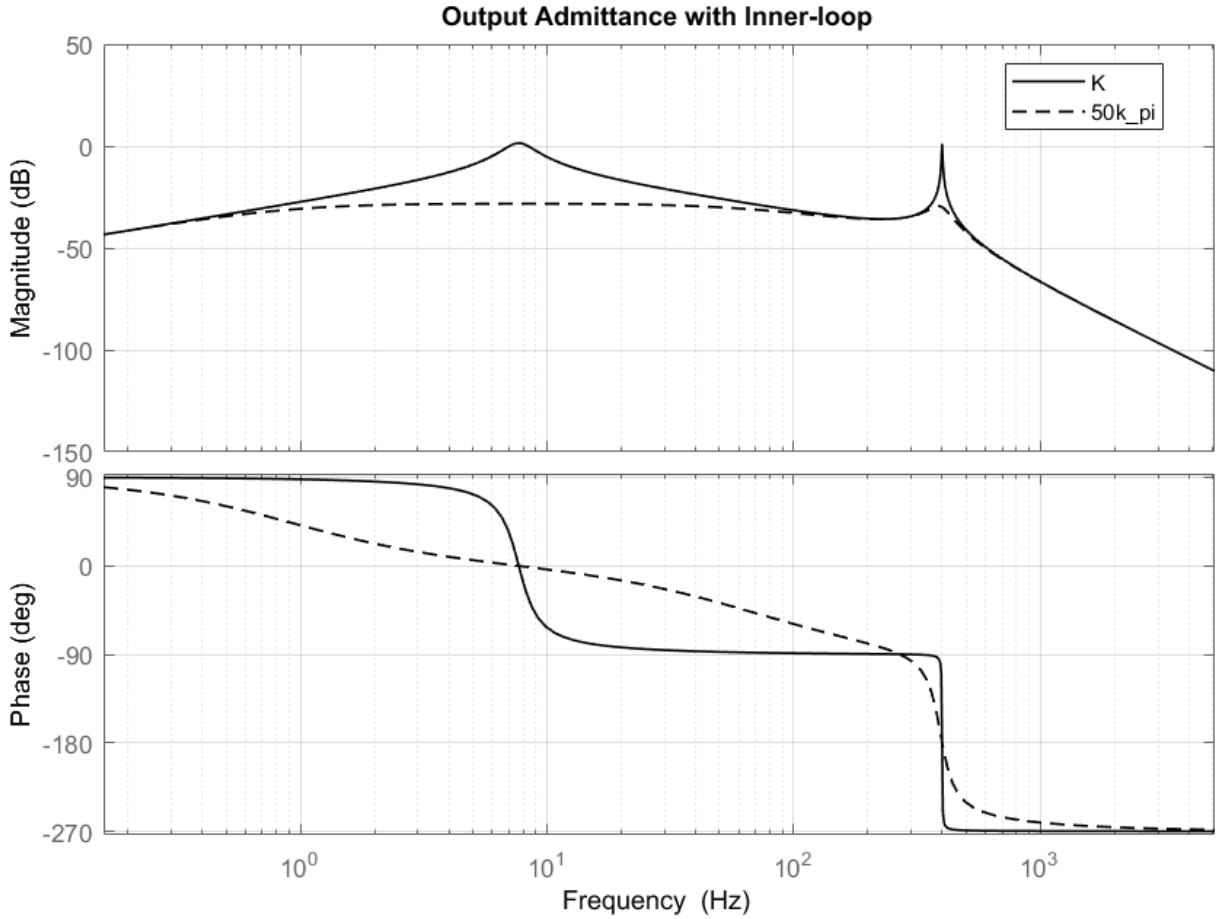
Results

- Sensitivity analysis to parameter variation (inner-loop)



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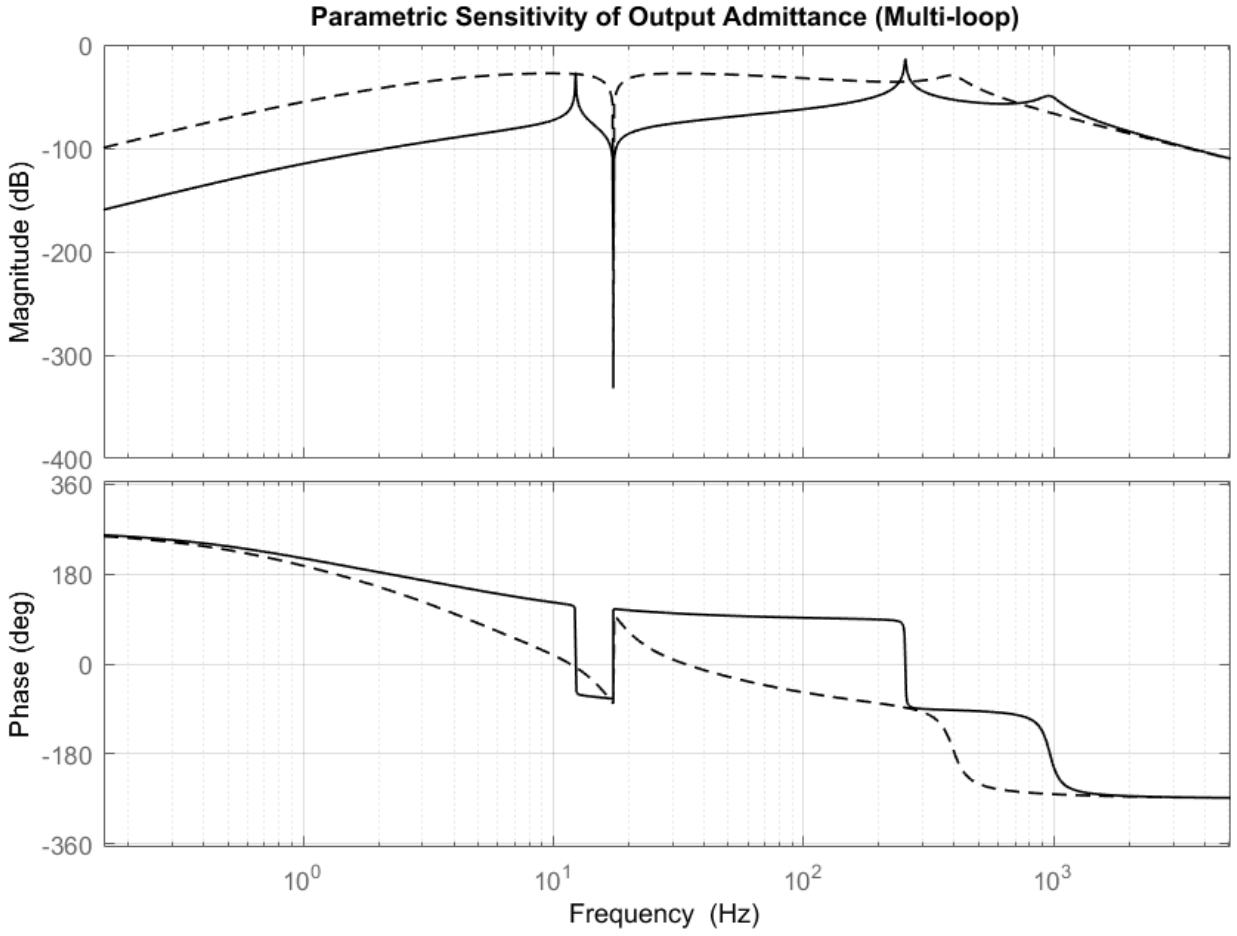
Results

- Sensitivity analysis to parameter variation (Multi-loop)



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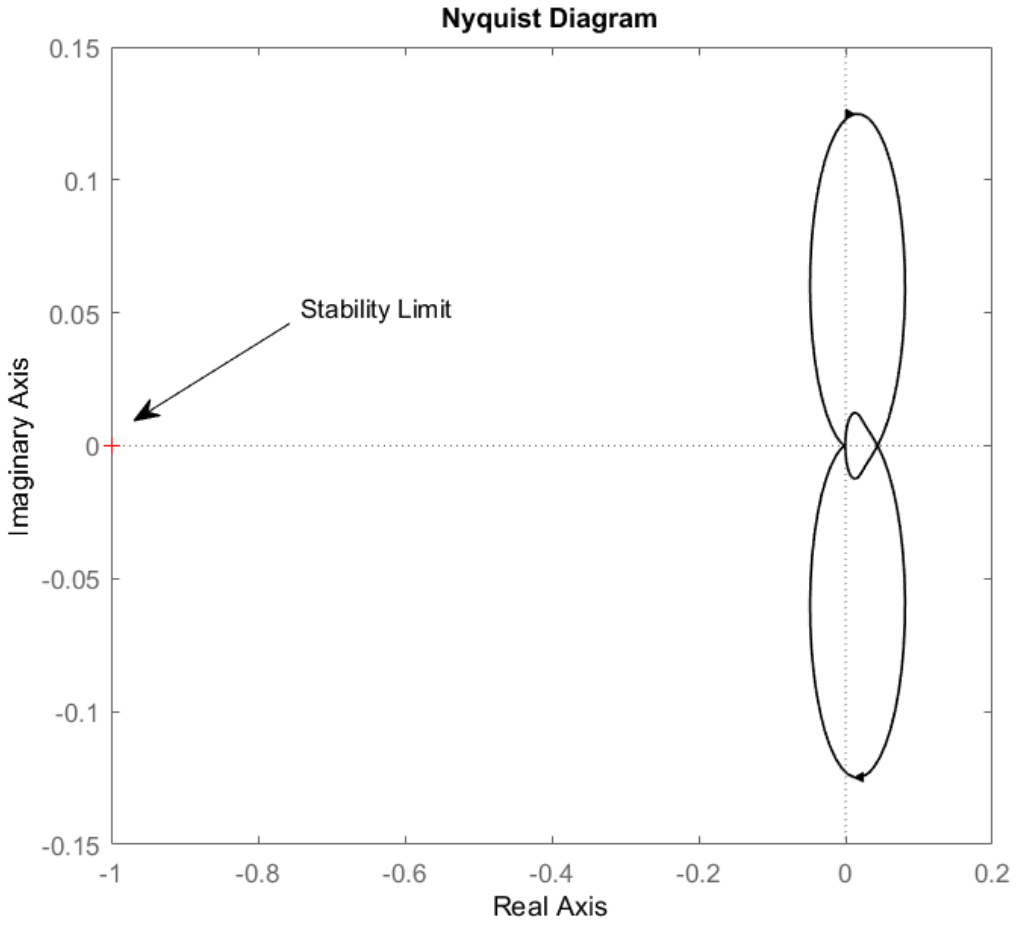
Results

- Stability based on Nyquist's criterion



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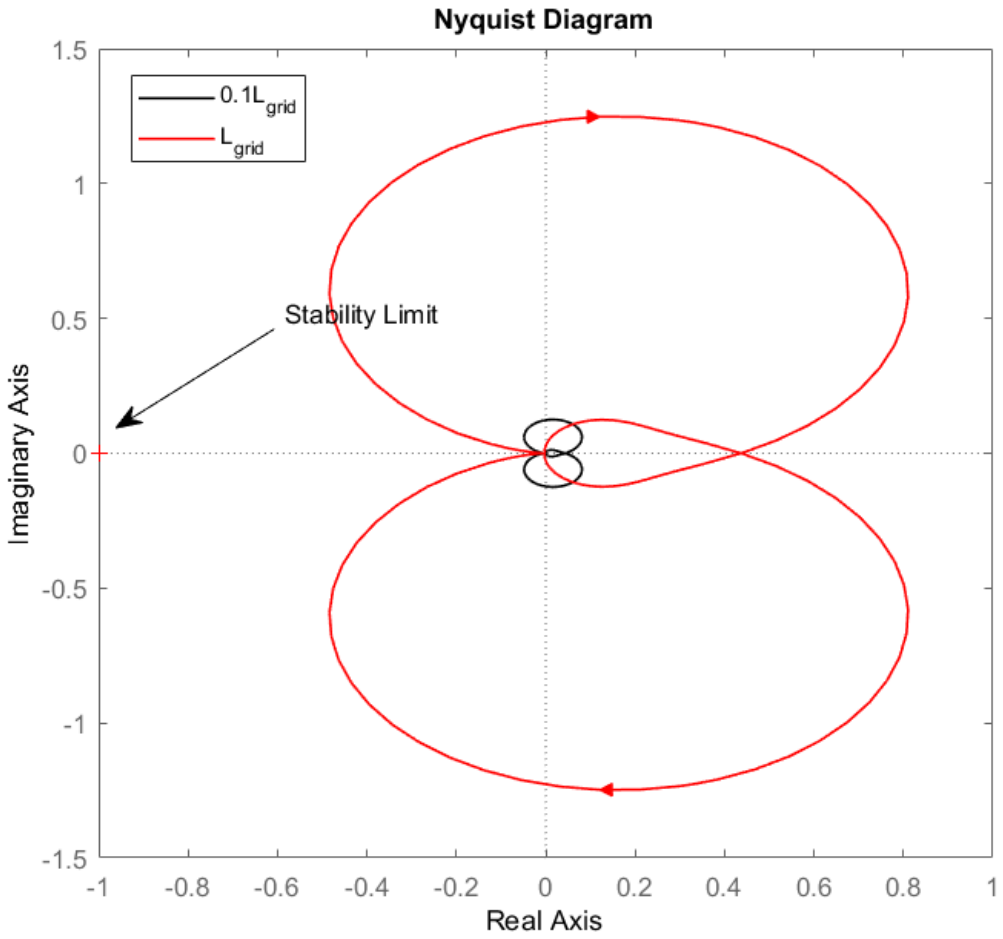

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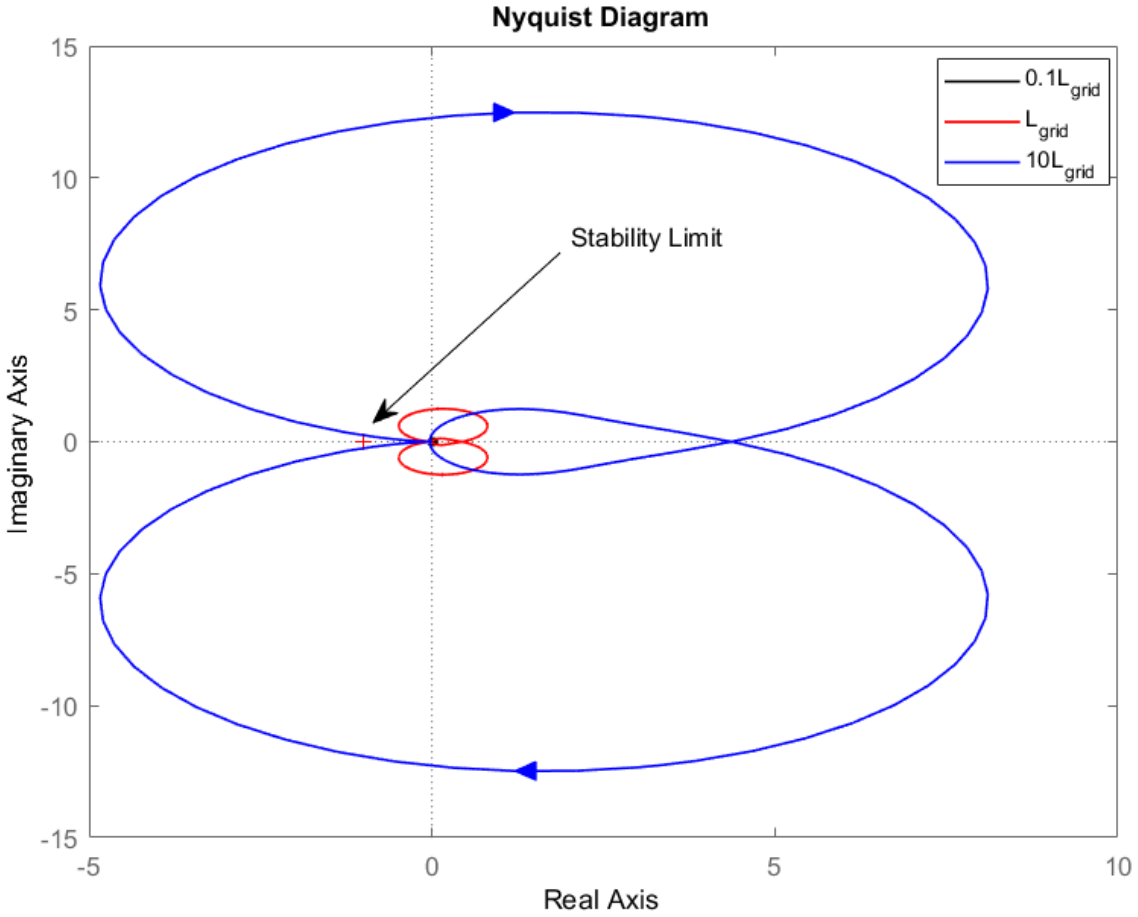

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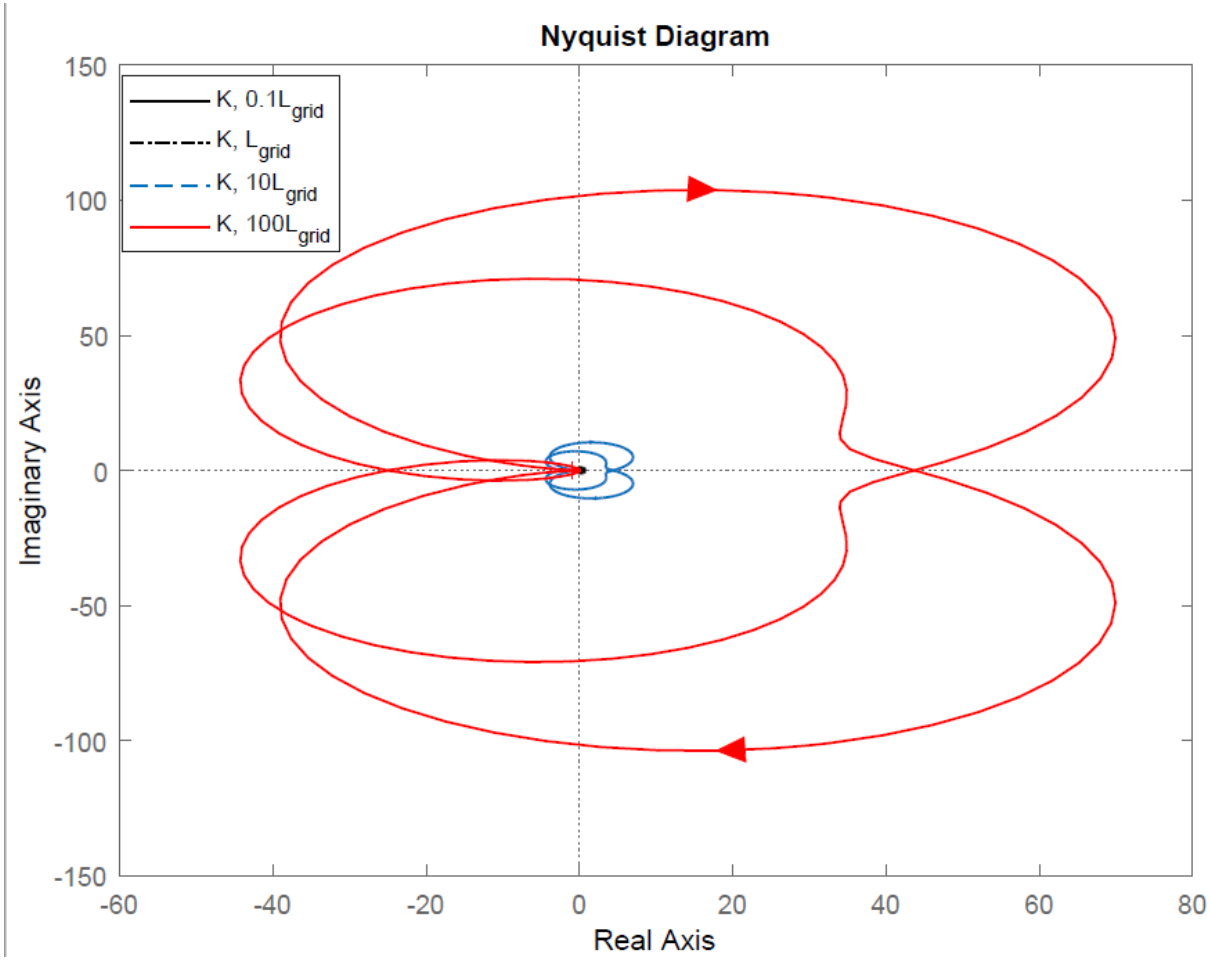
- Stability based on Nyquist's criterion (Outer-loop before tuning)



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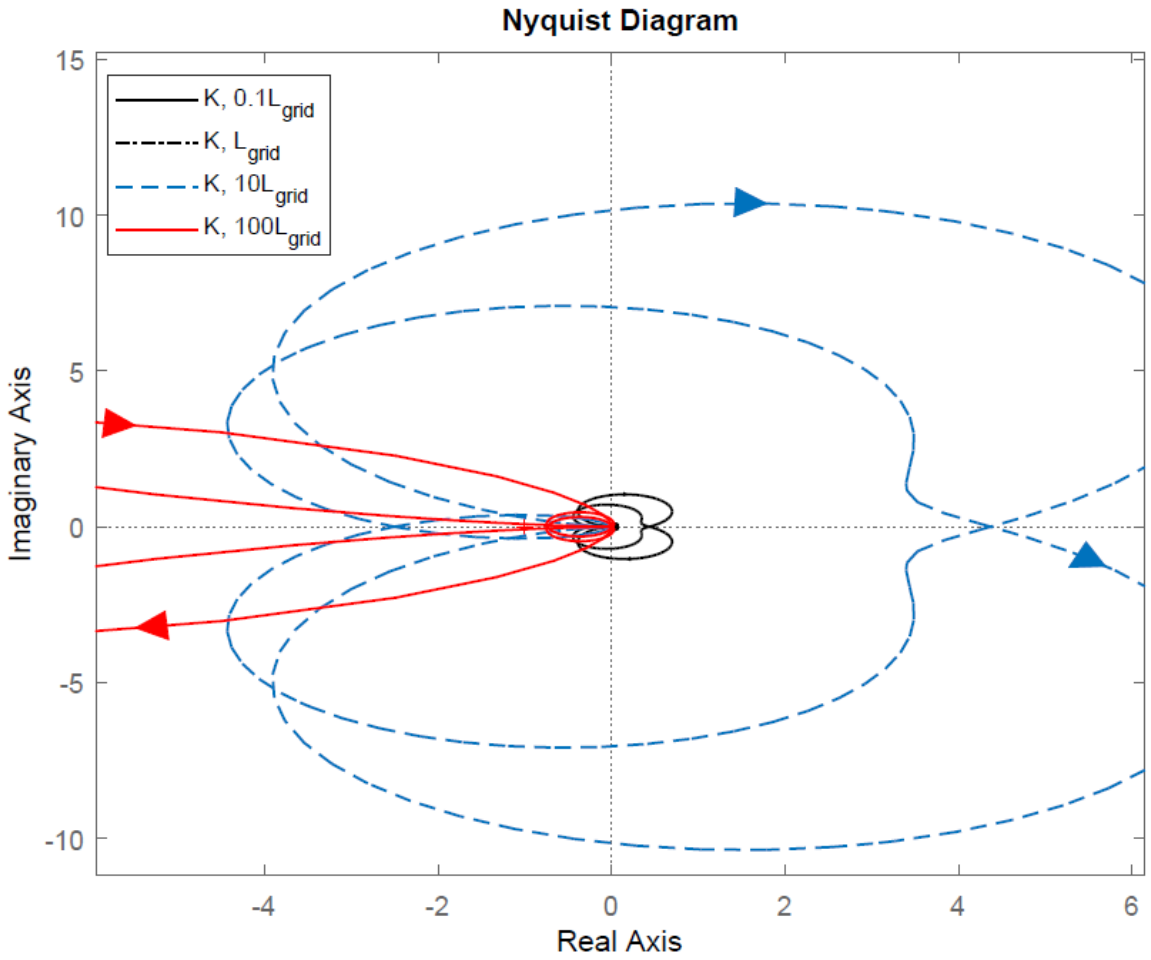

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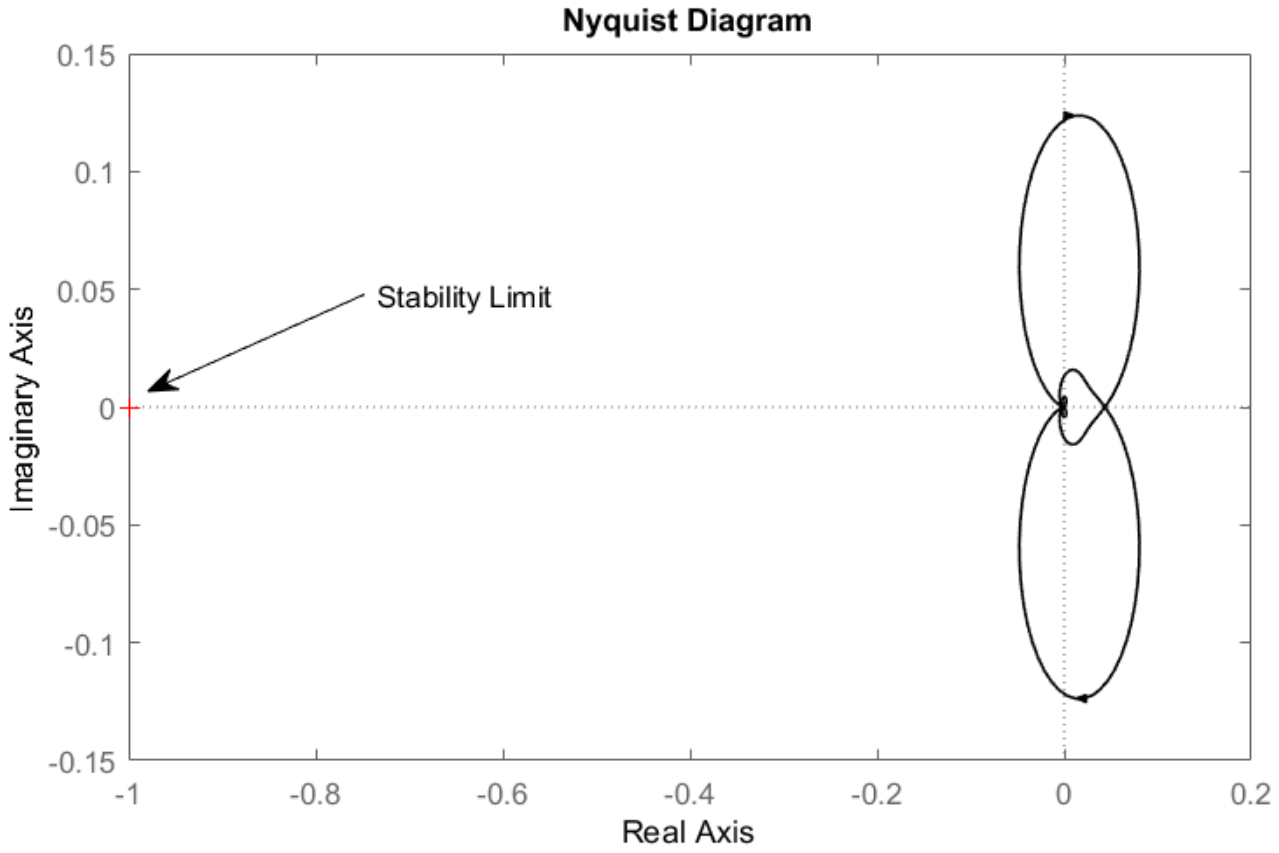

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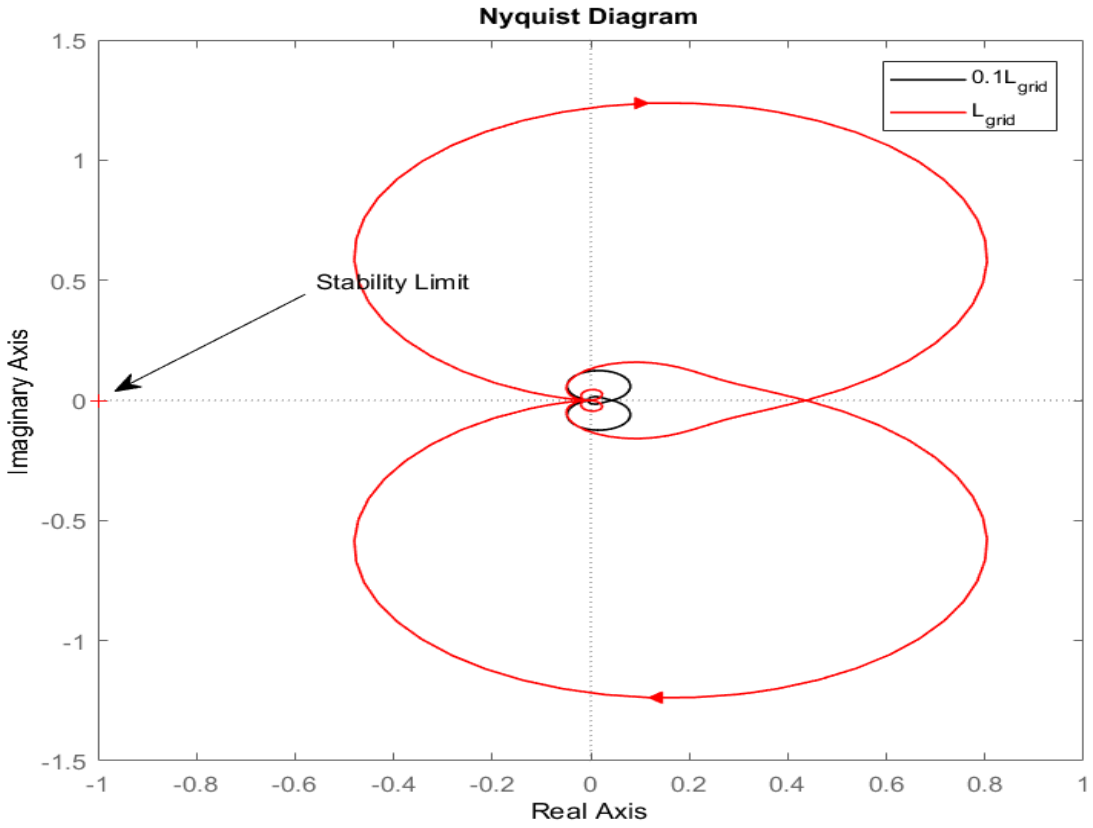

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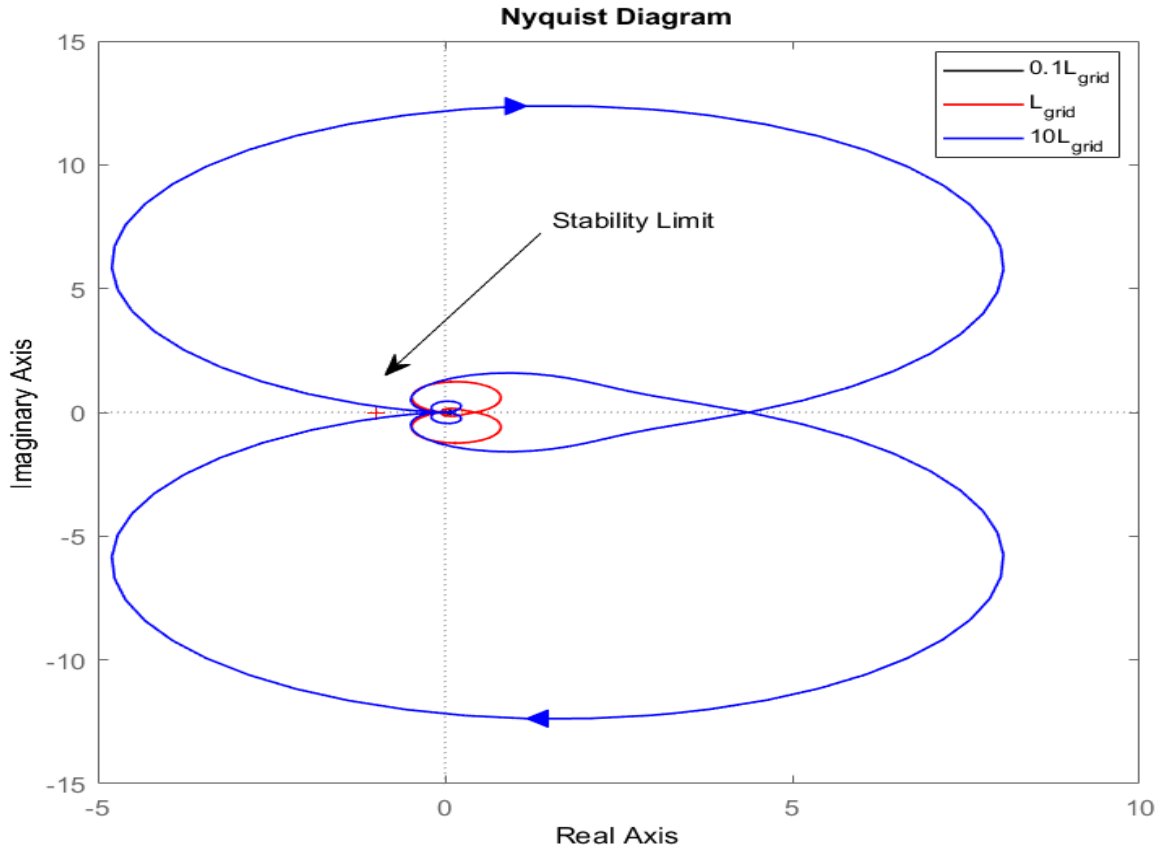

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Publications (Expected)

- Two conferences accepted – awaiting review.
- One journal on parametric sensitivity due in August.
- One journal on DC stability analysis with impedance models expected.
- One journal on AC stability analysis considering synchronous generator and converter controls.

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Thank you!

Questions/Feedback

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