Dynamic Passivity Multipliers for Plug-and-Play Stability Certificates

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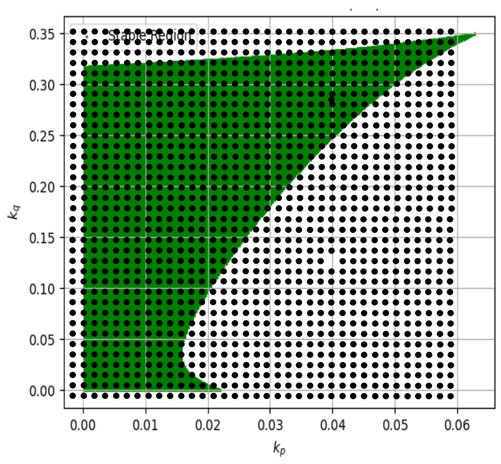
Case against Direct Modelling

How many simulations?

- 1 inverter – 100 (~10 ms)
- 4 inverters – 100^4 (~3 hours)
- 10 inverters – 100^{10} (~ **300 million years!**)

A classical case of the "curse of dimensionality" phenomenon



Key Idea

Introduce a frequency-dependent 2x2 multiplier $m(j\omega)$ so that each component 'looks passive' after premultiplication

$$m(j\omega)Y(j\omega) + Y^H(j\omega)m^H(j\omega) \succ 0$$

With one common multiplier for all components

Homotopy-free simplification:

choose passive line admittances as the reference; then only the endpoint needs checking

Contributions

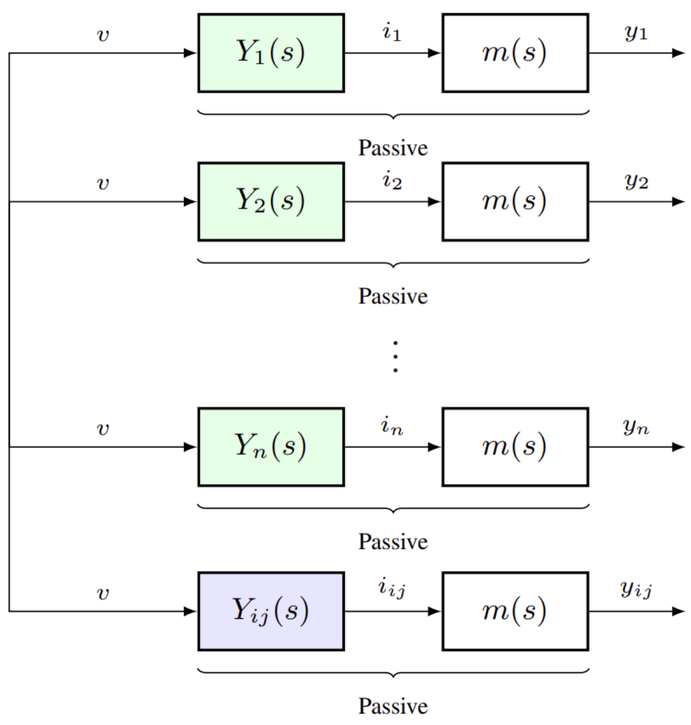
- ***Plug-and-Play*** stability certificates requiring only dq admittances
- No restrictions on network losslessness, homogeneity, or static behaviour – ***electromagnetic dynamics***
- No controller redesign; multiplier is an off-line certificate
- Systematic synthesis is scalable with no restrictions on the device complexity

Dynamic Multipliers Synthesis

Parametrise $m(s)$ as a fixed-order state-space filter and tune it so that $m(s)Y(s)$ is passive for all devices and lines.

State-space parameterisation:

$$m(s) = C_m(sI - A_m)^{-1}B_m + D_m$$



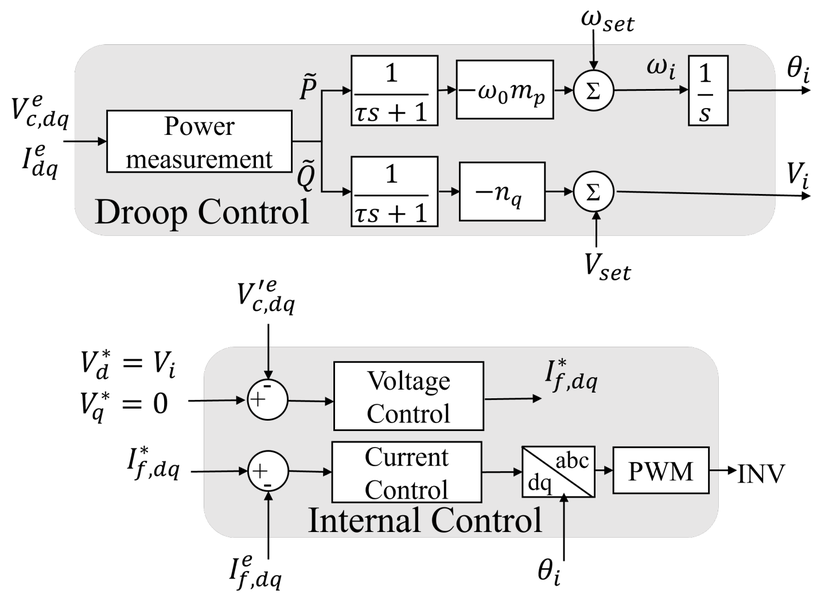
Optimisation (MATLAB *systune*): enforce *PassivityGoal* on each series interconnection $G_k(s) = m(s)Y_k(s)$

Scattering transform objective:

$$R_k(s) = (I - mY_k)(I + mY_k)^{-1}$$

$$\min_m \max_k |R_K(s)|_\infty \text{ (target <= 1)}$$

Droop-controlled Grid-Forming inverter

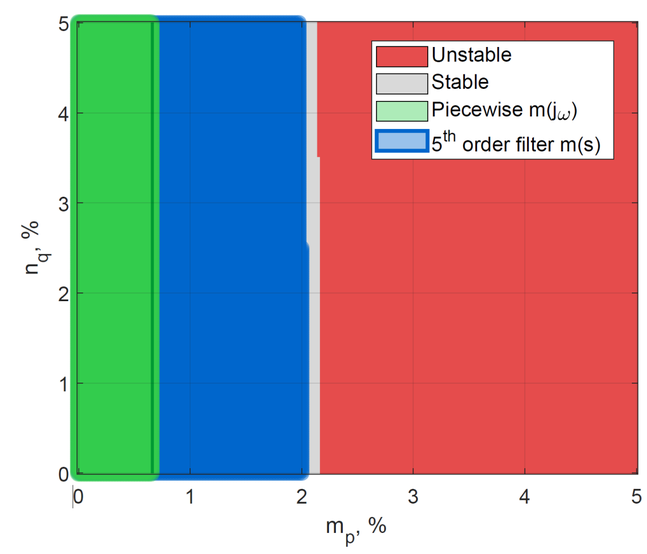


Future work

- Automate multiplier order selection and objective shaping to enlarge certified regions
- Use partial network knowledge
- Extend to other device classes

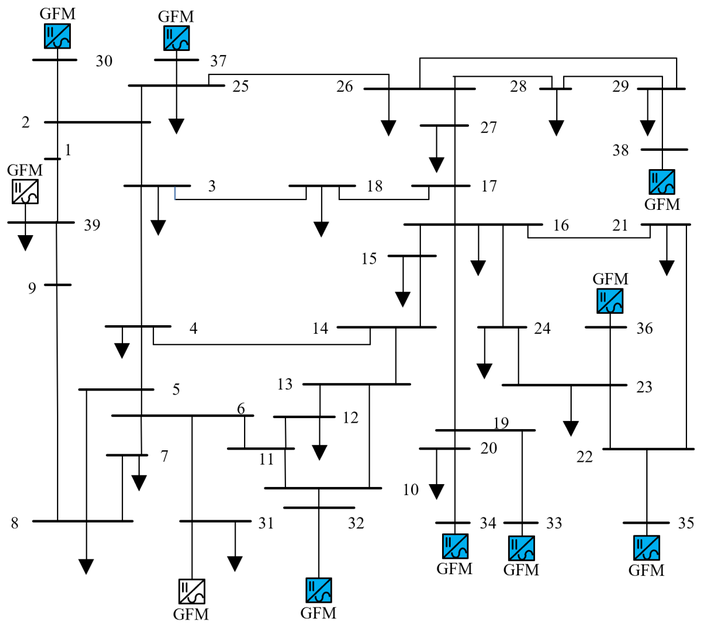
Two-bus Case

A 5th-order tuned multiplier certifies a practical droop settings



IEEE 39-bus setup

Synchronous generators are replaced by 10 GFMs. All use droop gains within the certified region (example: $m_p = n_q = 1\%$)



Plug-and-Play validation

50 random inverter placements were tested; for each, full-system eigenvalues were computed and all remained in the left half-plane