# Stability Analysis of Converter Control Modes in Low-Inertia Power Systems

By Markovic et al. in 2018 IEEE PES Innovative Smart Grid Tech. Conf. Europe

EE290O

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Google Sheets Link

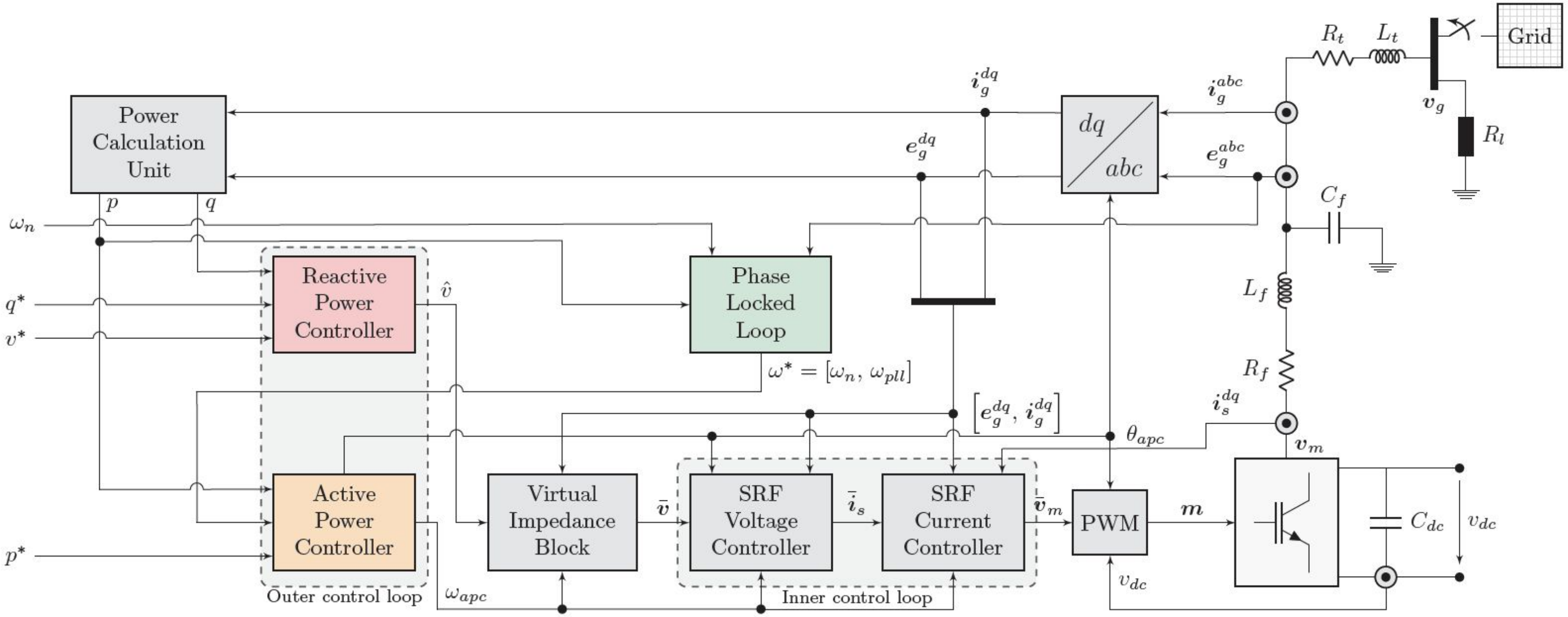
# Scope

Specific cases: grid-forming (islanding) and grid-feeding (droop?) from [9]:

1. **<u>Grid-forming (g-form)</u>:** complete voltage vector from commands $v^*$ and $\omega^*$
2. <u>Frequency-forming</u>: freq. from command $\omega^*$, voltage follows measurement $\tilde{v}$
3. <u>Voltage-forming</u>: drives voltage magnitude to $v^*$ at "Point of Common Coupling (PCC)" and synchronizes vector with measured $\tilde{\omega}$ via PLL
4. **<u>Grid-feeding (g-feed)</u>**: voltage vector dependent on measured $\tilde{v}$ and $\tilde{\omega}$ (PLL)


9. U. Markovic, O. Stanojev, P. Aristidou, and G. Hug, "Partial grid forming concept for 100% inverter-based transmission systems," in 2018 IEEE Power and Energy Society General Meeting (PESGM), Aug 2018.

# System Configuration



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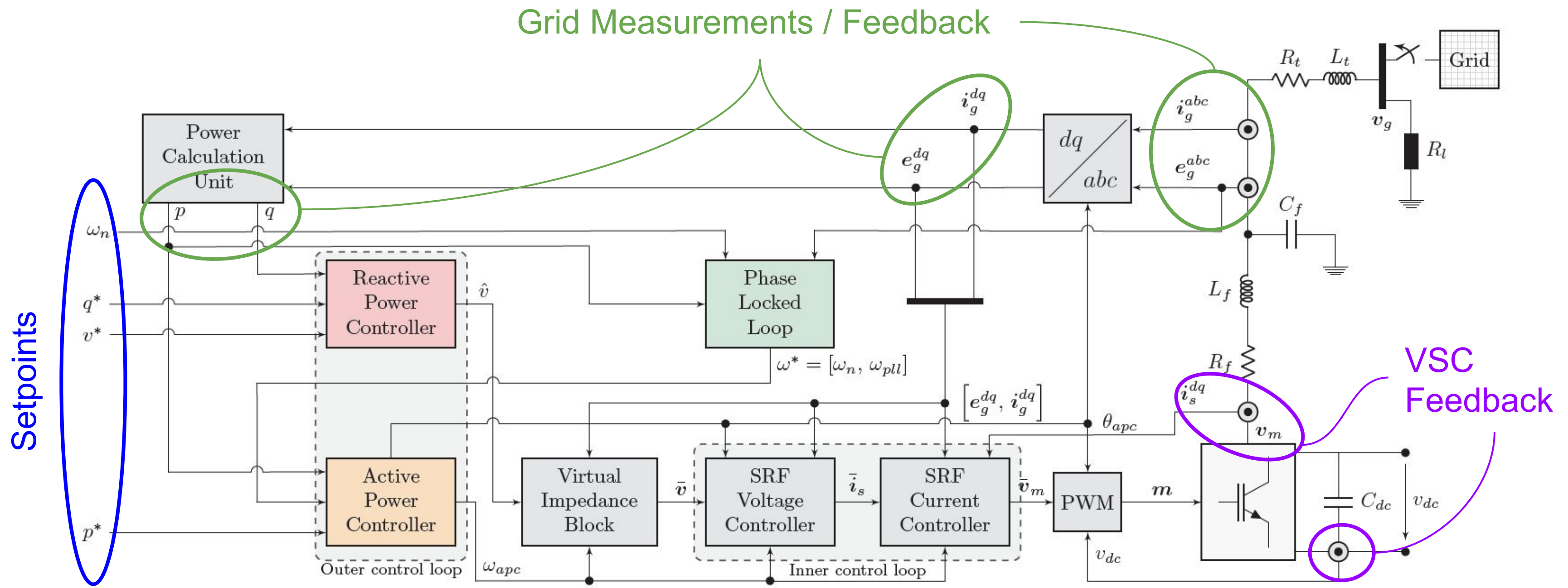
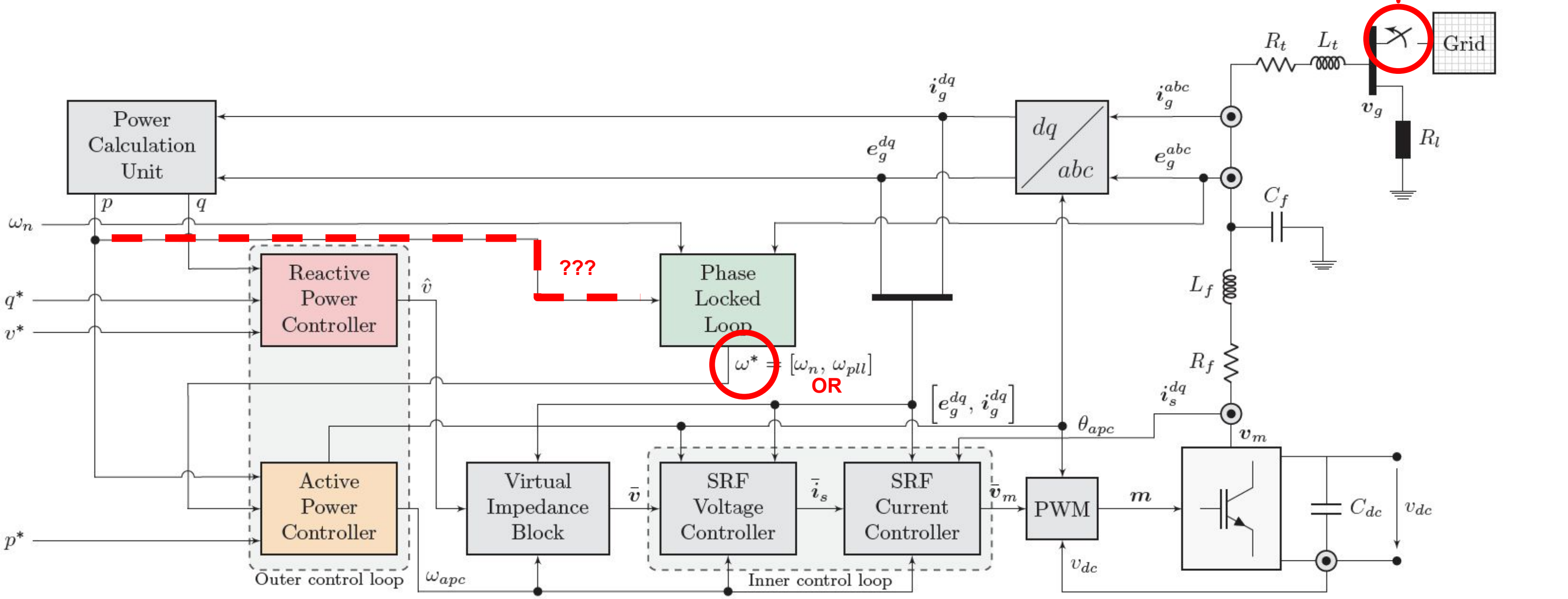


# System Configuration

: g-form

: g-feed

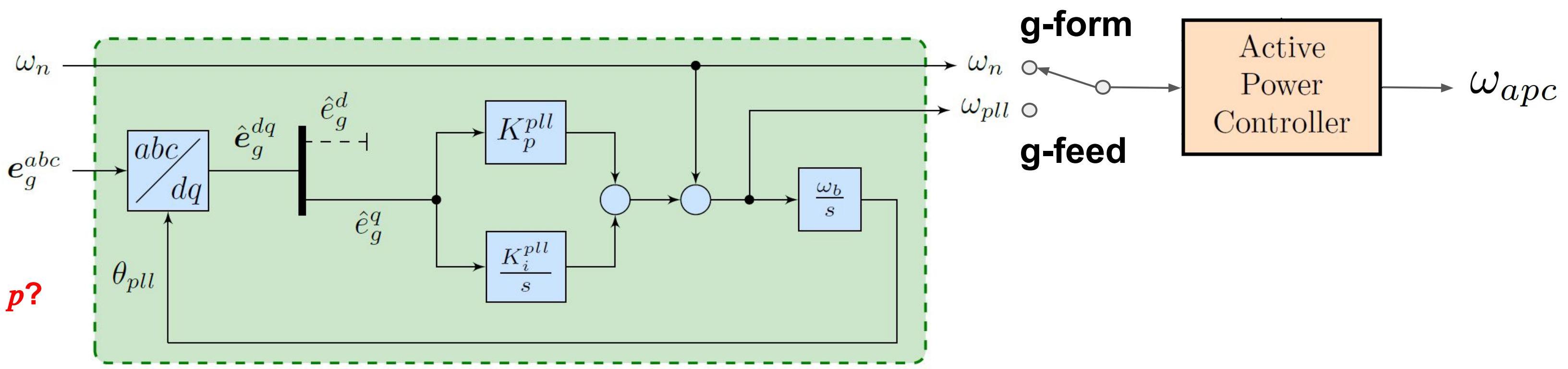
Frequency configuration, PLL and g-form vs g-feed



# PLL for g-feed (bypassed for g-form)

Specific cases: grid-forming and grid-feeding from [9]:

1. **Grid-forming (g-form):** complete voltage vector from commands $v^*$ and $\omega^*$
4. **Grid-feeding (g-feed)**: voltage vector dependent on measured $\tilde{v}$ and $\tilde{\omega}$ (PLL)





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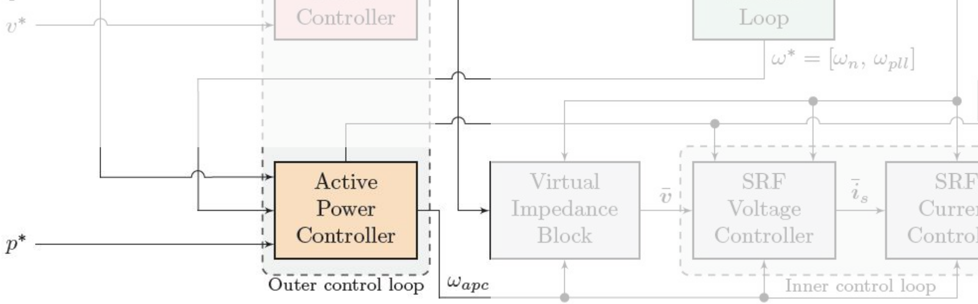
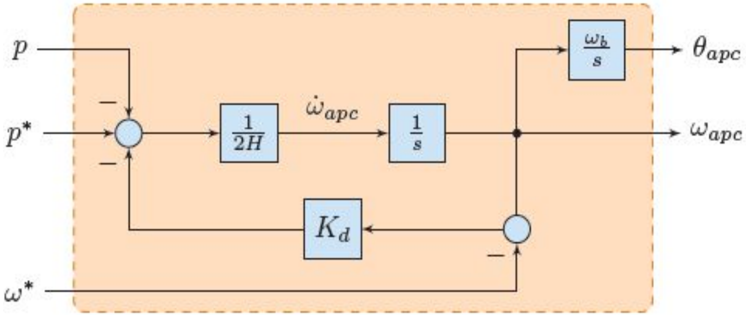



## Active Power Controller

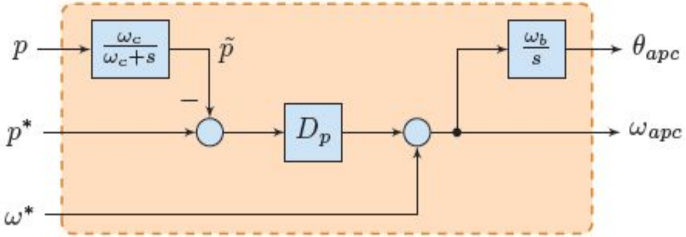
Establishes reference frame $\omega_{apc}$ for VSC controller

Two methods analyzed: Virtual Inertia (swing) Emulation (VIE) & Droop

VIE



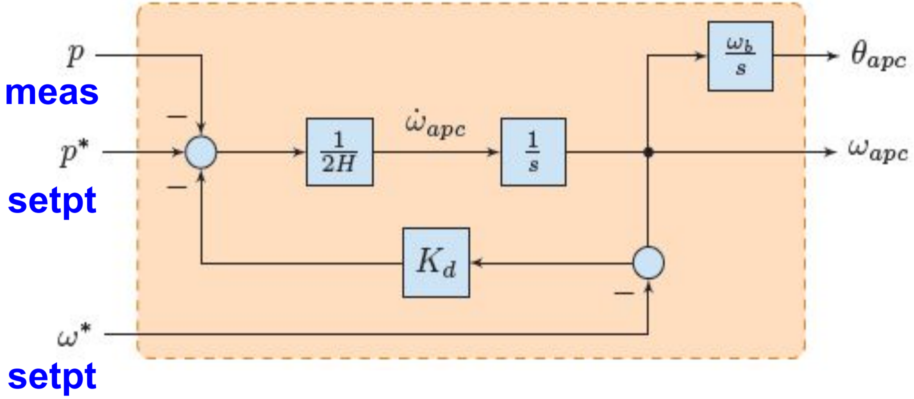

Droop




“Mathematically equivalent under certain steady-state conditions”

# Active Power Controller - Virtual Inertia Emulation

Emulates synchronous machine swing dynamics



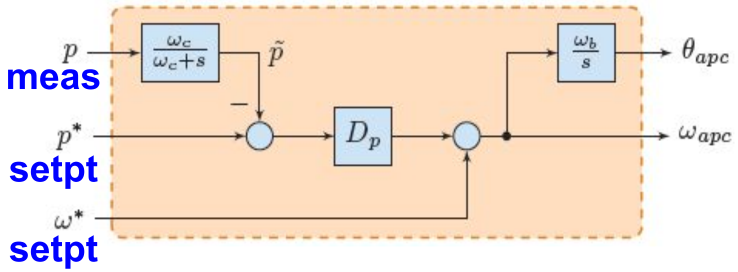

$$M\frac{\mathrm{d}\Delta\omega}{\mathrm{d}t} = P_\mathrm{m} - P_\mathrm{e} - P_\mathrm{D}$$

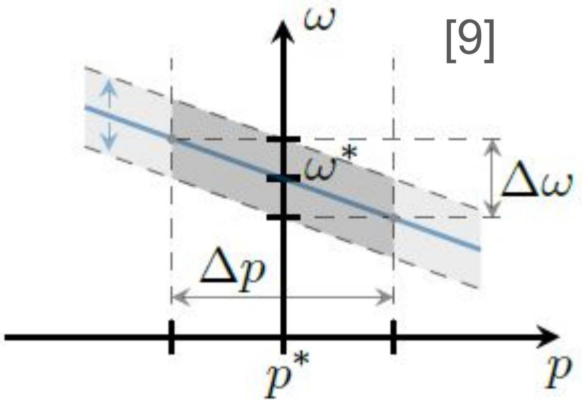
$$\frac{\mathrm{d}\Delta\omega}{\mathrm{d}t} = \left(P_\mathrm{m} - P_\mathrm{e} - D\frac{\mathrm{d}\delta}{\mathrm{d}t}\right)\frac{\omega_\mathrm{s}}{2HS_\mathrm{n}}$$

$$\dot{\omega}_{apc} = \frac{1}{2H}\underbrace{(p^* - p)}_{p_m - p_e} - \frac{1}{2H}\underbrace{K_d(\omega_{apc} - \omega^*)}_{p_d}$$

# Active Power Controller - Droop Control

Emulates slowing/speeding of the prime mover as load changes




$$\omega_{apc} = \omega^* + D_p(p^* - \tilde{p})$$

$$\dot{\tilde{p}} = \omega_c(p - \tilde{p})$$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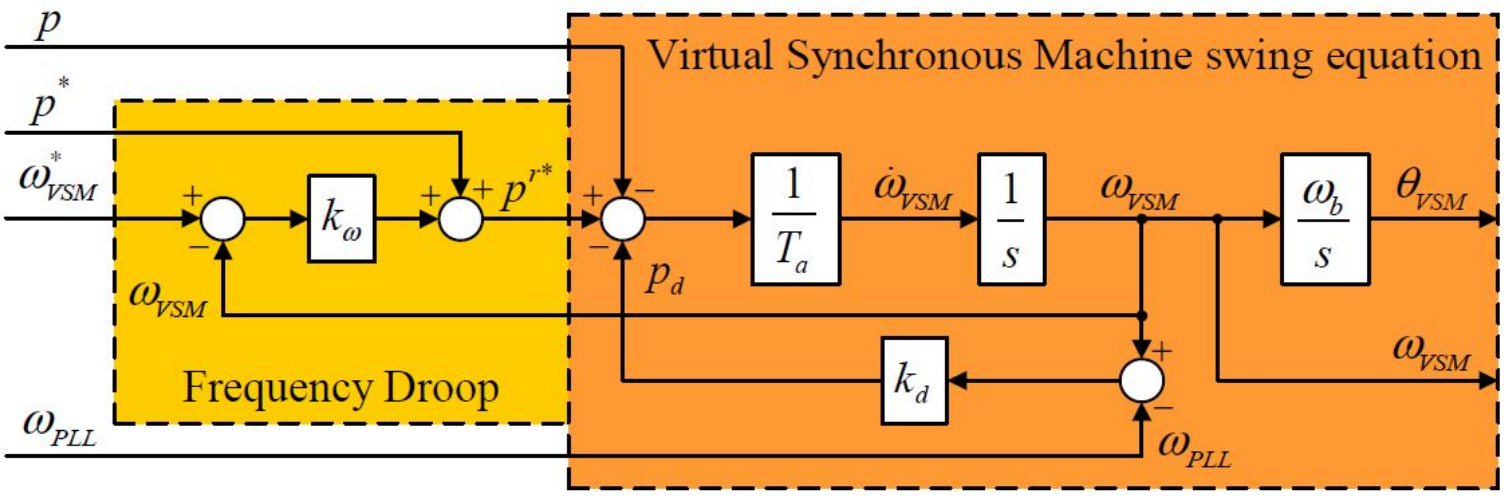
# Active Power Control - Cascade droop and VIE

Perhaps analysis of APC in [3] is a better approach

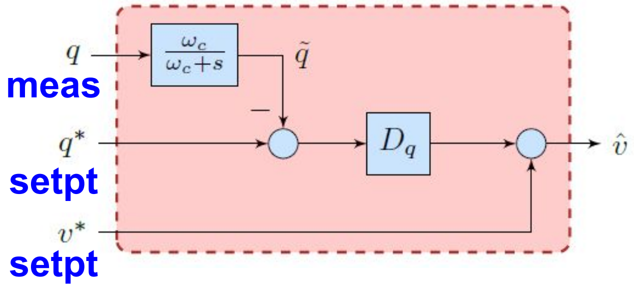


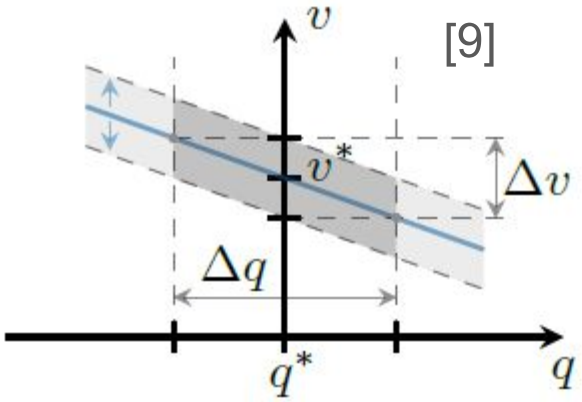


3. S. D'Arco, J. A. Suul, and O. B. Fosso, "Small-signal modelling and parametric sensitivity of a virtual synchronous machine," in 2014 Power Systems Computation Conference, Aug 2014.

# Reactive Power Controller - Droop Control

Emulates standard reactive power control for synchronous machines




$$\hat{v} = v^* + D_q(q^* - \tilde{q})$$
$$\dot{\tilde{q}} = \omega_c(q - \tilde{q})$$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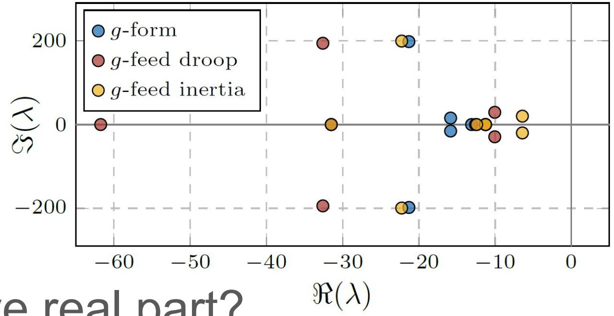
# Stability Results

Eigenvalue analysis of the 15th order state-space system:

$$\boldsymbol{x} = \left[\boldsymbol{e}_g^{dq},\, \boldsymbol{i}_g^{dq},\, \boldsymbol{i}_s^{dq},\, \boldsymbol{\xi}^{dq},\, \boldsymbol{\gamma}^{dq},\, \varepsilon,\, \vartheta_{apc},\, \vartheta_{pll},\, \tilde{p},\, \tilde{q}\right]^T$$

$$\boldsymbol{u} = \left[p^*,\, q^*,\, v^*,\, v_g,\, \omega_n,\, \omega_g\right]^T$$

$$\Delta\dot{\boldsymbol{x}} = \boldsymbol{A}\Delta\boldsymbol{x} + \boldsymbol{B}\Delta\boldsymbol{u}$$




Focused on the eigenvalues with most positive real part?

In [3] it is shown that certain eigenvalues are more sensitive:

$$\alpha_{n,k} = \frac{\partial \lambda_n}{\partial \rho_k} = \frac{\boldsymbol{\Phi}_n^T \dfrac{\partial \mathbf{A}}{\partial \rho_k} \boldsymbol{\Psi}_n}{\boldsymbol{\Phi}_n^T \boldsymbol{\Psi}_n}$$

$\alpha$ = sensitivity

$\lambda_n$ = eigenvalue n

$\varrho_k$ = parameter k

$\boldsymbol{\Psi}_n^T$ and $\boldsymbol{\Phi}_n$ are the left and right eigenvectors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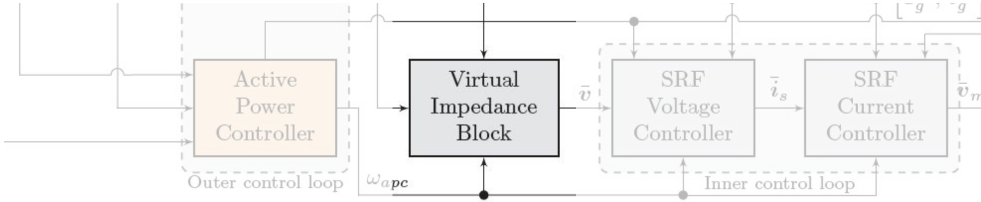
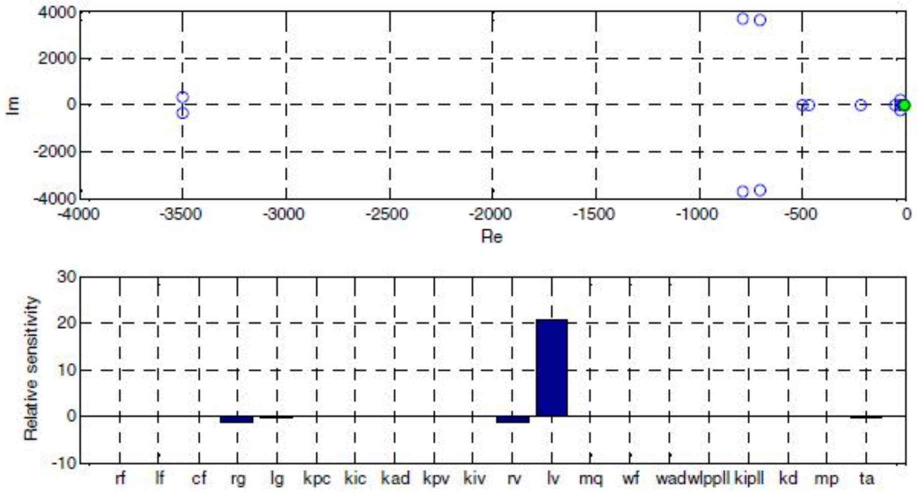
# System Configuration




Virtual impedance used to decouple frequency and voltage control

From [3], the virtual impedance can have a significant impact on stability





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# Further Exploration

Explore more detailed alternatives to infinite bus

- DC-side dynamics
- Synchronous Machine
- 3-Bus Network
- 14-Bus Network

Test stability under different PLL implementations