Passivity characteristics of three virtual synchronous machine implementations

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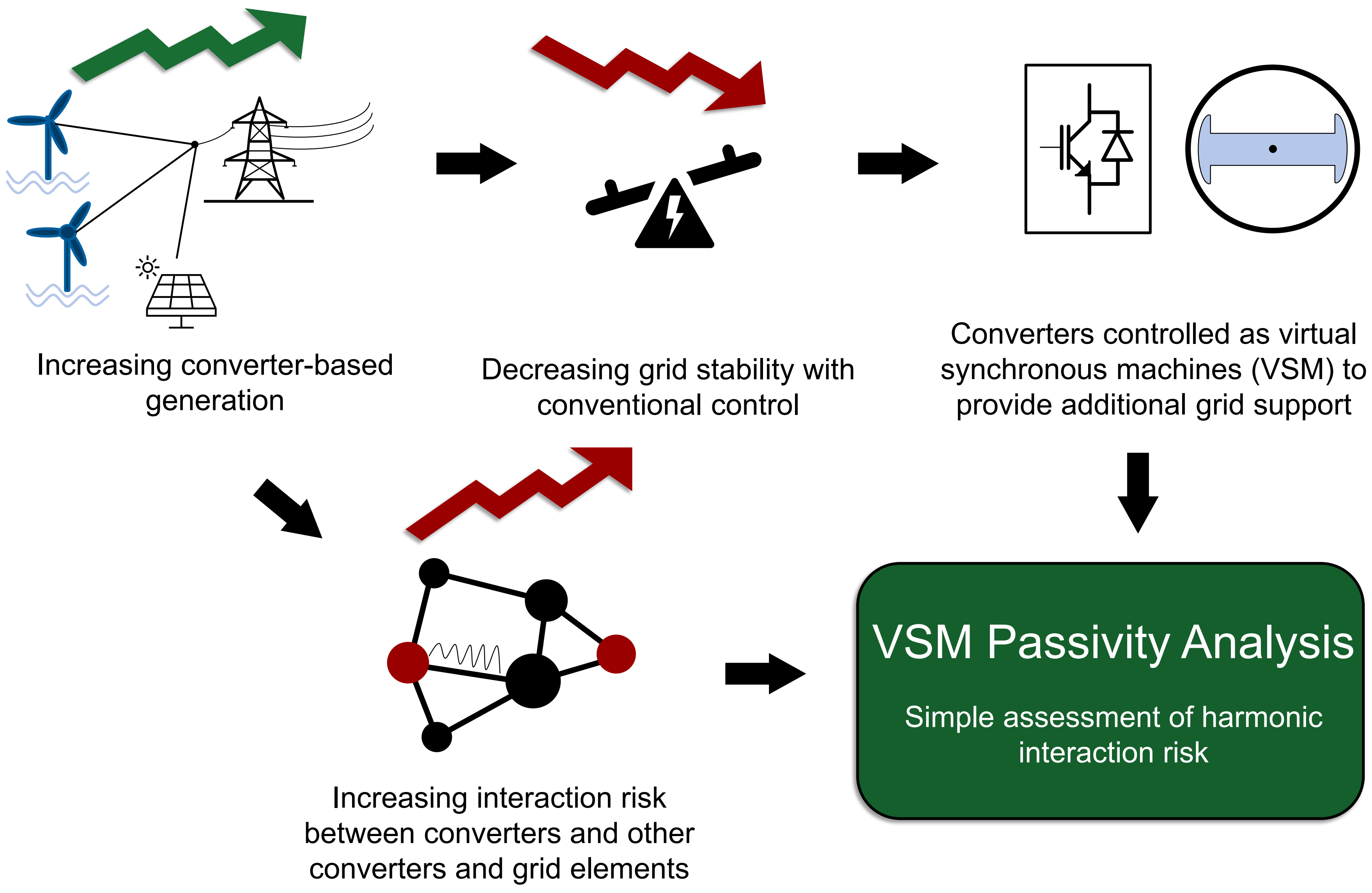
Motivation



Increasing converter-based generation

Decreasing grid stability with conventional control

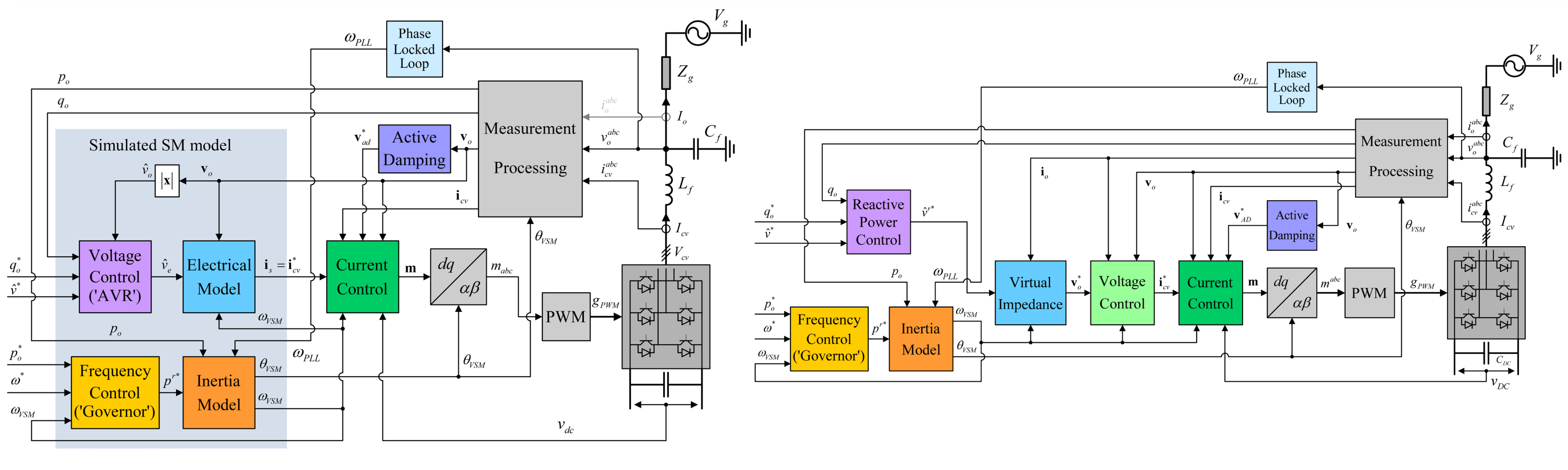
Converters controlled as virtual synchronous machines (VSM) to provide additional grid support

Increasing interaction risk between converters and other converters and grid elements

VSM Passivity Analysis

Simple assessment of harmonic interaction risk

VSM Model and Passivity



(a) (b)

Figure 1: Control diagram of the VSM implementations. ***(a)*** *Current-controlled implementation, valid for DEM and QSEM [1].* ***(b)*** *Voltage-controlled implementation, valid for VC VSM [2].*

Current-controlled VSM (Fig 1.a)

Dynamic electrical model (DEM)

$$\frac{d\mathbf{i}_s}{dt} = \frac{\omega_b}{l_s}\mathbf{v}_e - \frac{\omega_b}{l_s}\mathbf{v}_o - \left(\frac{r_s\omega_b}{l_s} + j\omega_{VSM}\omega_b\right)\mathbf{i}_s$$

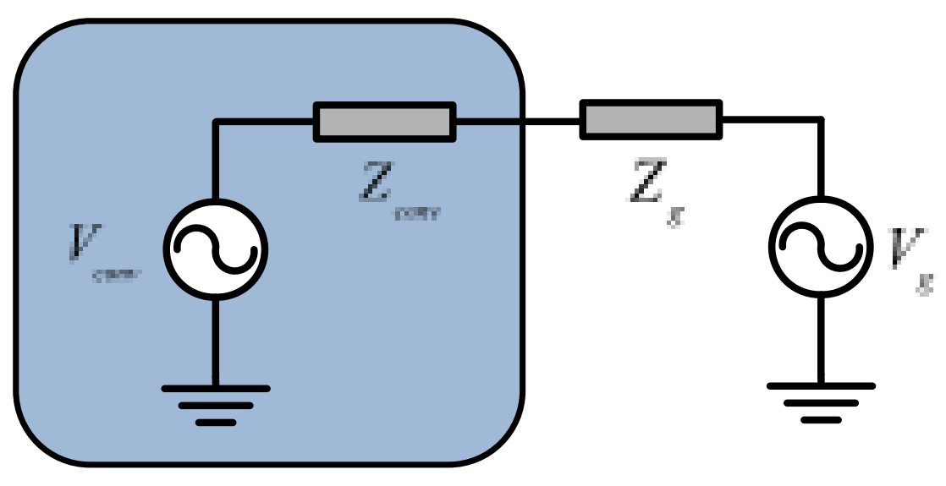
Quasi-stationary electrical model (QSEM)

$$\mathbf{i}_s = \frac{\mathbf{v}_e - \mathbf{v}_o^m}{r_s + j\omega_{VSM} l_s}$$

$\mathbf{v}_o^m$ = low-pass filtered voltage

Voltage-controlled VSM (VC VSM) (Fig 1.b)

Converter Impedance Representation



$$\mathbf{Z}_{conv} = \mathbf{Z}_{dq}(s) = \begin{bmatrix} Z_{dd}(s) & Z_{dq}(s) \\ Z_{qd}(s) & Z_{qq}(s) \end{bmatrix}$$

MIMO Passivity Definition

$$\min\left[\lambda_{1,2}\left[\mathbf{Z}_{dq}(s) + \mathbf{Z}_{dq}^H(s)\right]\right] \geq 0$$

Passive system → inherently stable
Partial passivity: passive in certain frequency ranges, unlikely to result in instability in these ranges

Acknowledgments
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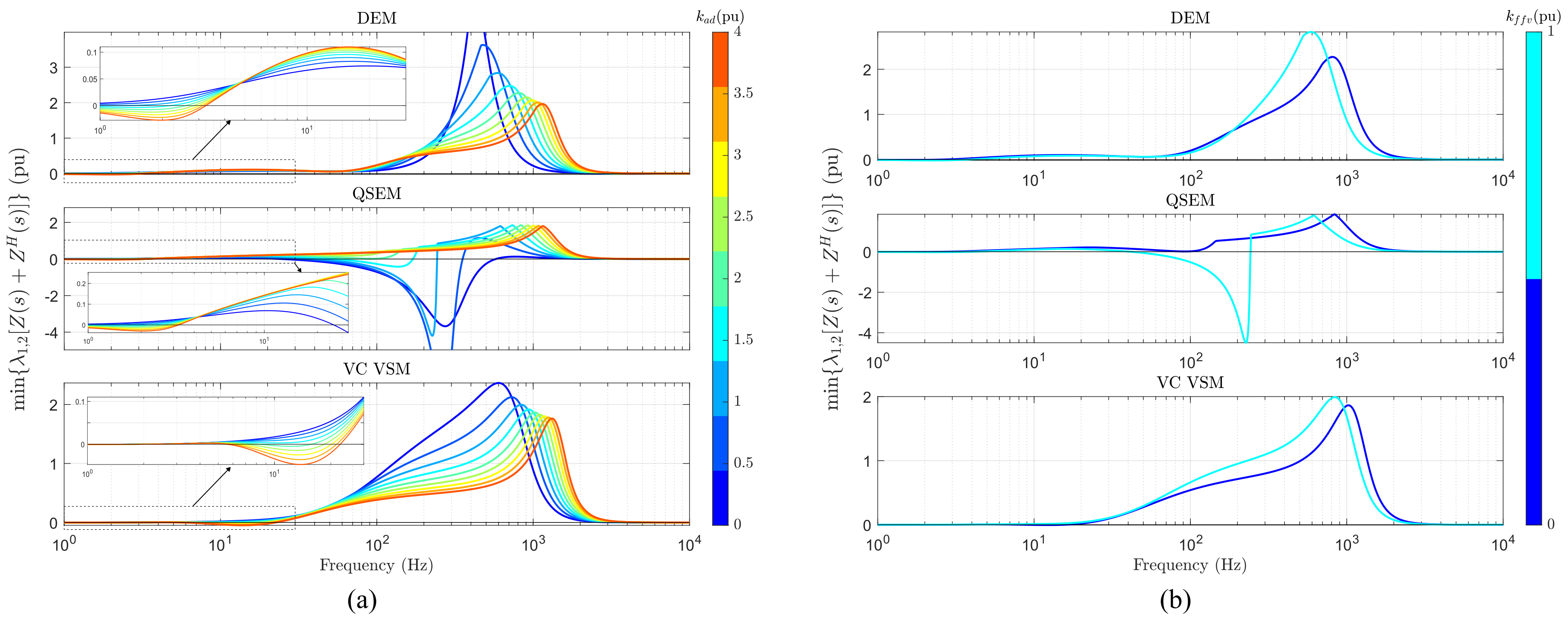
References

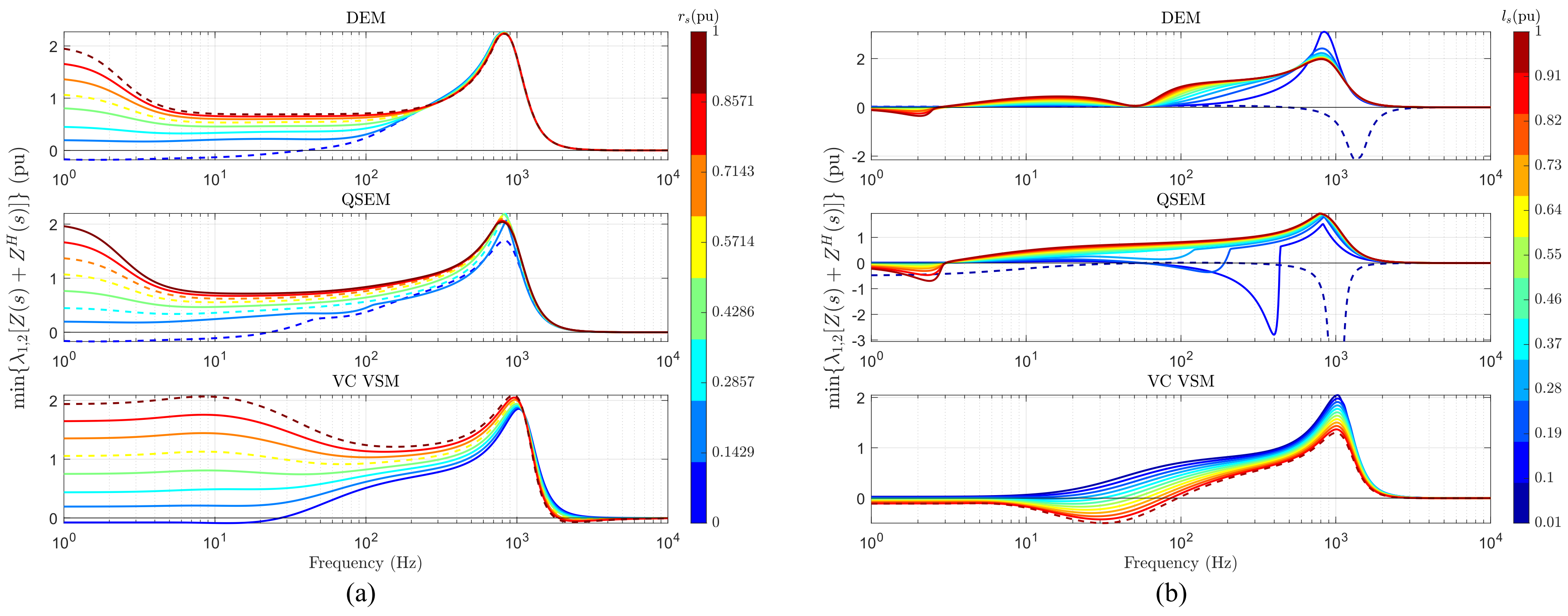
[1] O. Mo, S. D'Arco, and J. A. Suul, "Evaluation of virtual synchronous machines with dynamic or quasi-stationary machine models," *IEEE Trans. Ind. Electron.*, vol. 64, no. 7, pp. 5952–5962, Jul. 2017.
[2] S. D'Arco, J. A. Suul, and O. B. Fosso, "Small-signal modelling and parametric sensitivity of a Virtual Synchronous Machine," presented at the 2014 Power Systems Computation Conference, Aug. 2014, pp. 1–9.

Results



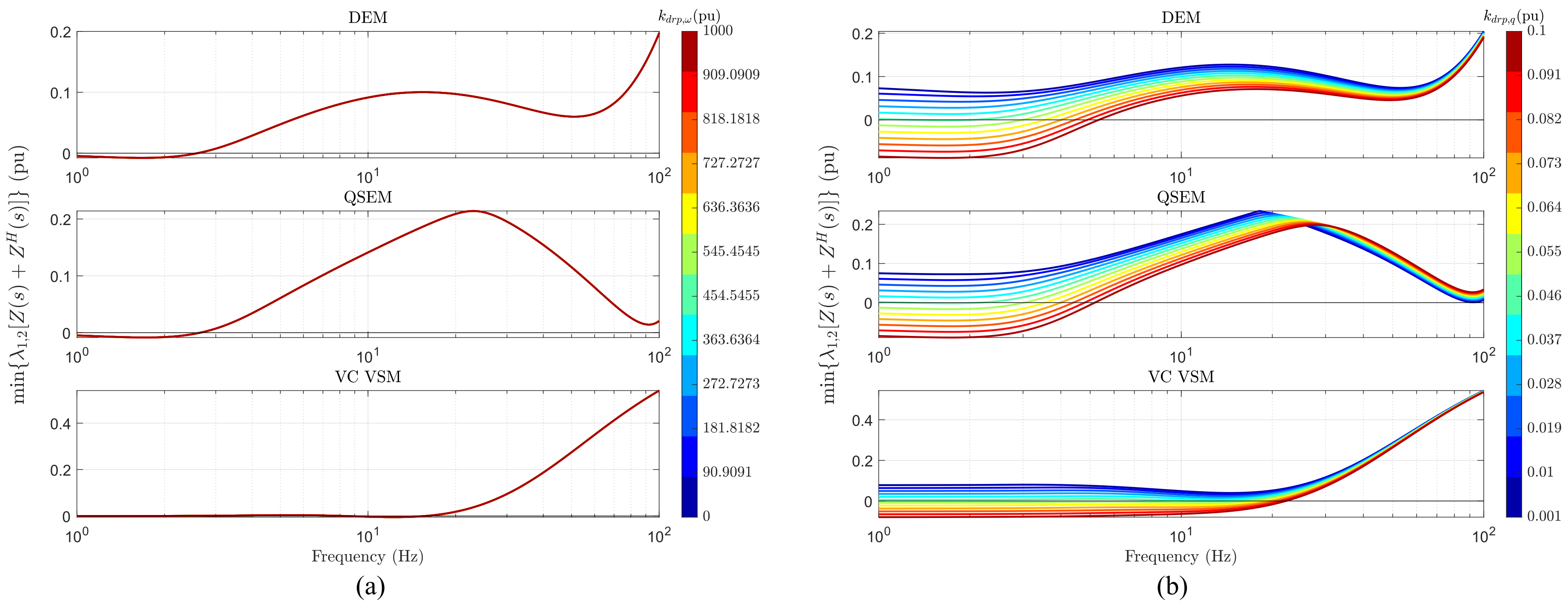
(a) (b)

Figure 2: Passivity of the converter, varying active damping and voltage feedforward. ***(a)*** *Variation in active damping coefficient, k_{ad}.* ***(b)*** *Variation in voltage feedforward, k_{ffv}.*



(a) (b)

Figure 3: Passivity of the converter, varying the virtual impedance, where a dashed line indicates an unstable system. ***(a)*** *Variation in virtual resistance, r_s.* ***(b)*** *Variation in virtual inductance, l_s.*



(a) (b)

Figure 4: Passivity of the converter, varying the droop parameters. ***(a)*** *Variation in frequency droop coefficent, $k_{drp,\omega}$.* ***(b)*** *Variation in reactive power droop coefficient, $k_{drp,q}$.*

Conclusions

- Careful parameter selection can reduce/shift the non-passive frequency range
- Increasing passivity in one region can result in decreased passivity in another

Specific parameter conclusions

- Increasing active damping can eliminate supersynchronous non-passivity but introduces subsynchronous non-passivity.
- Increasing virtual inductance leads to non-passivity at subsynchronous frequencies.
- Increasing reactive power/voltage droop results in reduced passivity.
- Electrical machine parameters (T_a and k_d) have little effect on passivity.