Parallel Operation of Grid-Forming Power Inverters

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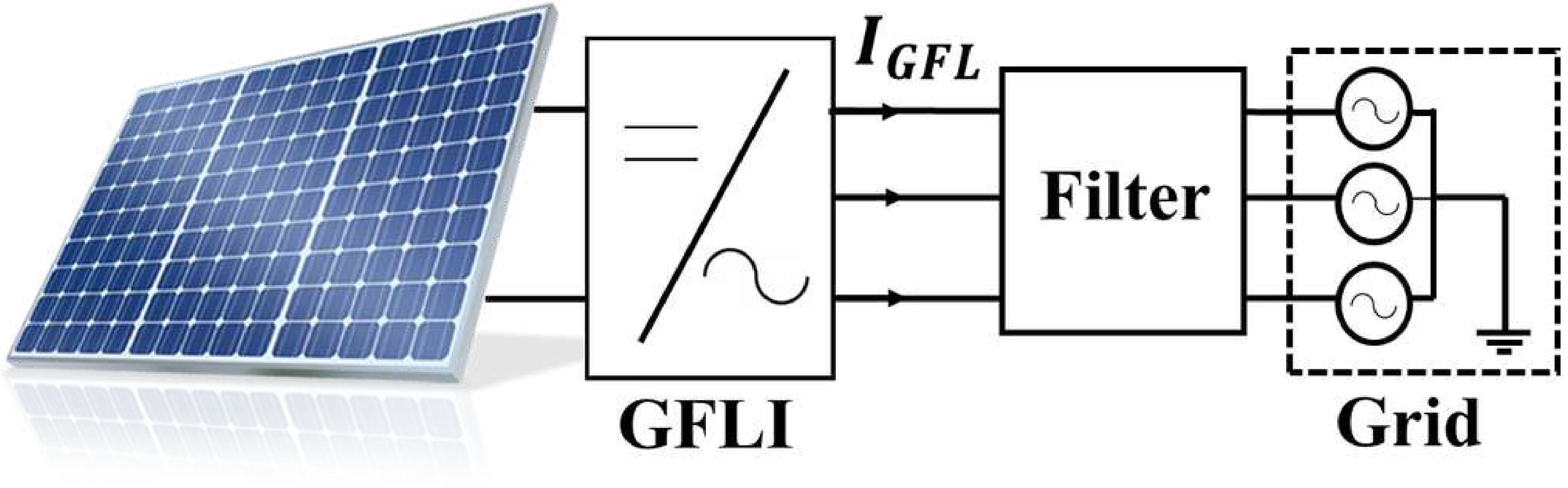
Introduction

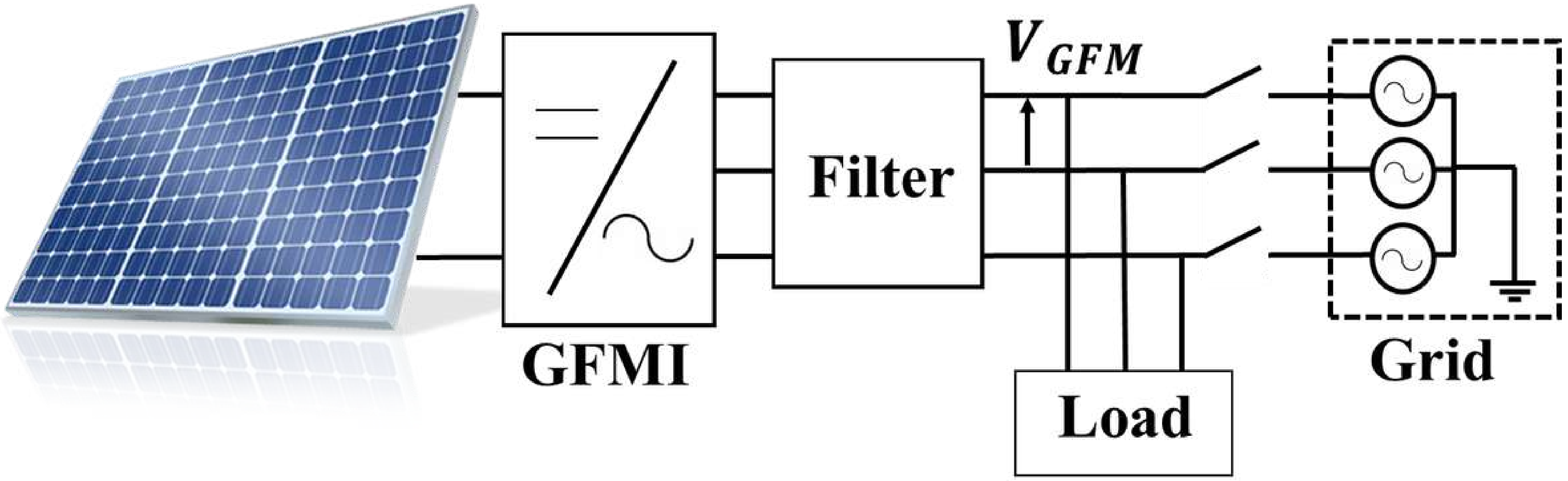
Grid-Following Inverters (GFLIs)



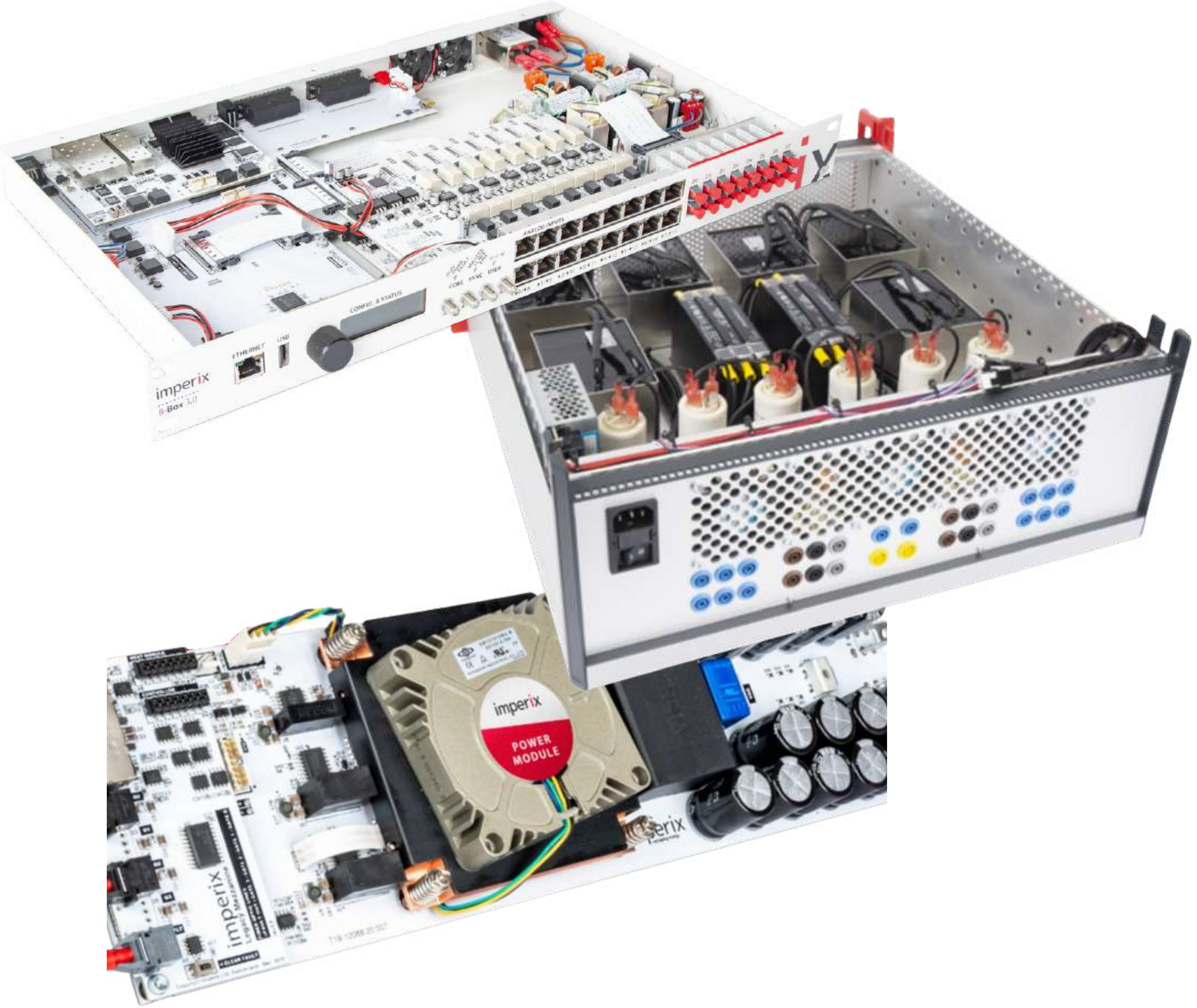
- Current Sources
- Synchronized to the grid
- Grid-Connected mode

Grid-Forming Inverters (GFMIs)

- Voltage Sources
- Grid-Connected mode
- Standalone mode



Introduction



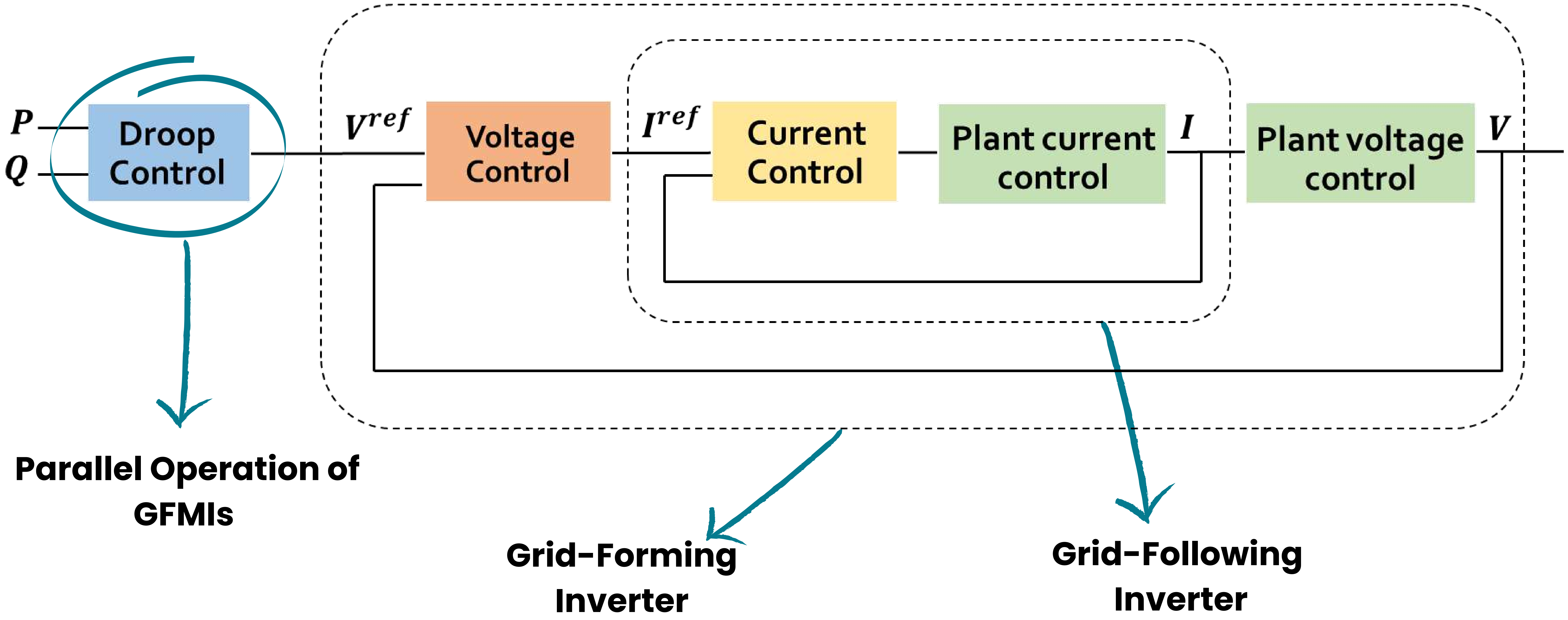
Research Question

Control Techniques for parallel GFMIs without communication and in standalone mode, connected through inductive and resistive lines

Focus

Power-sharing and frequency variation for a load step

Method

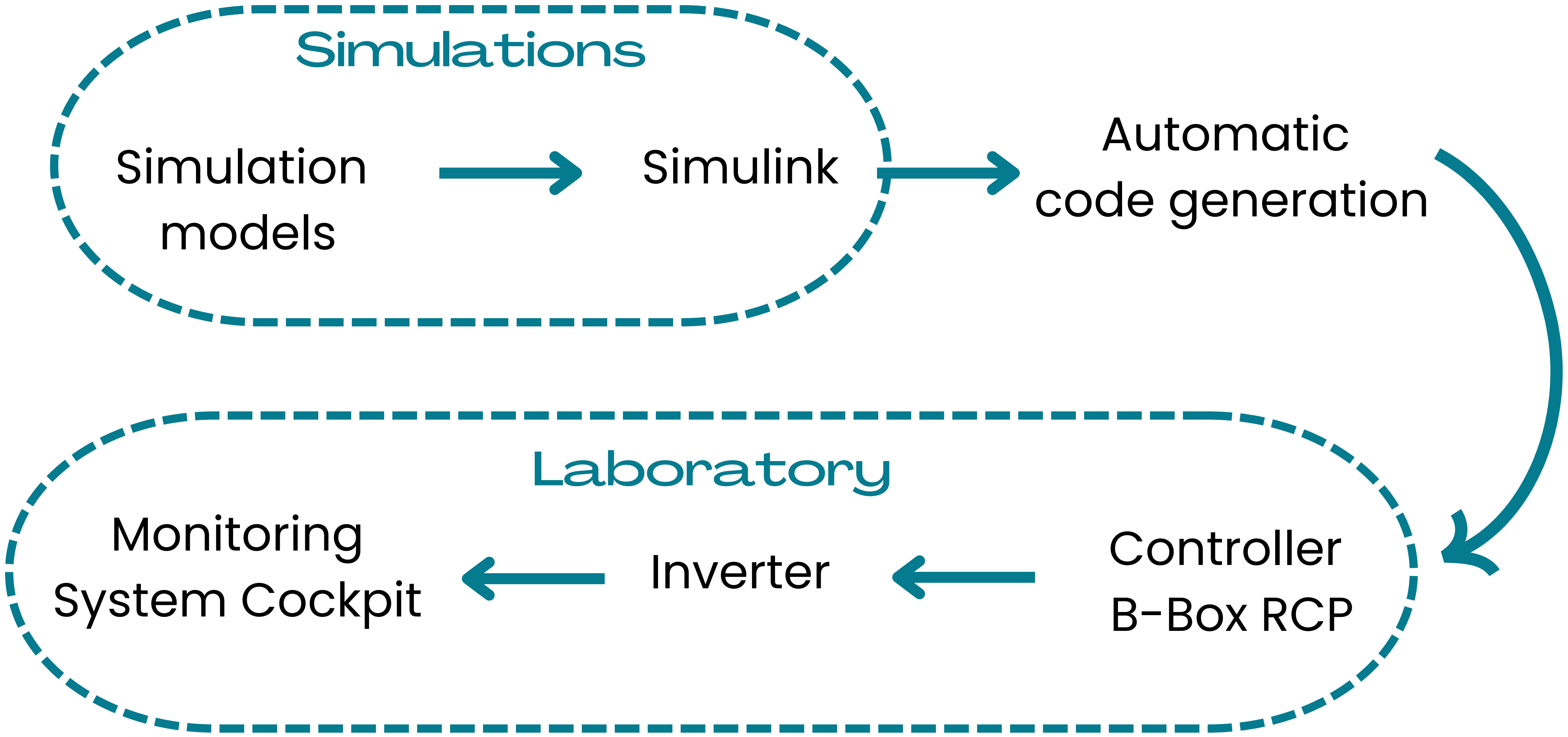

P
Q
Droop Control
V^{ref}
Voltage Control
I^{ref}
Current Control
Plant current control
I
Plant voltage control
V
Parallel Operation of GFMIs
Grid-Forming Inverter
Grid-Following Inverter

Method

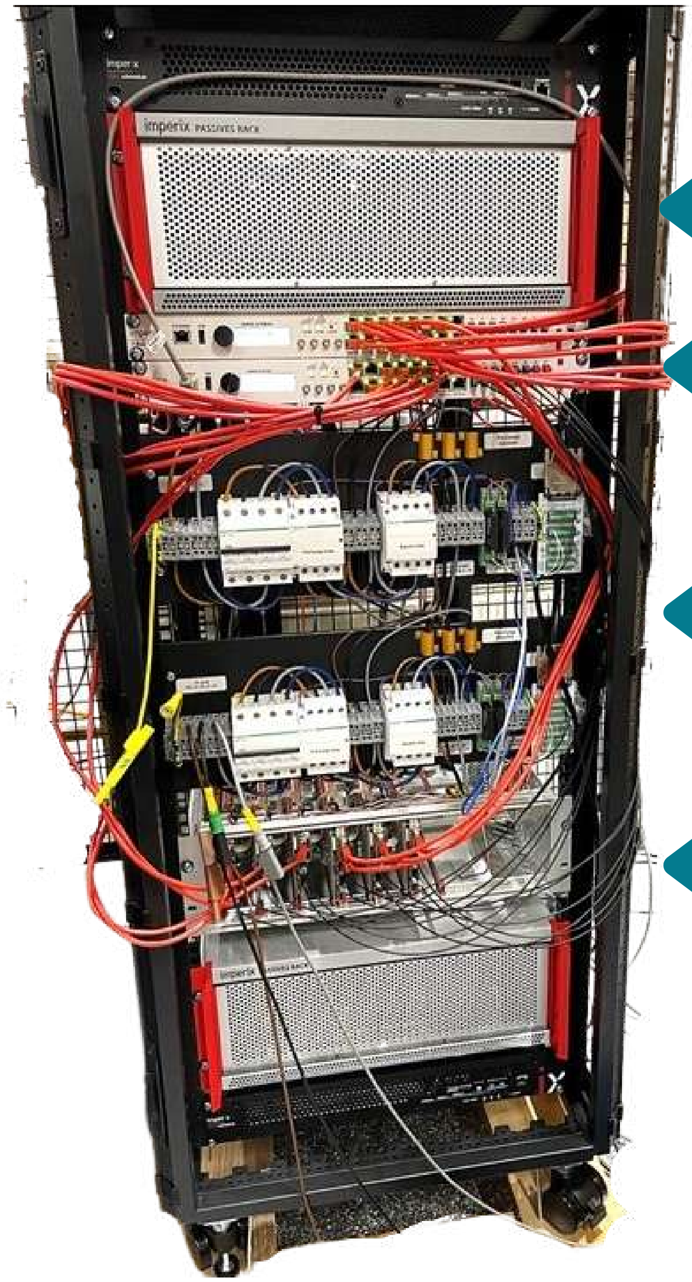
LITERATURE REVIEW

SIMULATIONS

LABORATORY VALIDATION



Parallel Operation of GFMIs

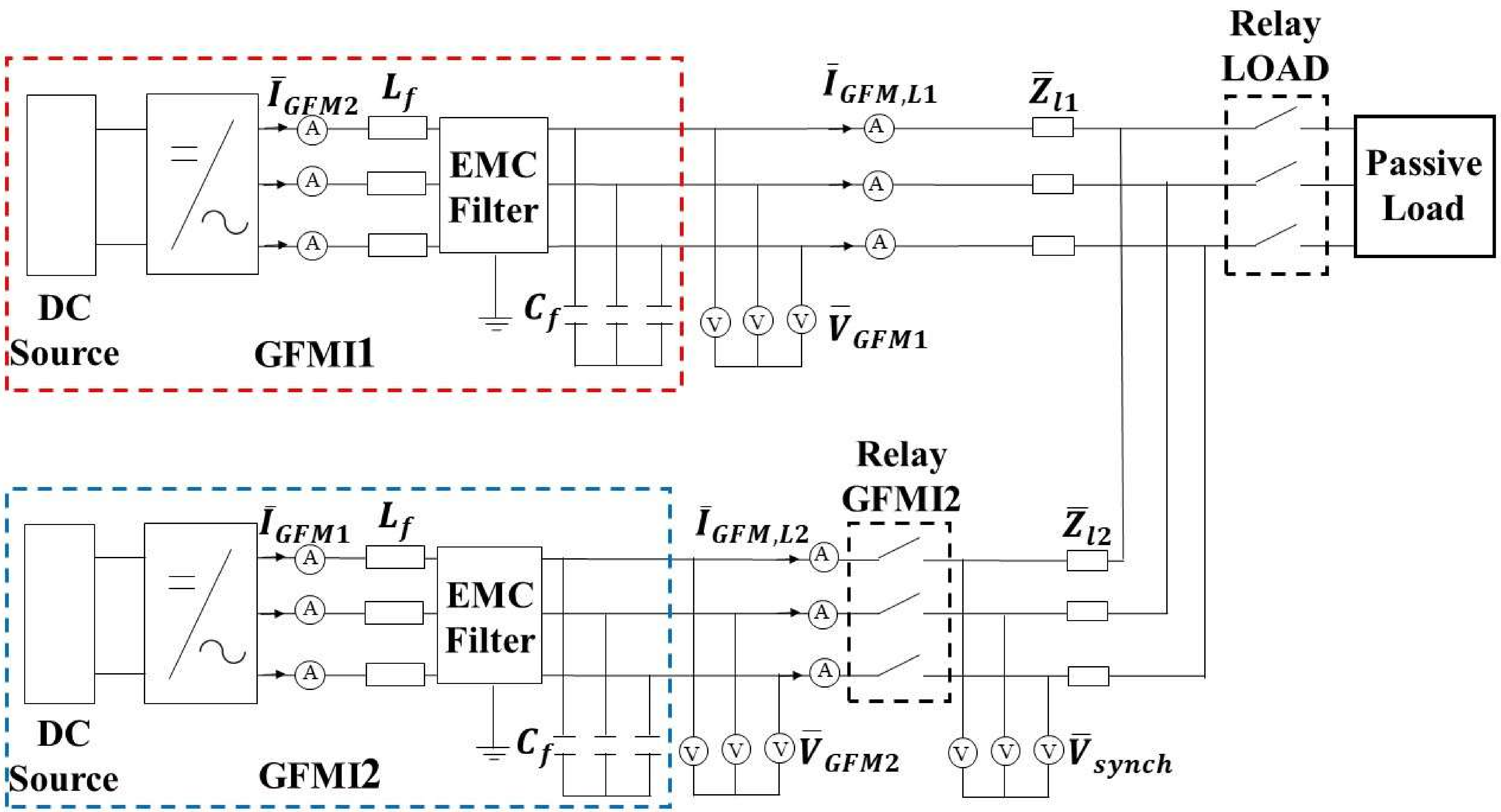


Output filter

Controllers

Circuit breakers and relays

Inverters



Droop Control Methods for mostly Inductive Lines

MOSTLY INDUCTIVE LINES

Active and reactive power decoupling

$$P \propto \Delta\omega \qquad Q \propto \Delta V$$

Proportional Droop Control

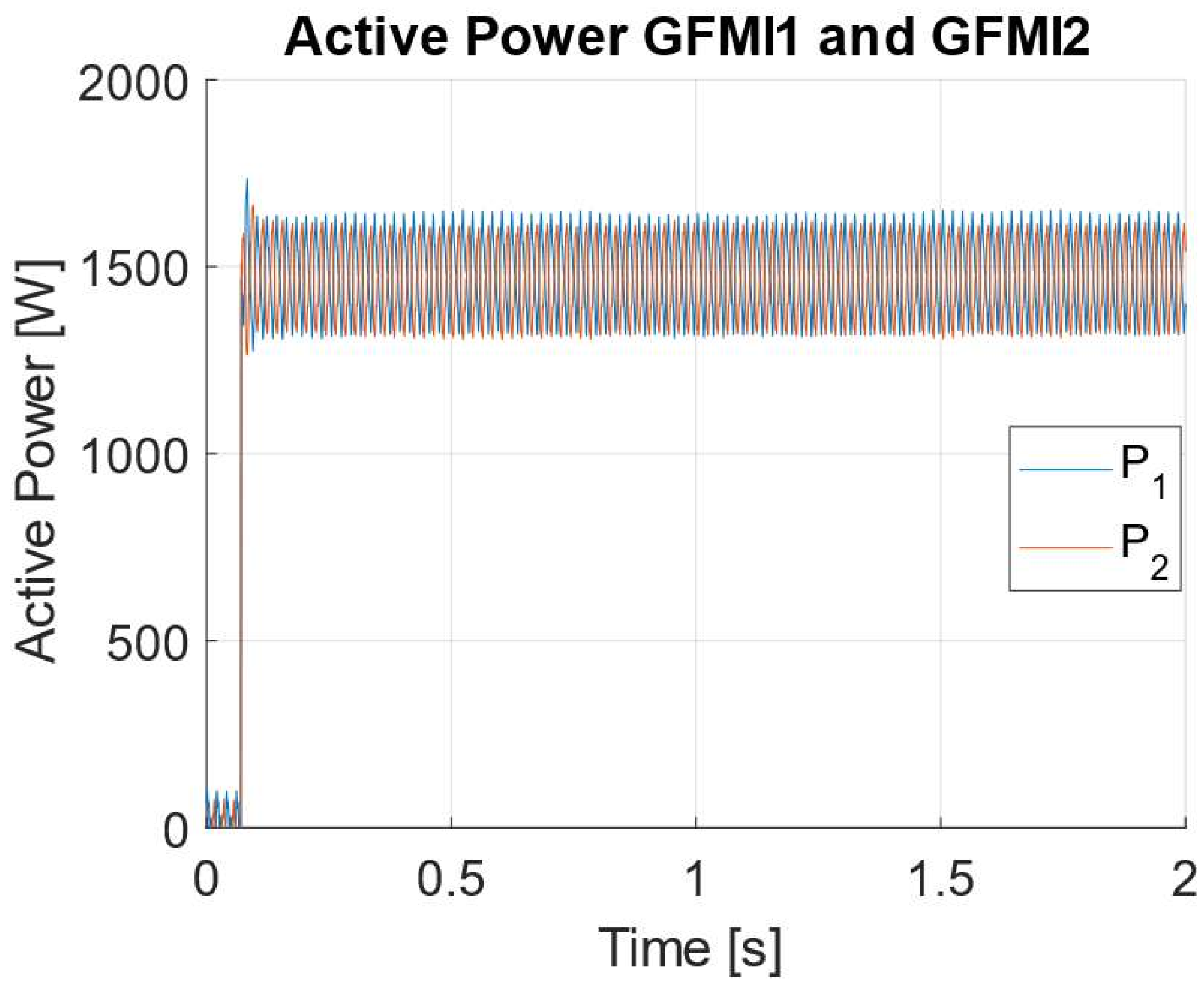
$$\omega^{ref} = \omega_0 - mP$$

$$V^{ref} = V_0 - nQ$$

$$m_1 = m_2$$

EXPERIMENTAL RESULTS

Even power sharing among units

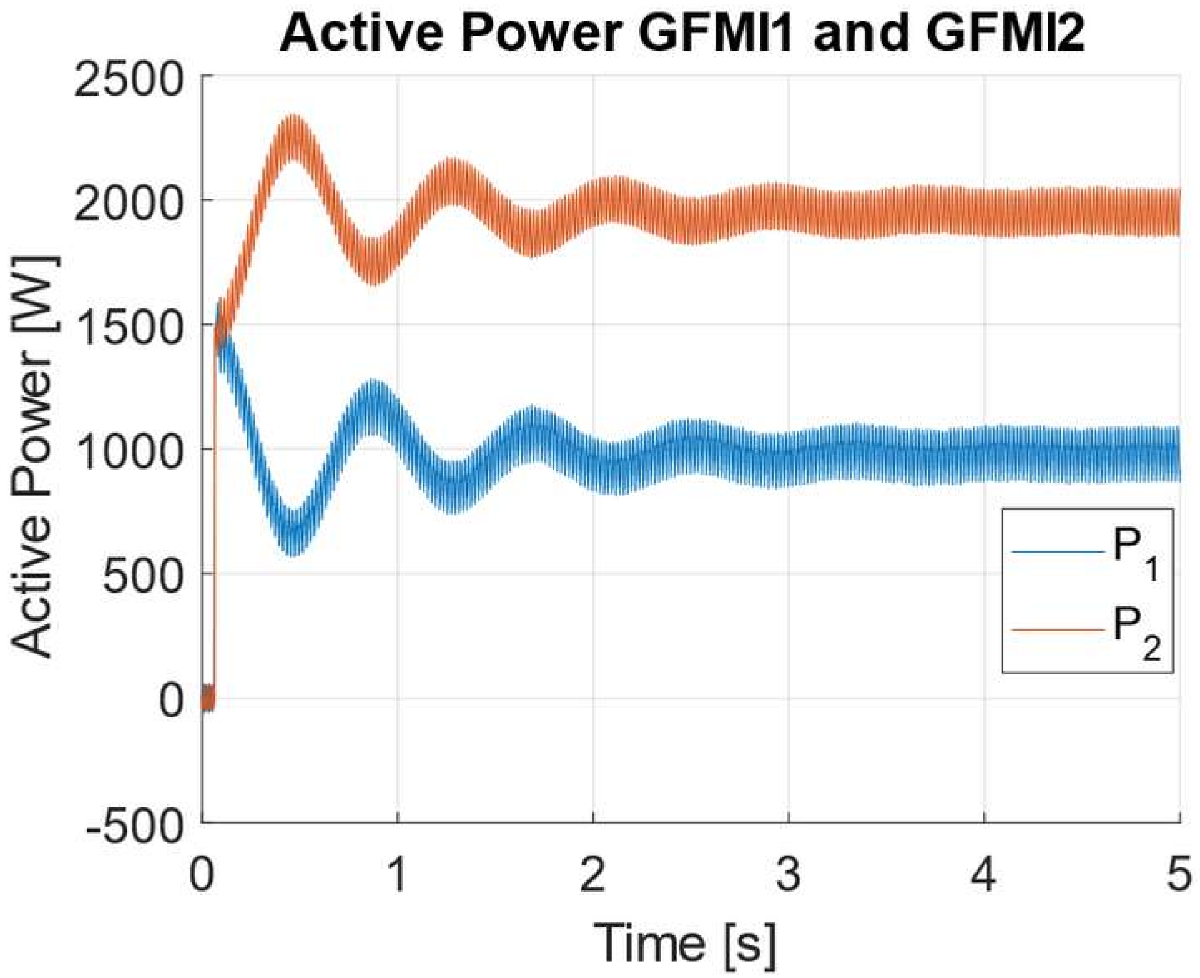


Droop Control Methods for mostly Inductive Lines

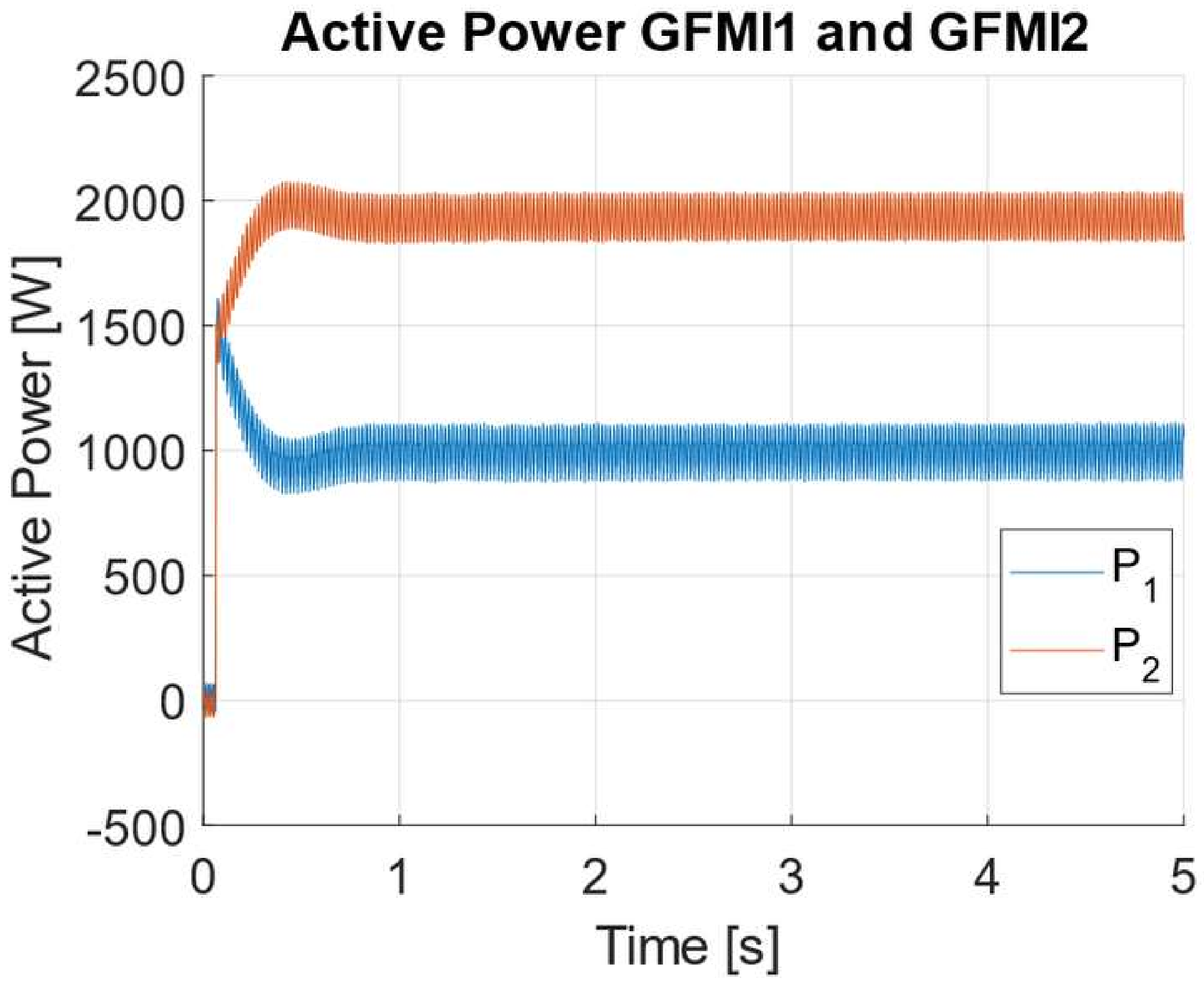
What if parallel inverters have different coefficients?

$$m_1 = 2m_2$$

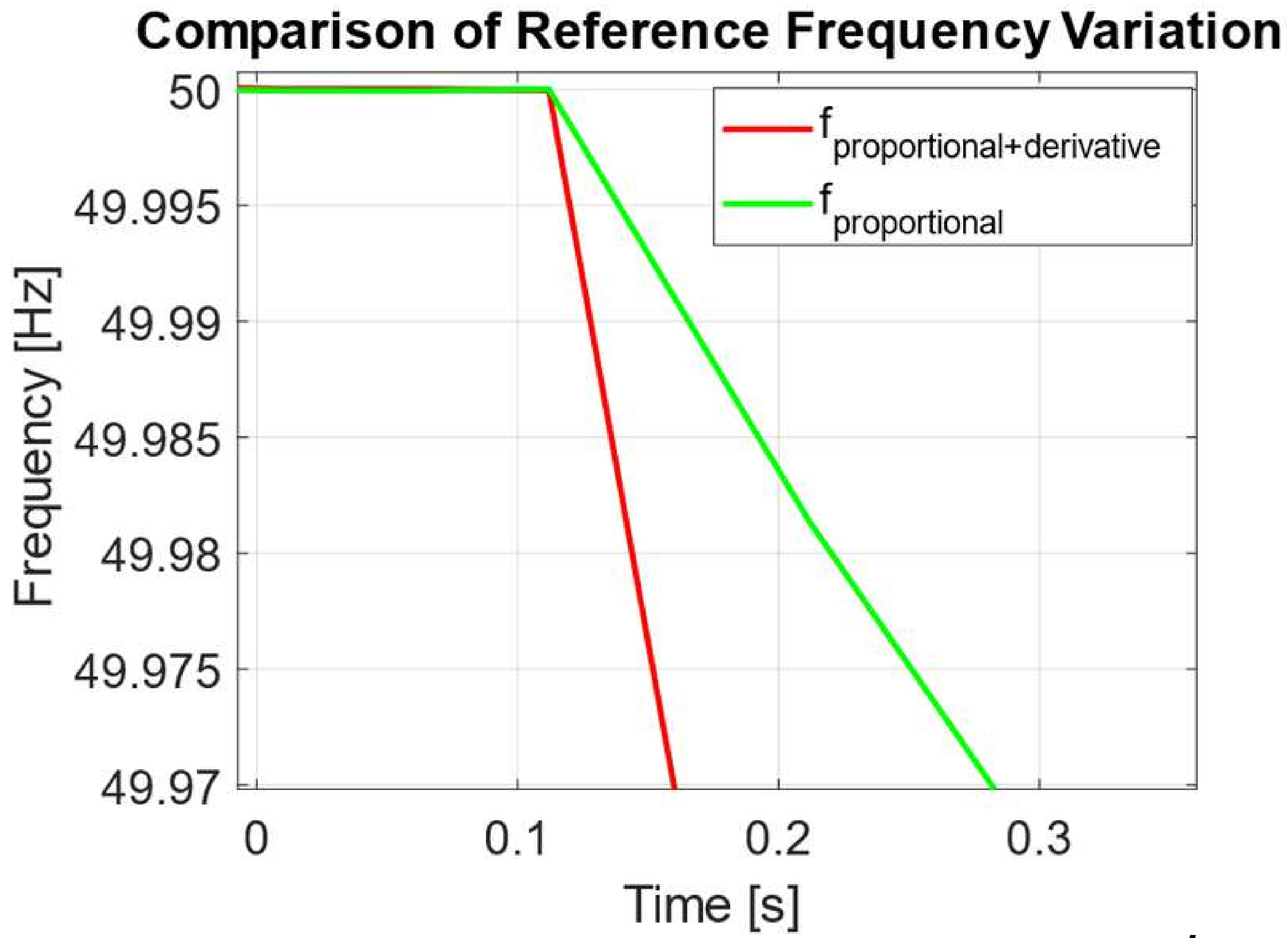
Damped response ✓ Larger frequency derivative ✗



PROPORTIONAL



PROPORTIONAL+DERIVATIVE



Droop Control Methods for mostly Inductive Lines

VIRTUAL SYNCHRONOUS GENERATOR (VSG)

Emulation of a virtual synchronous generator dynamics with a first-order control

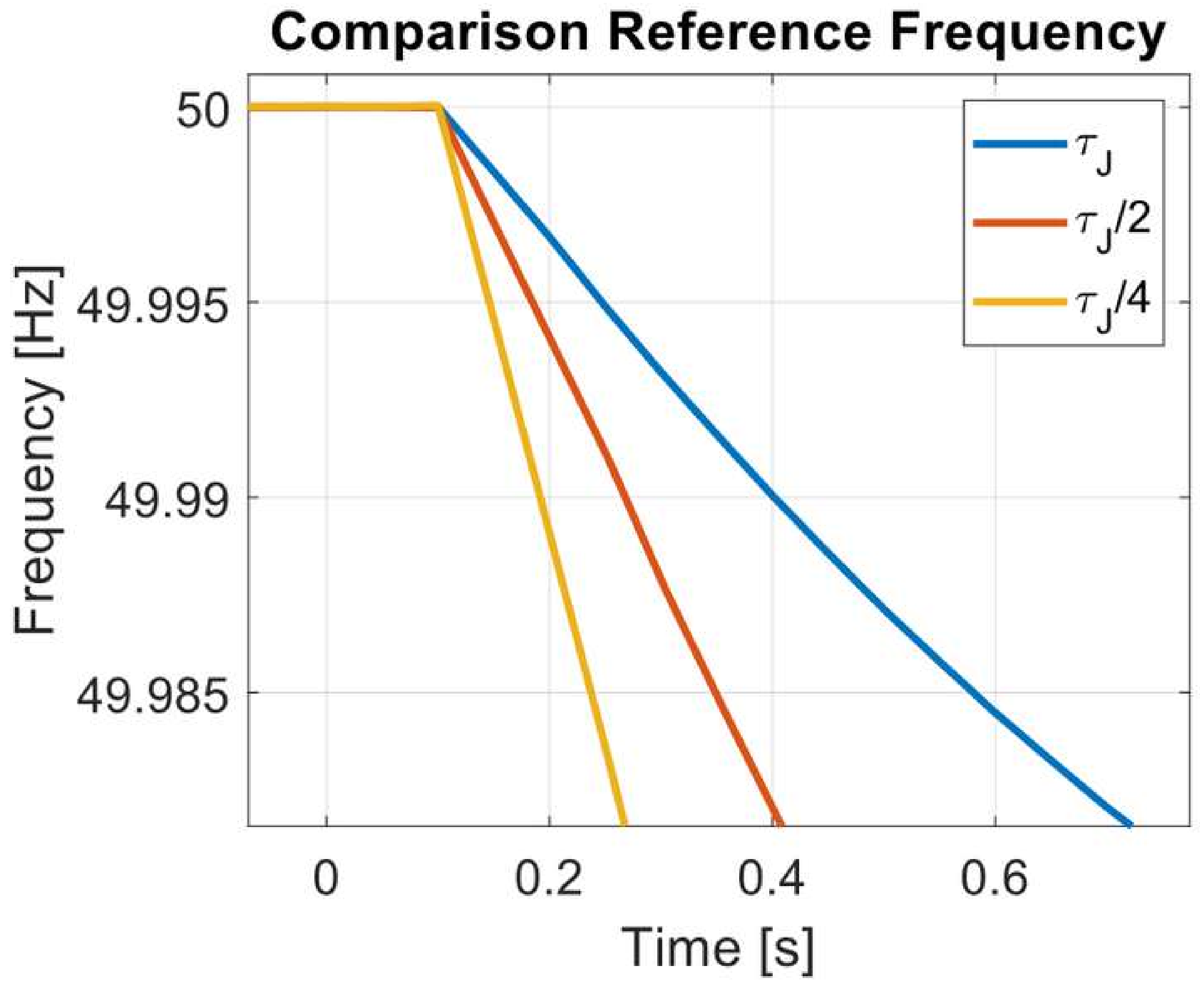
$$-P - \frac{\Delta\omega}{m} = J\omega_0 \frac{d\Delta\omega}{dt}$$

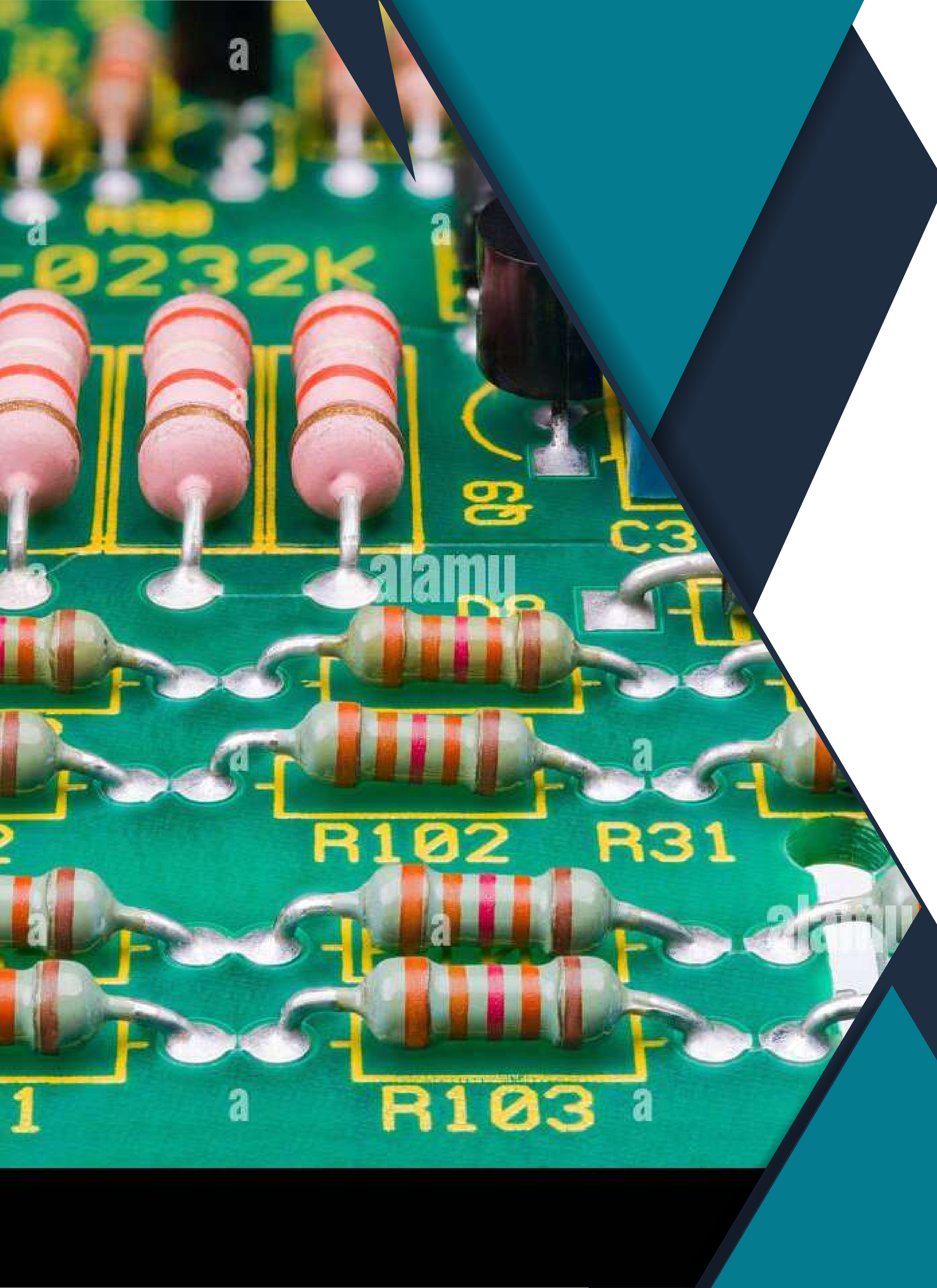
Same as the proportional droop (m)

Indicated as τ_J ($J\omega_0$)

EXPERIMENTAL RESULTS

Larger τ_J → Smaller frequency derivative





Droop Control Methods for mostly Resistive Lines

MOSTLY RESISTIVE LINES → Active and reactive power coupling

$$P \propto f_P(\Delta\omega, \Delta V)$$
$$Q \propto f_Q(\Delta\omega, \Delta V)$$

Conventional droop may cause **oscillation** in the system response and possible **instability**

DECOUPLING METHODS

Droop Control Methods for mostly Resistive Lines

VIRTUAL IMPEDANCE

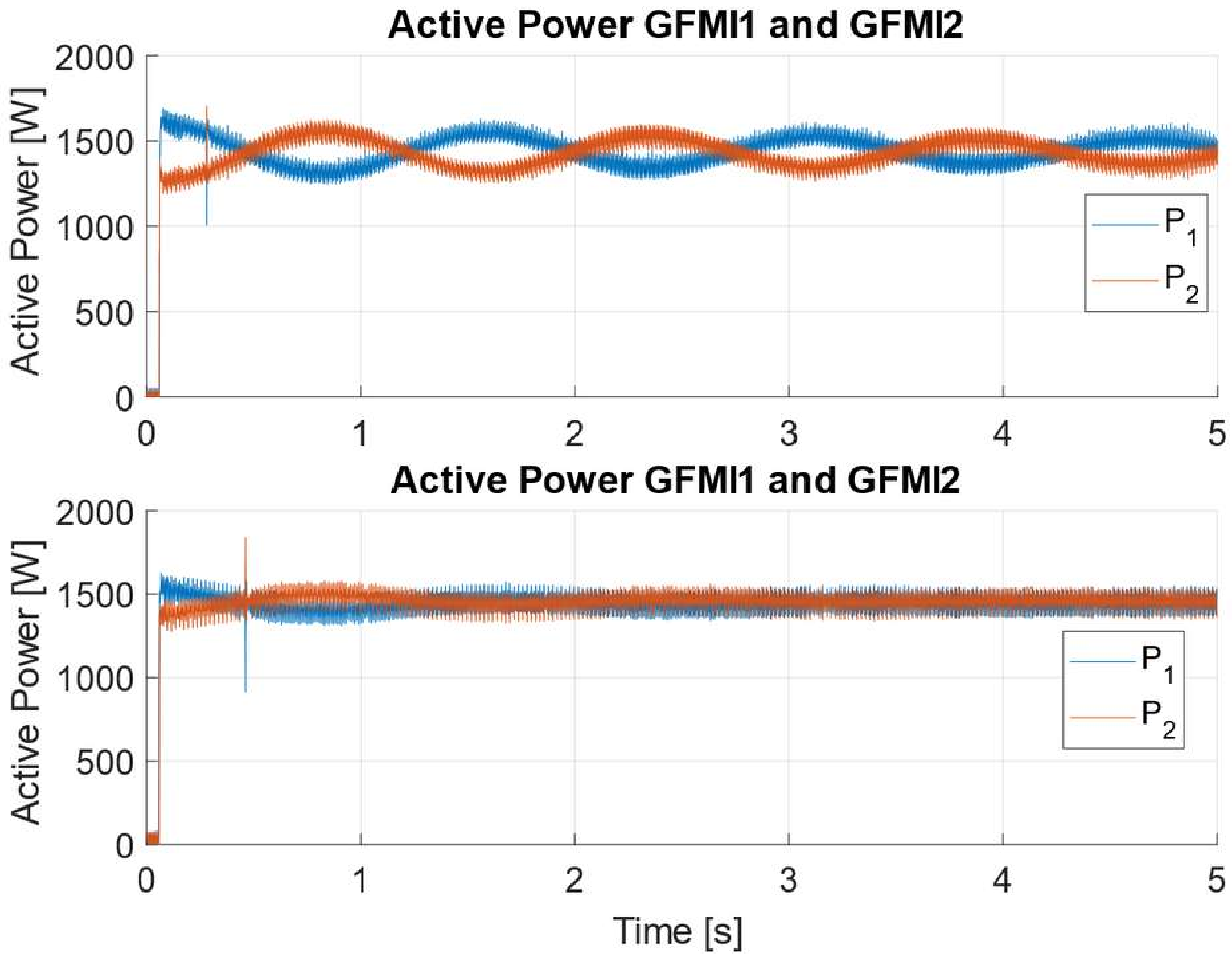
Add a virtual voltage drop in the voltage reference to emulate a larger X/R ratio

- No additional components
- Not necessary to know line parameters

EXPERIMENTAL RESULTS

$X/R \approx 0.5$ →

$X/R \approx 1.2$ →



Conclusion

	Inductive Line			Resistive Line
	Proportional Droop	**VSG**	**Proportional+ Derivative Droop**	**Virtual Impedance**
Power-sharing	✓	✓	✓	✓
Frequency derivative	✓	✓	✗	✓
Damped response	✗	✗	✓	✗

Not suitable for grid-connection (Proportional Droop – Damped response)

Design of a second-order VSG (VSG – Damped response)

Further Investigation (Proportional+ Derivative Droop – Frequency derivative; Virtual Impedance – Damped response)

Conclusion

Personal Contribution

- Grid-Following Inverter
- Grid-Forming Inverter
- Droop Control Methods

→

- **Literature review**
- **Design of the control parameters**
- **Simulations in Simulink**
- **Assembly of the experimental setup**
- **Experimental validation**

Thank You

For Your Attention