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Investigation of Passivity Behavior of Synchronous Generators Connected to Passive Network

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Introduction

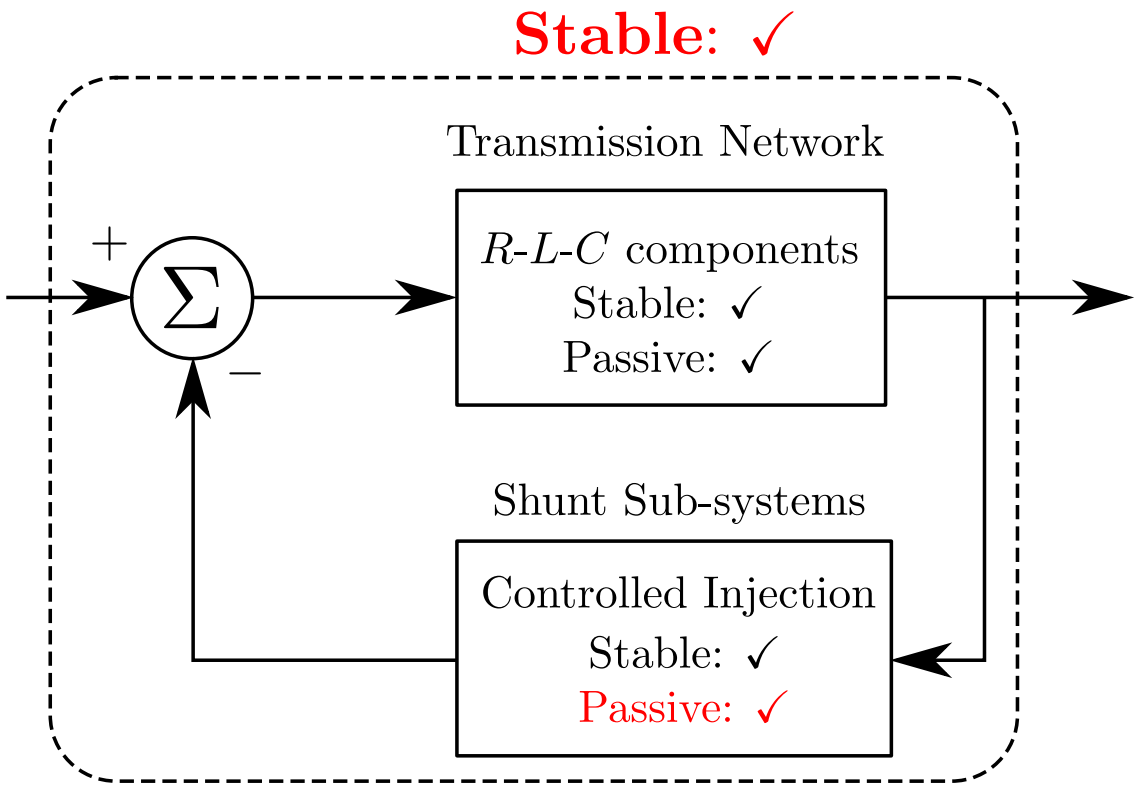
- Stability studies: dependent on entire system information.
- New device installation: new studies every time.
- Stability criterion: dependent on grid information.

Positive Real Systems

- Stable: $G(s)$ is stable (all poles in LHP).
- Passive: $G(j\omega) + G^T(-j\omega) \geq 0, \quad \forall \omega \in \mathbb{R}$.
- A square $G(s)$ is positive real if it is passive and stable.
- Property: Negative feedback connection is also positive real.

Small-Signal Stability Criterion

Passivity based "decentralized" stability criterion.[1]

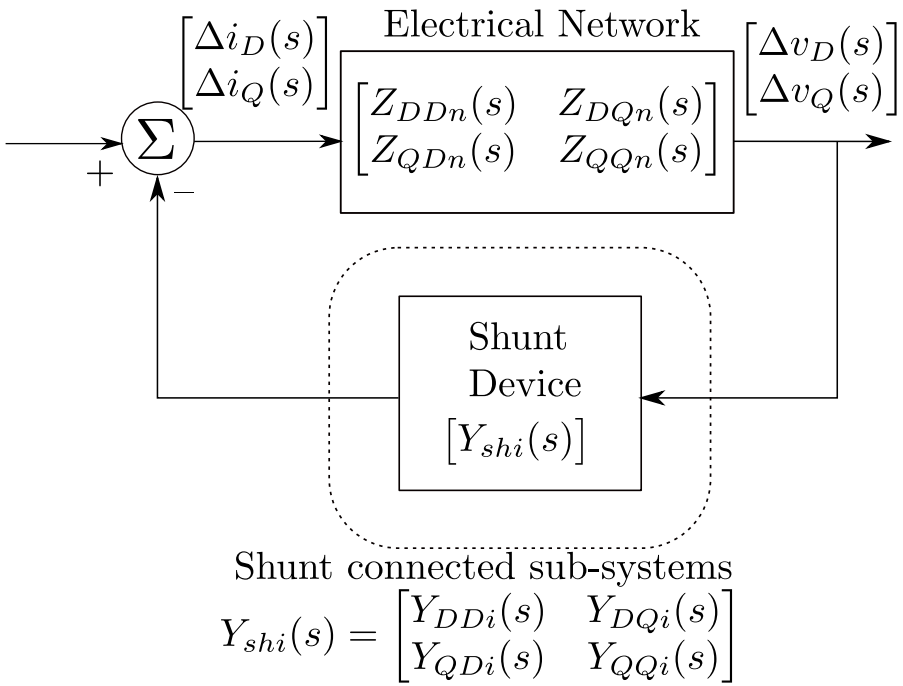


[1] K. Dey and A. M. Kulkarni (2019), "Passivity Based Grid-Connectivity Criterion for Ensuring Stability of a Network With Controlled Power Injection Devices".

Advantages

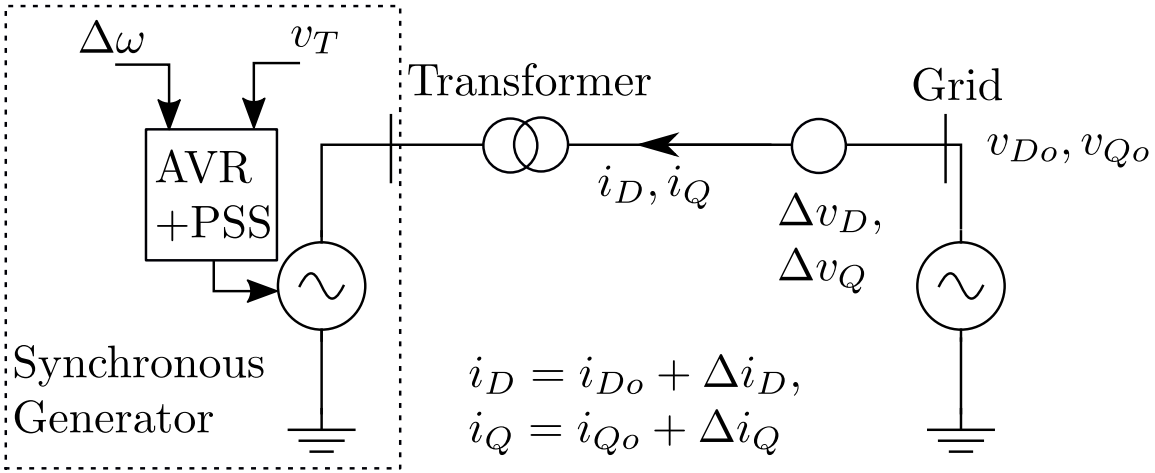
- Decouples the stability analysis into independent system studies.
- Shunt sub-systems are positive real $\Longrightarrow$ system is stable.

- Criterion can be checked easily and independently for different devices.
- Grid frequency response is NOT needed.
- Can be extended independently for multiple devices.



Passivity of Synchronous Generators

- Stability criteria: Frequency domain check.
- Obtain frequency response numerically: frequency scanning[2].

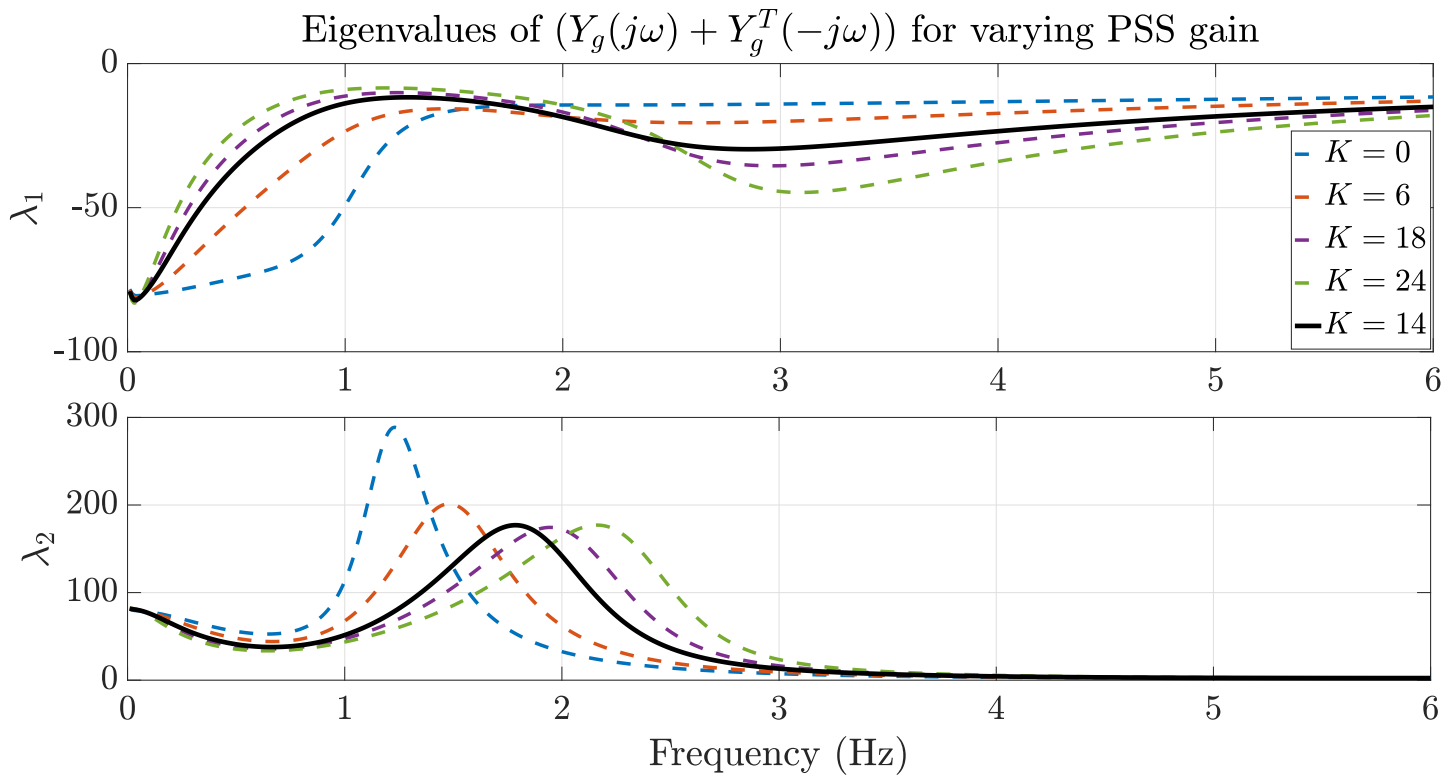


- Passivity of synchronous machine: Impact of different controllers.
- PSS and governor gain variation: checked here.

[2]X. Jiang and A. Gole (1995), "A frequency scanning method for the identification of harmonic instabilities in hvdc systems,"

Effect of PSS

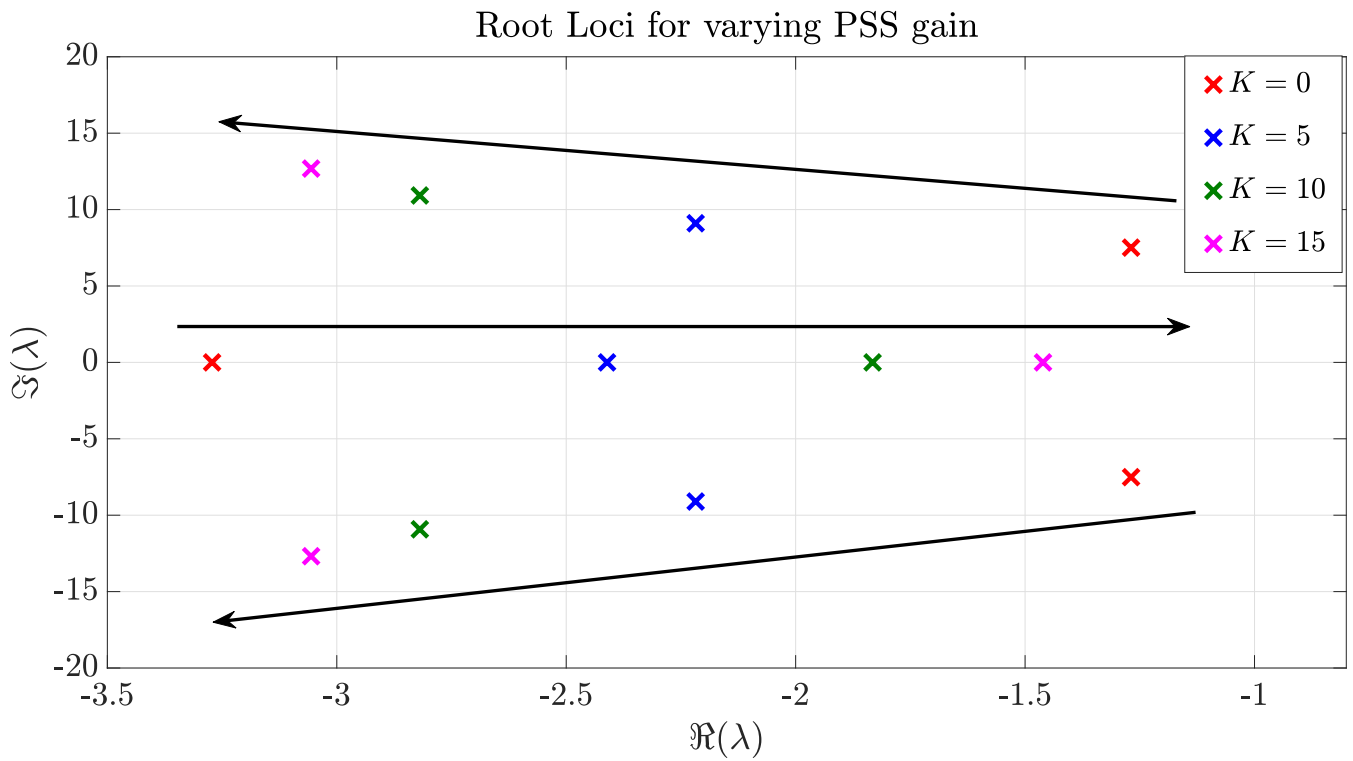
- Swing frequency range: passivity is modified with PSS gain variation.



- Proper tuning of PSS gain **minimizes** non-passivity.

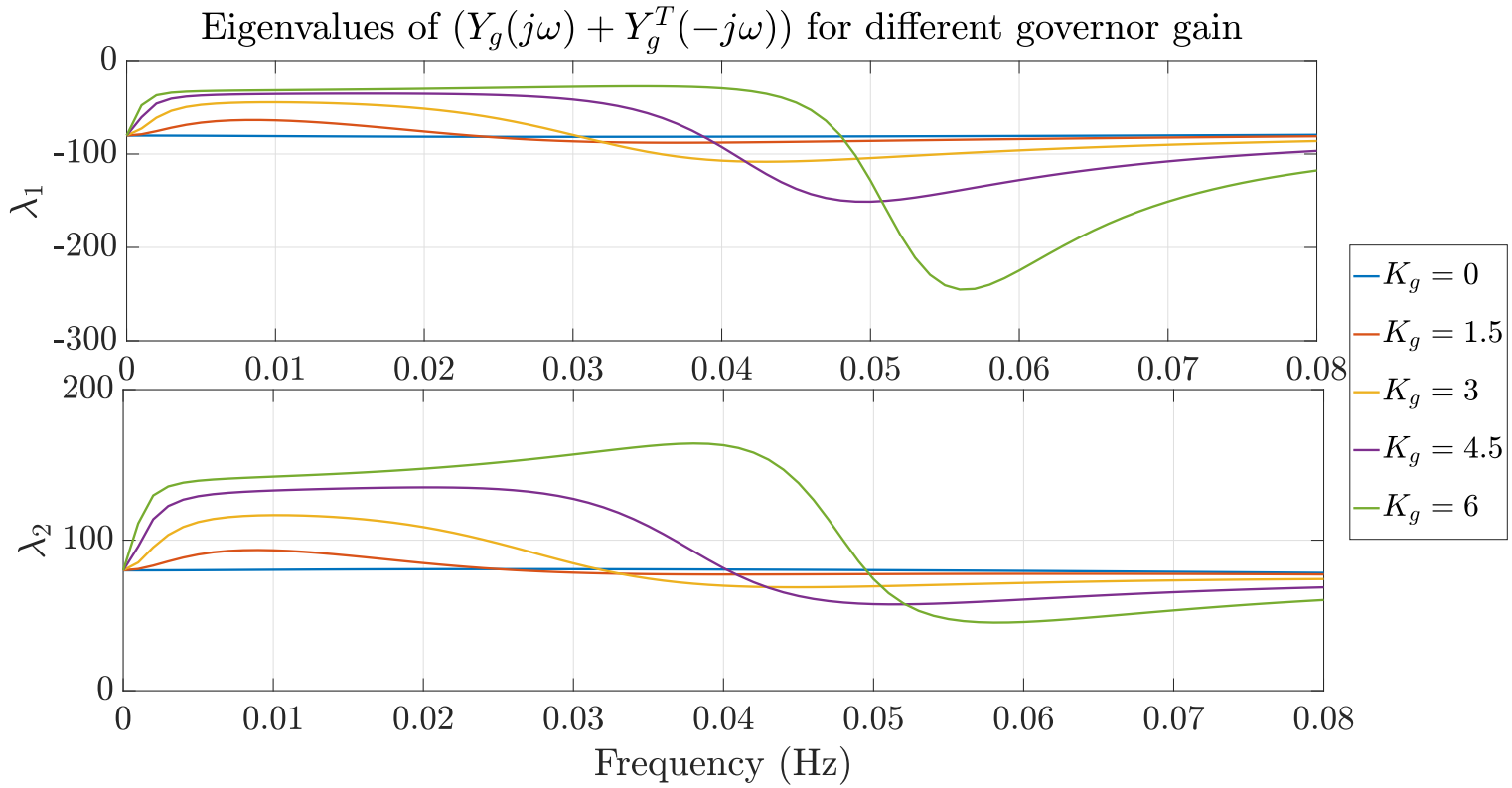
Correlation with PSS Tuning

- Optimal gain: trade-off in root loci of the system.



Effect of Governor

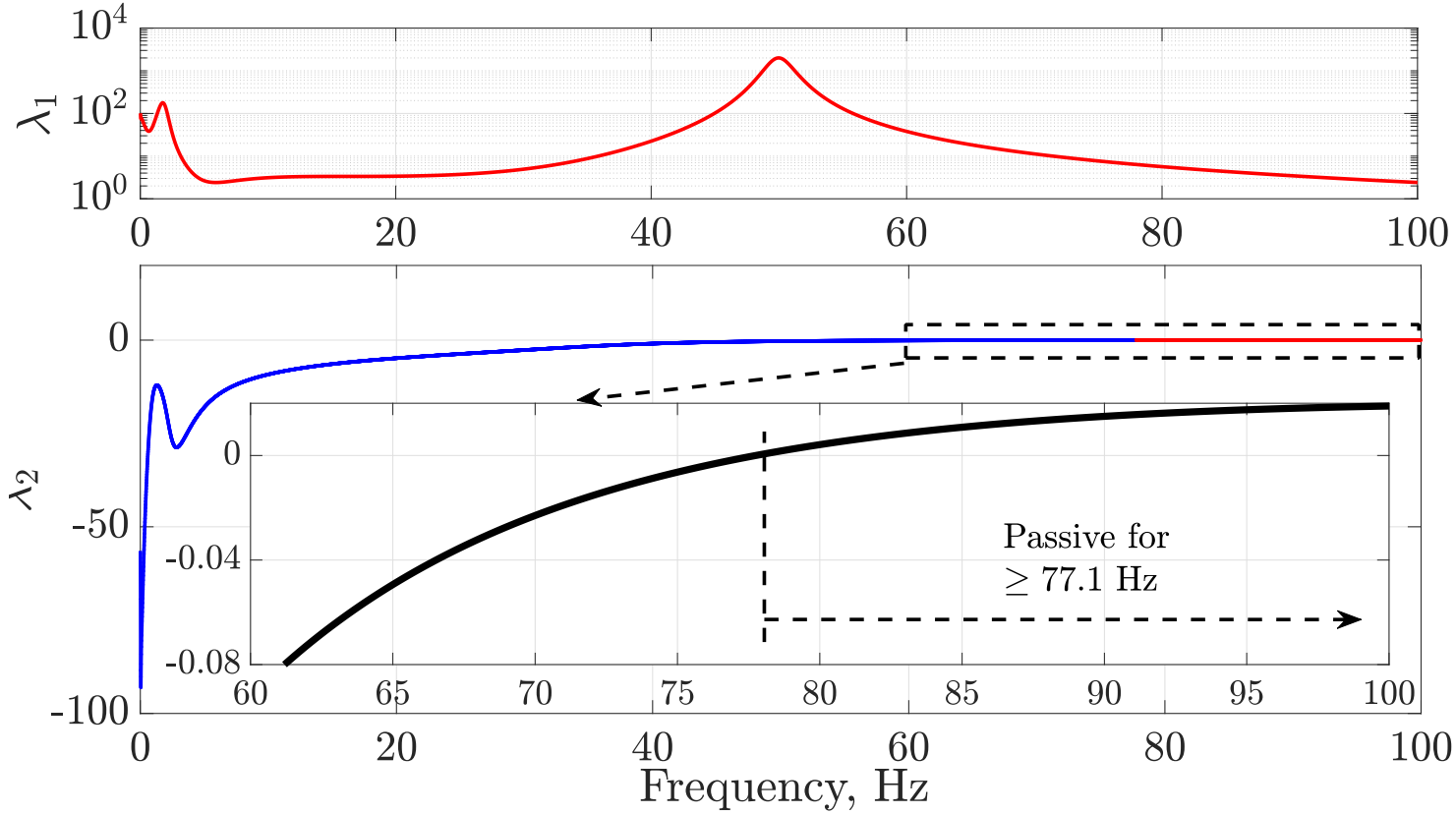
- Governor does not improve passivity behavior.



- Passivity of droop control strategy (analytically): ✗

Overall Frequency Range

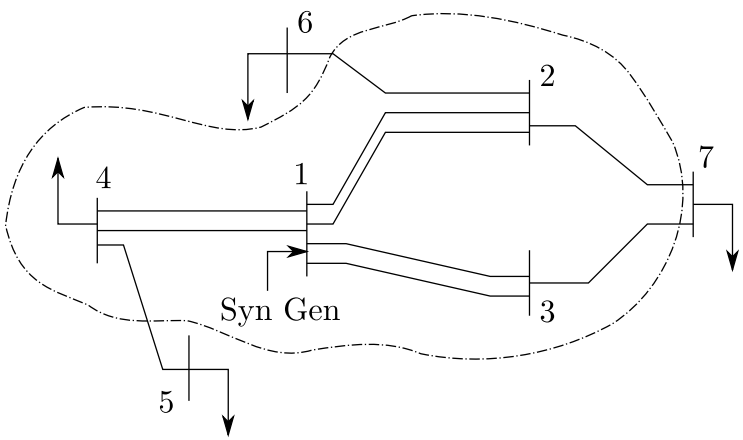
- Passive in higher frequency range (beyond the controller bandwidth).

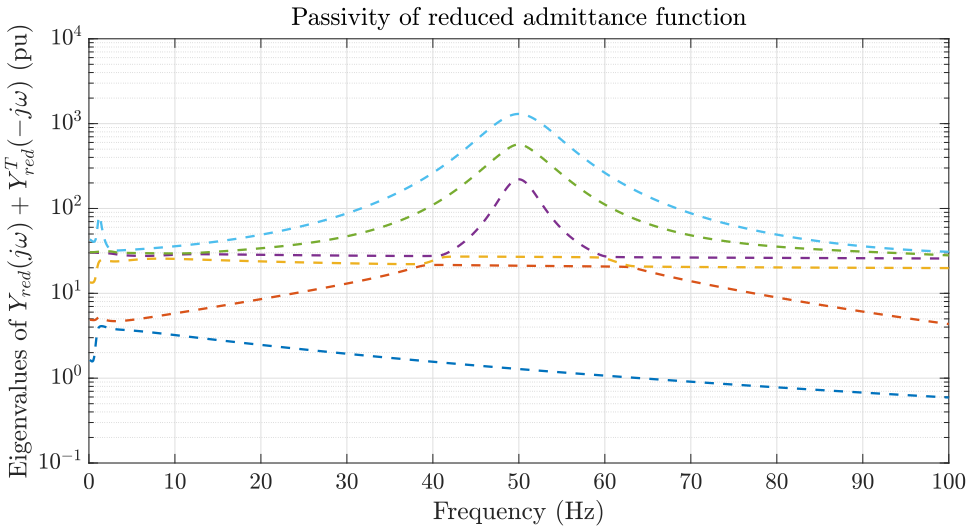


- Passivity in lower frequency range: ✗

Network Encapsulation: Observations

- Can we **encapsulate** the non-passivity of these devices?
- Passivity of the reduced impedance/admittance of each area.





Sufficient Condition

All the regions have to be positive real from their boundaries.

Conclusions

- Decentralized stability criterion: dependent on **individual** device behaviors only.
- Synchronous generators: controllers do not eliminate non-passivity.
- Form passive boundaries: Encapsulate non-passive devices by transmission links.
- Adaption: Requires positive real behavior from the boundaries.
- Grid frequency response needed: Only for the low frequency (non-passive) range.
- Alternate approach: Apply passivity based stability to **multi-time** scaled transients (with **appropriate** input-output pairs).

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