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Impedance-Based Stability Assessment of Power Systems: Correlation Study on Operating Conditions, Mode frequencies, and Stability Margins

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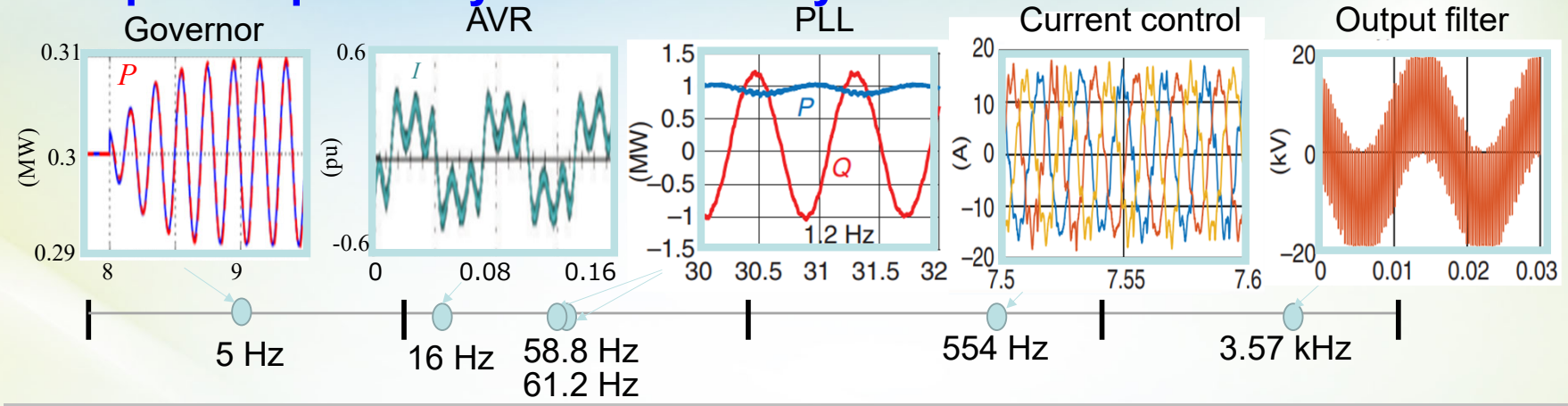
AIST

1. Background and Objective

2. Case Studies and Results

3. Conclusion

Examples of power system instability



[Ref.]
NREL: 10.1109/MELE.2020.3047166, S. Chen: 10.1109/TPEL.2025.3557035, J. Wang: 10.35833/MPCE.2024.000903

Above oscillations are caused by IBRs (inverter-based power resources).

Preliminary stability analysis is crucial.

→ **Impedance based analysis** has gained significant attention.

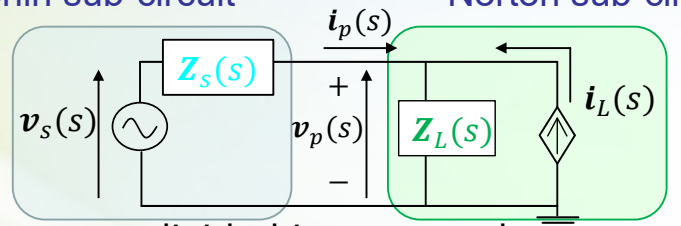
Features of impedance-based analysis

Source

Load

Thevenin sub-circuit

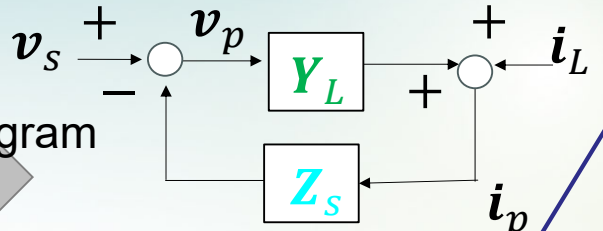
Norton sub-circuit



system divided into two subsystems

Loop Gain $L = Z_s Z_L^{-1}$

Block diagram

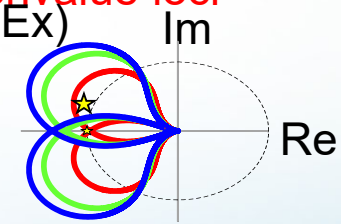


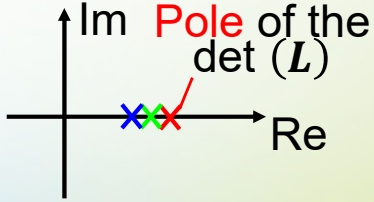
$$v_s \rightarrow \frac{-Y_L}{1 + Z_s Y_L} \rightarrow i_p$$

$\det(L - \lambda I) = 0$

Eigenvalue loci

Ex)

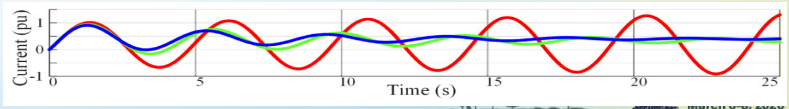




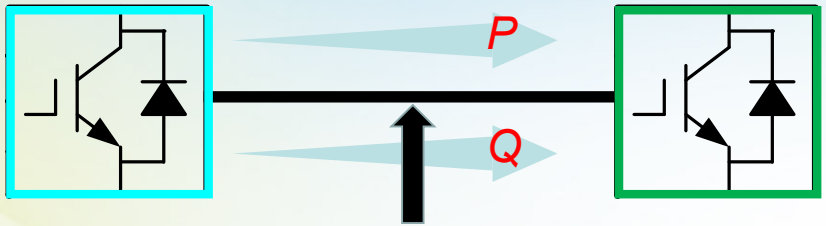
The Generalized Nyquist Criterion (GNC)

- Loop gain : $L = Z_s Z_L^{-1}$
- Characteristic equation : $\det(L - \lambda I) = 0$

Stability is determined by Z_s and Z_L.



Relation of Z, λ and Stability



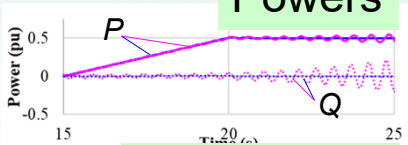
Stable? Unstable?

Ex)

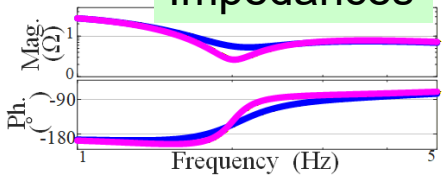
Operating Point \ IBR Parameter	Ex) PLL Proportional Gain	
	6	12
(P,Q) = (0.5,0)	Unstable	Stable
(P,Q) = (0.8,-0.8)	Unstable	Unstable

IBR Parameter Change

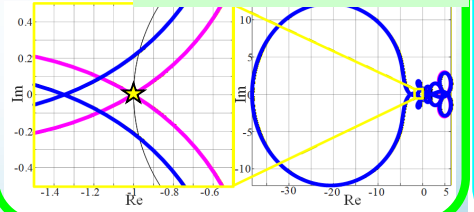
Powers



Impedances

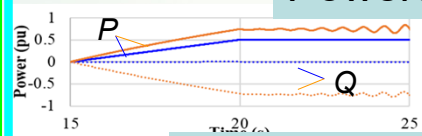


λ & Stabilities

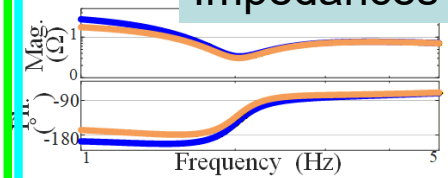


Operating Point Change

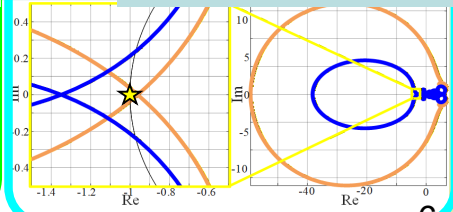
Powers



Impedances



λ & Stabilities



To be solved problem

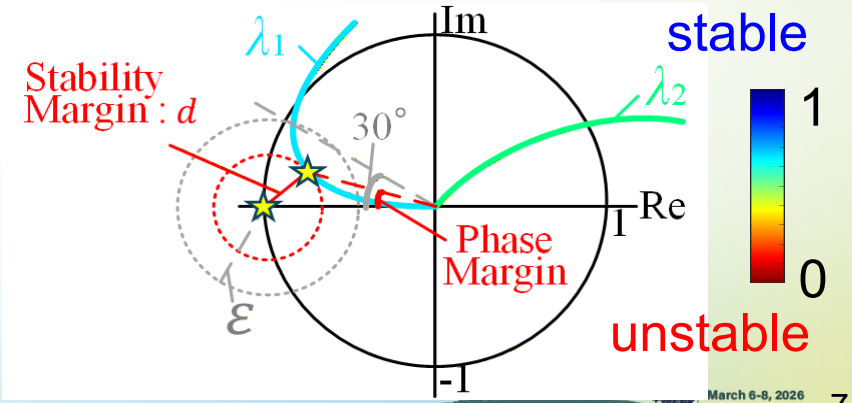
- Avoiding the unstable operation without stopping IBRs.
- Assessing the power system stability without using the GNC

Aim of the Research

Analysis and Improving the Grid Stability **By Changing the Power Flows Without Stopping the Inverter-Operation**

Stability Margin : d

- Evaluate the minimum distance between the eigenvalue loci and the critical point $(-1,0)$.
- The distance is evaluated under the phase-margin of $30°$.



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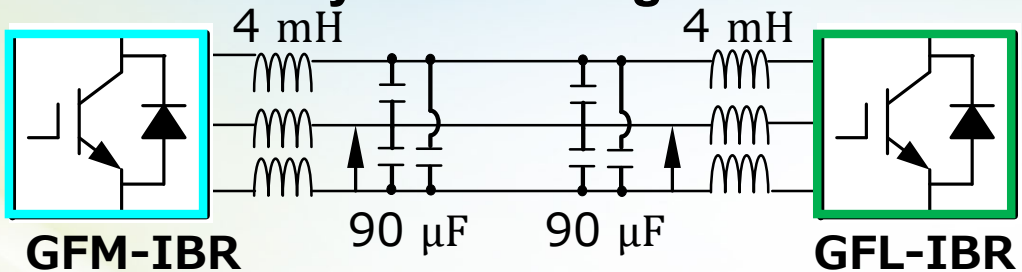
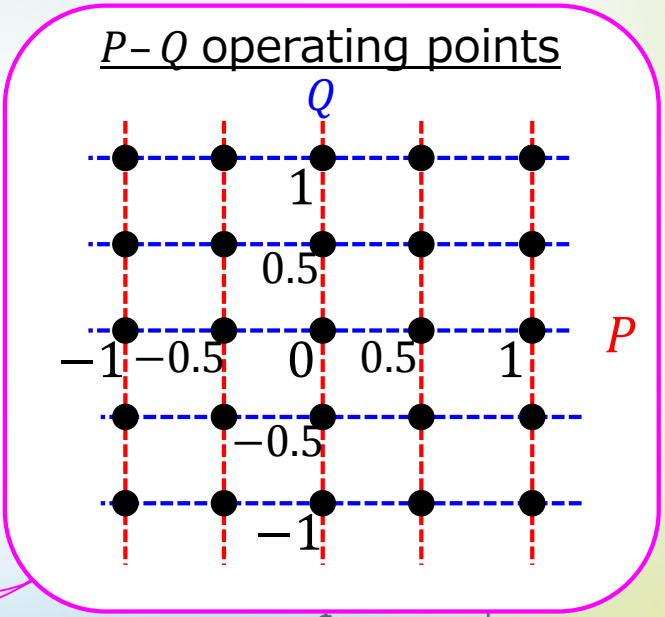
Case Studies

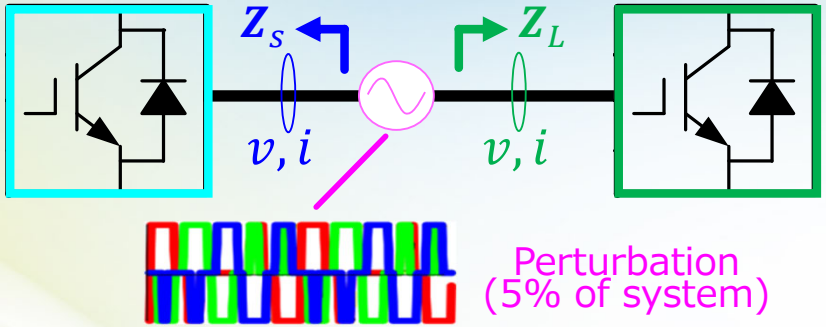
Test System Configuration

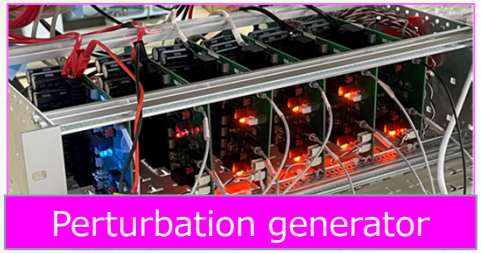


Test Cases

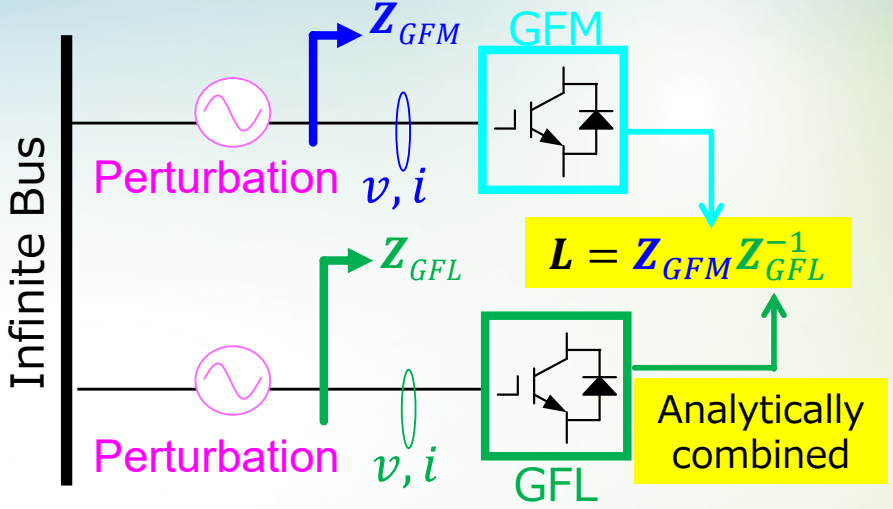


Measured Impedance




Perturbation generator

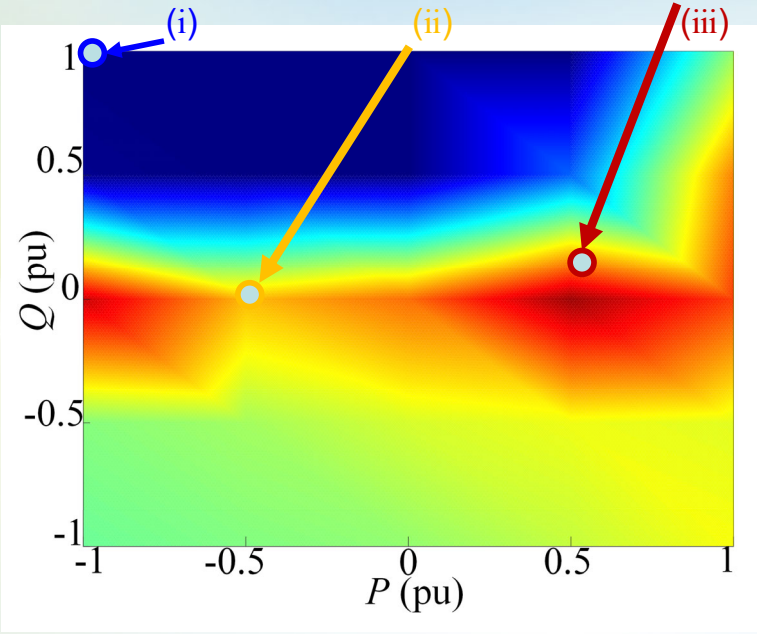
Perturbations worsen the resonance, and safe measurement becomes difficult.



- Each impedance can be measured in safe.
- Stability was evaluated by combining both impedances analytically.

[Ref.] T. Ide (10.1109/ECCE-Europe62795.2025.11238886)

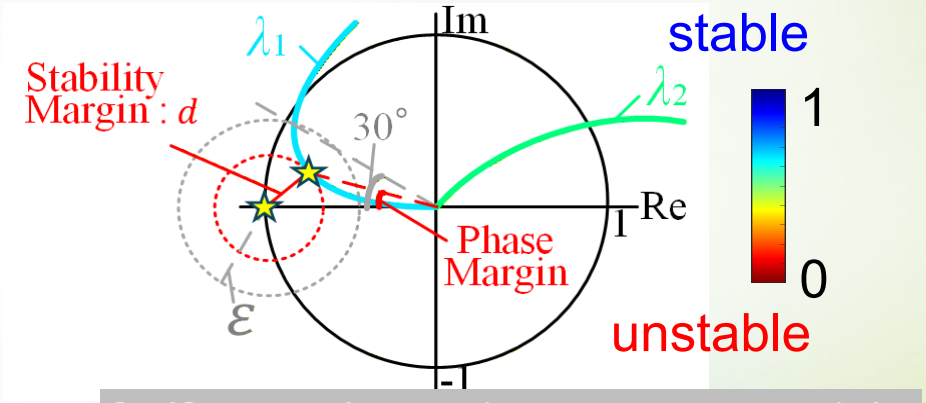
Stability Assessment



Loop gain : $\boldsymbol{L} = \boldsymbol{Z}_s \boldsymbol{Z}_L^{-1}$ Eigenvalue loci

Characteristic equation :$\det(\boldsymbol{L} + \lambda \boldsymbol{I}) = 0$

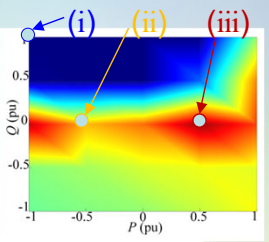
Stability margin d : $d = \min|\lambda - (-1,0)|$

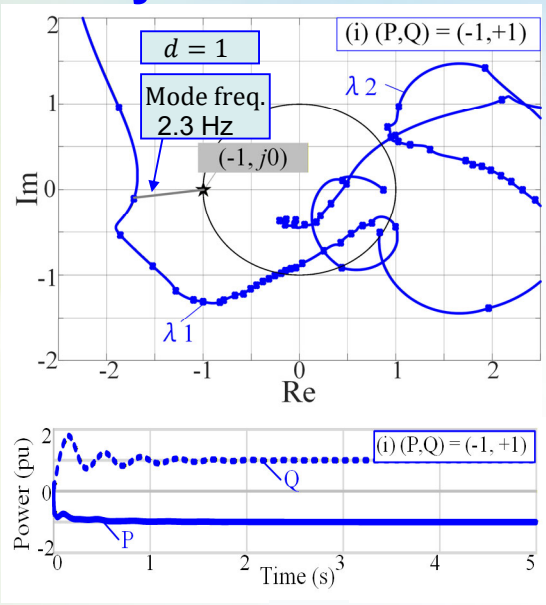


[Ref.] M. Amin (10.1002/047134608x.w1026.pub2)

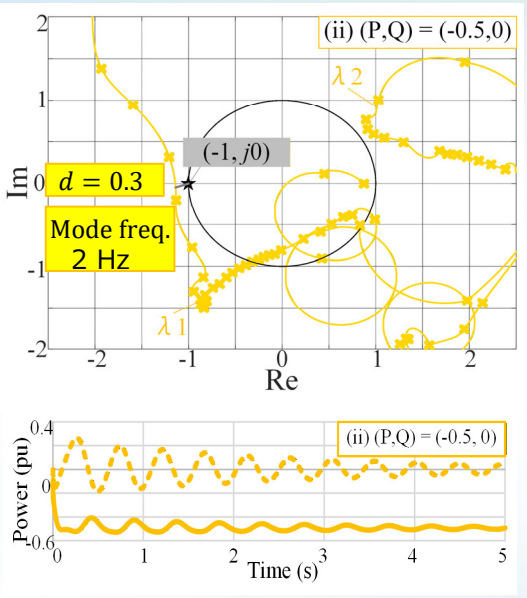
Only the second quadrant $(-P,+Q)$ is stable, all other operating conditions are unstable.

Stability Assessment

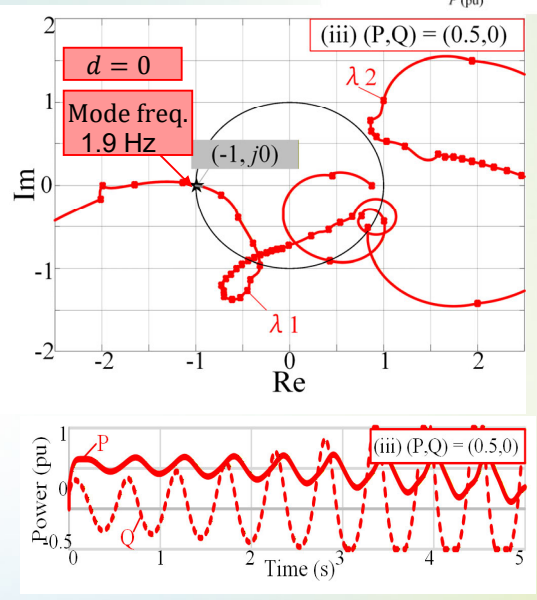




(i)



(ii)



(iii)

The map was validated using time- and frequency-domain responses.

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Proposed Method

Objective : Avoid unstable conditions without stopping the inverter.
Approach : Evaluate stability at each power flow operating point.

Key Achievements

- ✓ Mapping stability metrics over a wide range of power-flow conditions enables a rigorous and intuitive stability assessment.
- ✓ This map enables the prediction of potentially unstable power flows in advance, allowing countermeasures such as adjusting generation output or temporarily suppressing IBR.
  → Consequently, it avoids the need for inverter shutdowns or redesigns.

Thank you for your kind attention !

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