Robust Active Damping Design for Grid Current Feedback Control in Grid-connected Converters

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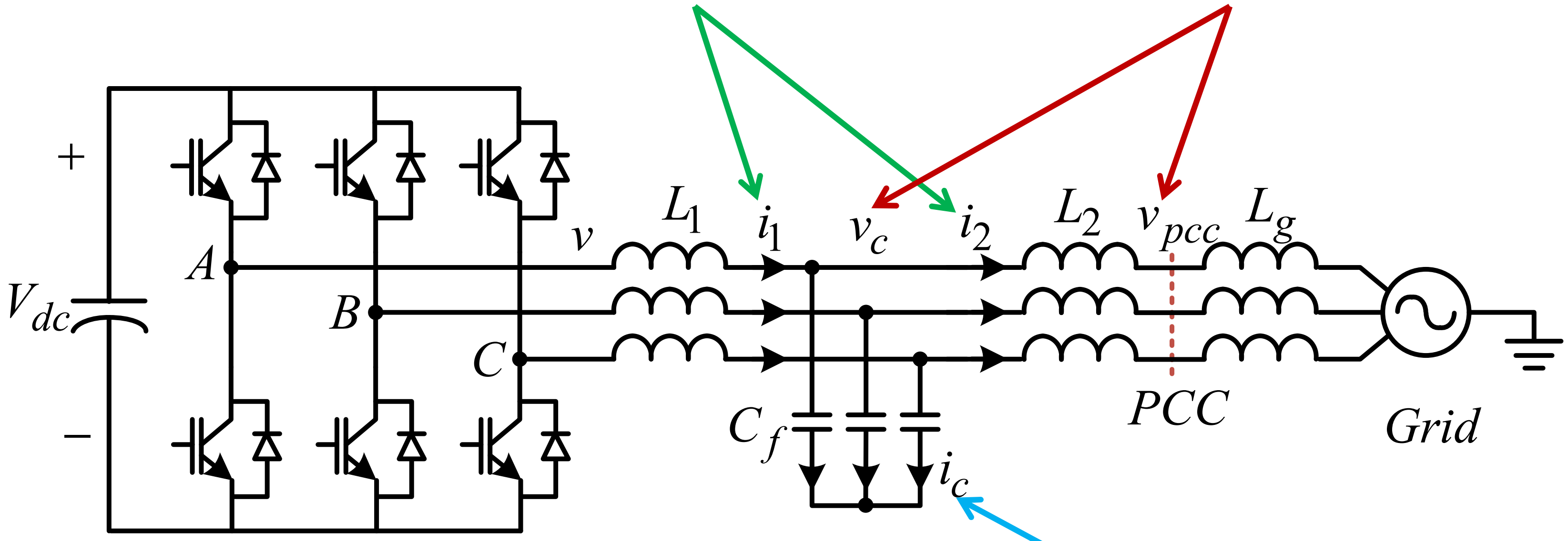
Outline

- ❑ **Background**

- ❑ **Robust Active Damping Design of the Grid-Current Control System**

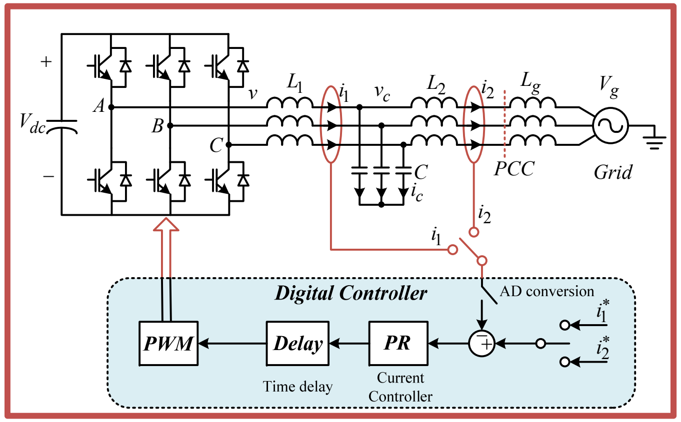
- ❑ **Highly Accurate Derivatives for Capacitor-Voltage Active Damping**

Background

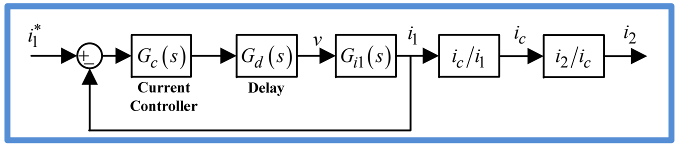


Grid-Tied Converter

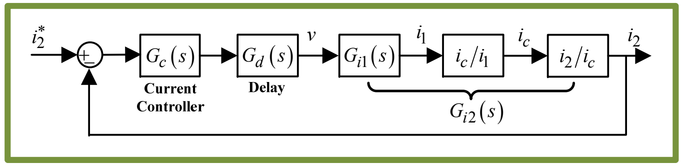
Stability Characteristic of the GCF and CCF



Three-phase grid converter with single-loop CCF control or GCF control



Single-loop CCF control



Single-loop GCF control

$$G_c(s) = K_p + \frac{K_i s}{s^2 + \omega_b^2}$$

$$G_{i1}(s) = \frac{i_1(s)}{v(s)} = \frac{1}{sL_1}\frac{s^2 + \omega_0^2}{s^2 + \omega_r^2}$$

$$G_{i2}(s) = \frac{i_2(s)}{v(s)} = \frac{1}{sL_1}\frac{\omega_0^2}{s^2 + \omega_r^2}$$

$$G_d(s) = e^{-1.5T_s s}$$

$$\frac{i_2(s)}{i_c(s)} = \frac{G_{i2}(s)}{G_{ic}(s)} = \frac{\omega_0^2}{s^2}$$

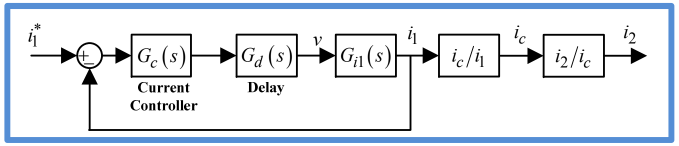
$$\frac{i_c(s)}{i_1(s)} = \frac{G_{ic}(s)}{G_{i1}(s)} = \frac{s^2}{s^2 + \omega_0^2}$$

Open-loop Transfer function of the Single-loop CCF and GCF:

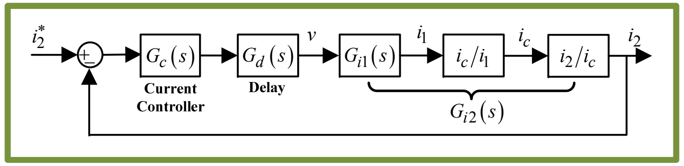
$$T_{i1}(s) = G_c(s)G_d(s)G_{i1}(s) \qquad T_{i2}(s) = G_c(s)G_d(s)G_{i2}(s)$$

Stability Characteristic of the GCF and CCF

Single-loop CCF control

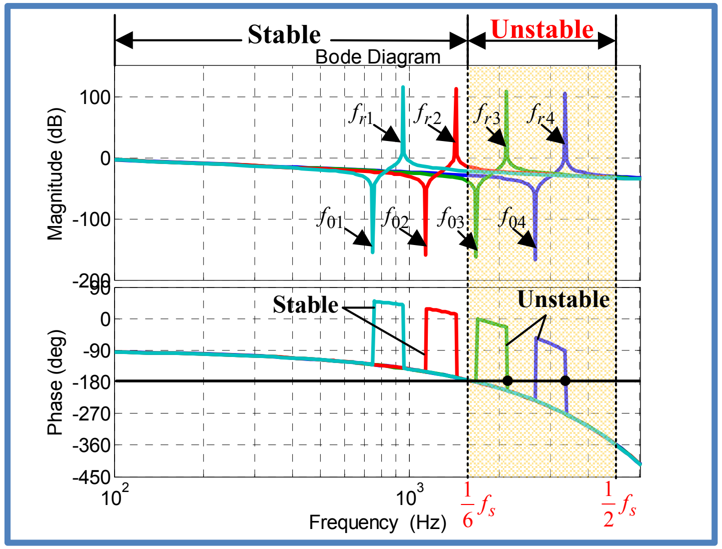


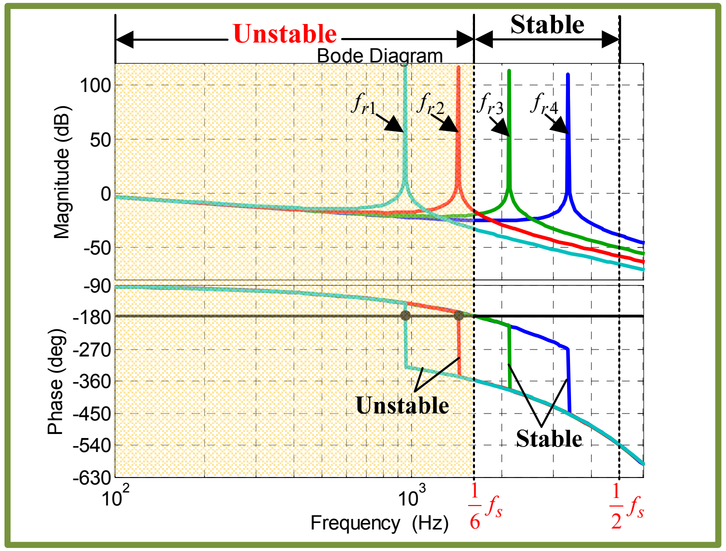
Single-loop GCF control



LCL-Filter Resonance Frequencies

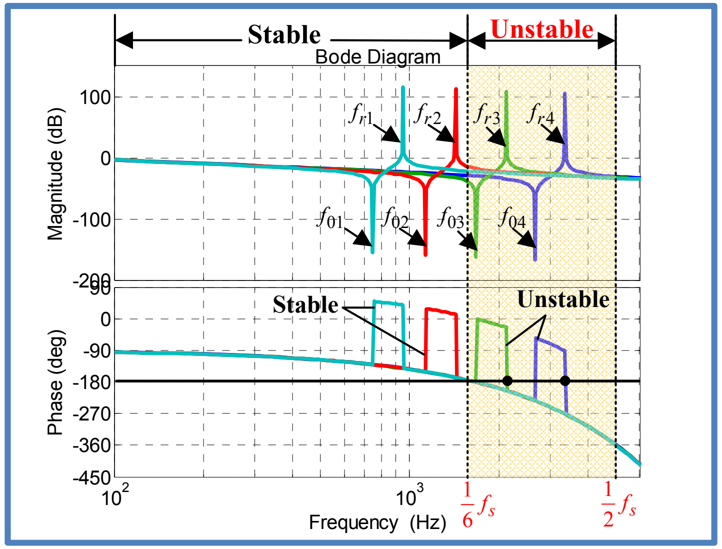
Capacitor	C_1 = 25 uF	C_2 = 11 uF	C_3 = 5 uF	C_4 = 2 uF
Resonance frequency	f_{r1} = 0.95 kHz	f_{r2} = 1.43 kHz	f_{r3} = 2.12 kHz	f_{r4} = 3.36 kHz



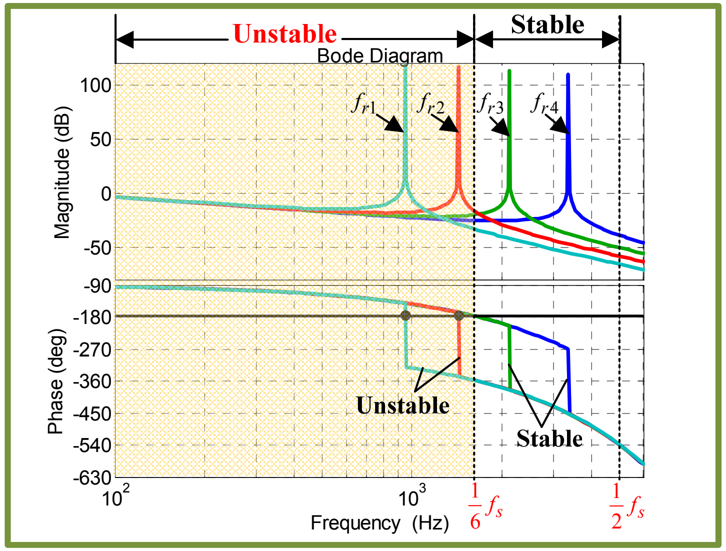


Stability Characteristic of the GCF and CCF

Single-loop CCF control



Single-loop GCF control



How to widen the stable regions of these two systems?

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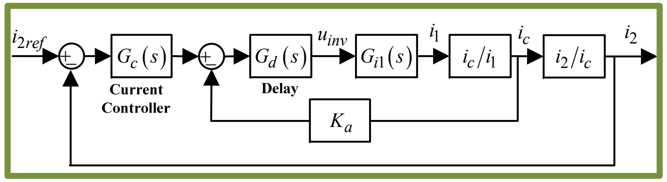
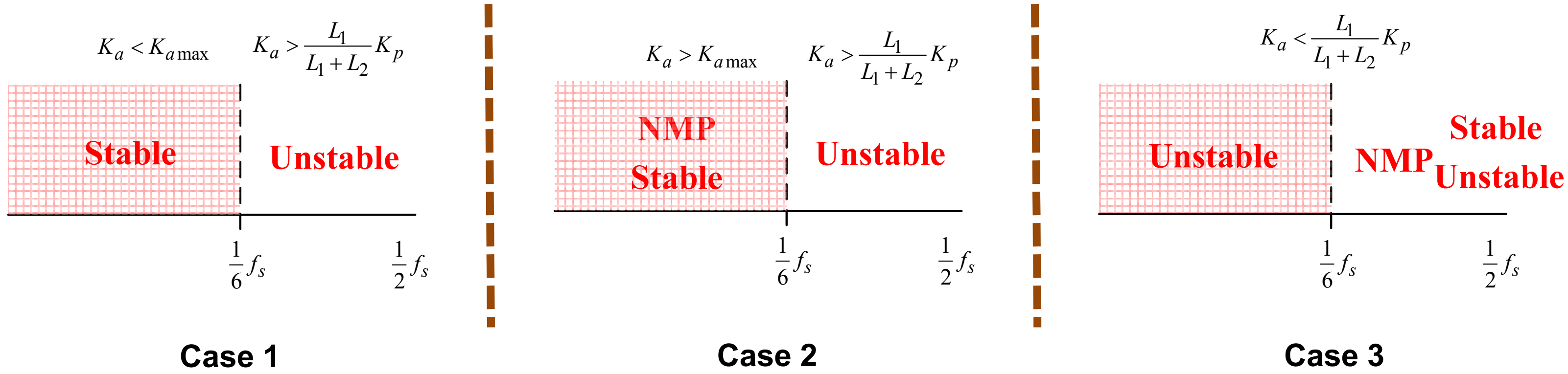
Capacitor Current Feedback AD

Dual-loop GCF control



Can it be always stable in (0, fs/6)?

Stability Characteristics of the Dual-loop GCF Control [1]

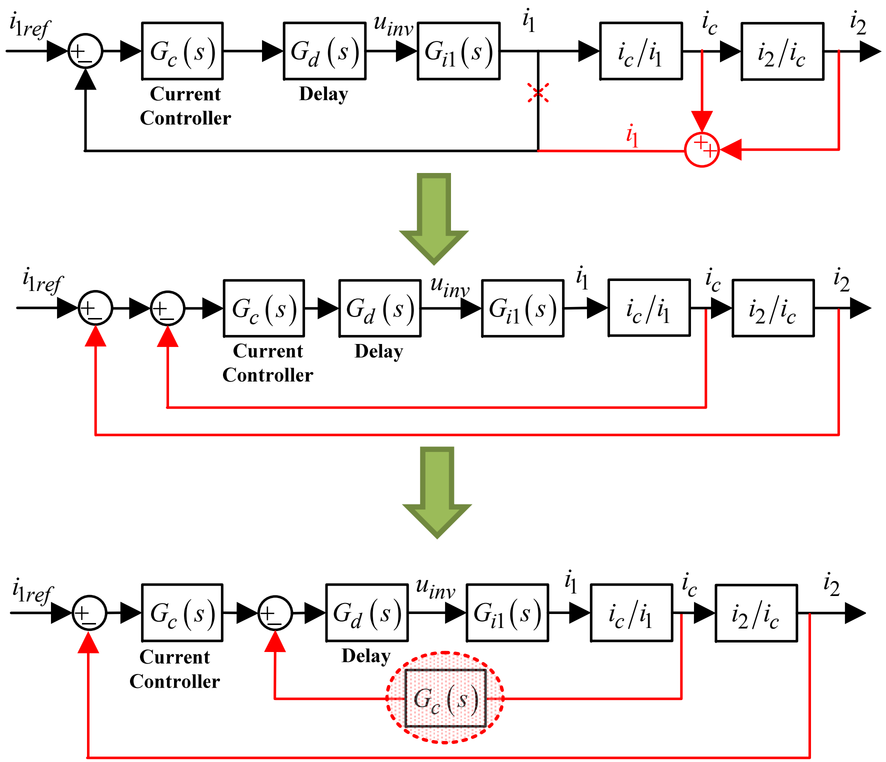


How to design Ka in order to make the system always stable in (0, fs/6)?

[1] D. Pan, X. Ruan, C. Bao, W. Li, and X. Wang, "Capacitor-current-feedback active damping with reduced computation delay for improving robustness of LCL-type grid-connected inverter," *IEEE Trans. Power Electron.*, vol. 29, no. 7, pp. 3414–3427, Jul. 2014.

Capacitor Current Feedback AD

Signal Flow Graph Method



The single loop CCF becomes the dual-loop GCF!

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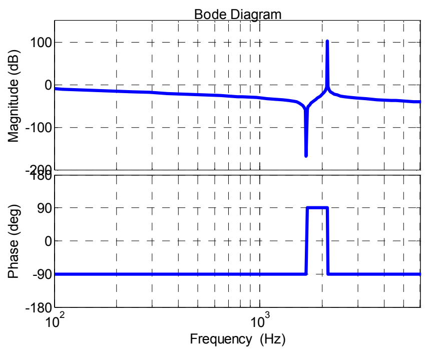
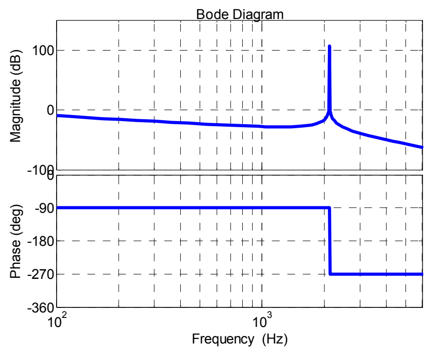
Capacitor Current Feedback AD

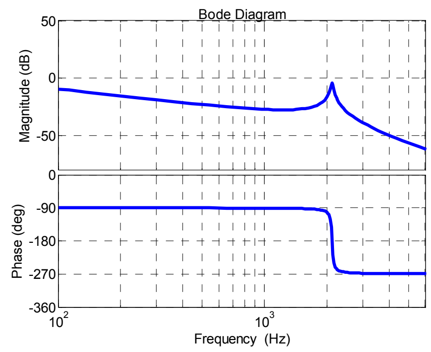
Without time delay



Single-loop CCF

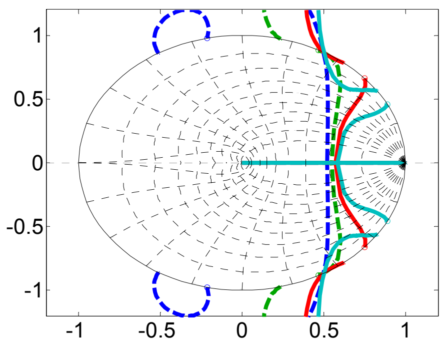


Single-loop GCF

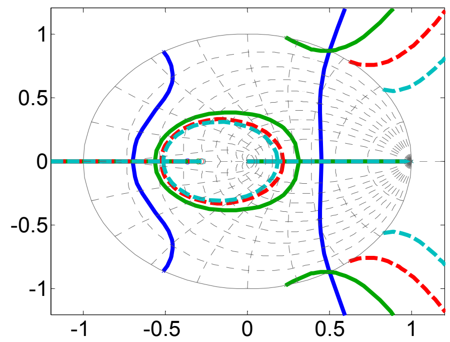


Dual-loop GCF (Ka=Kp)

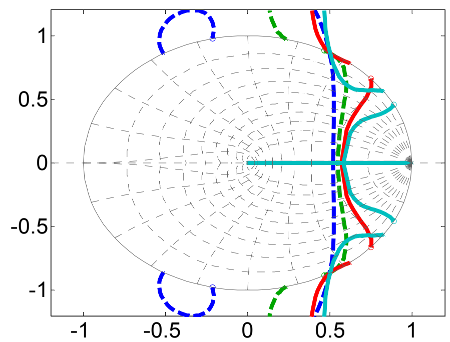
With time delay



Single-loop CCF



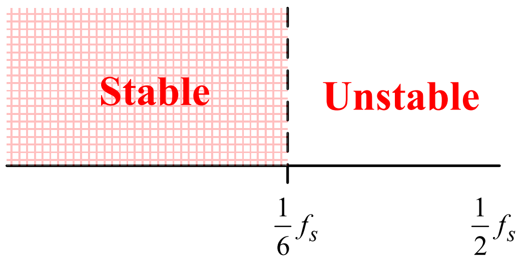
Single-loop GCF



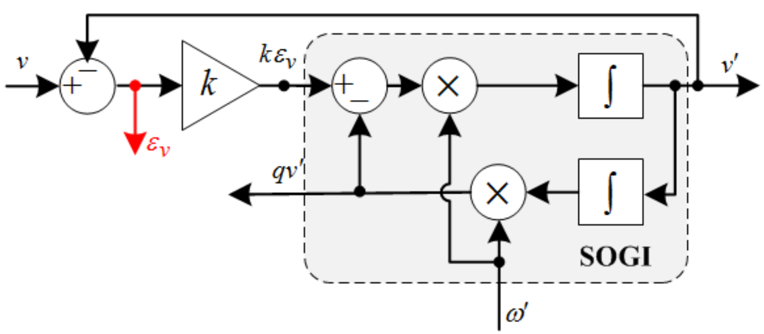
Dual-loop GCF (Ka=Kp)

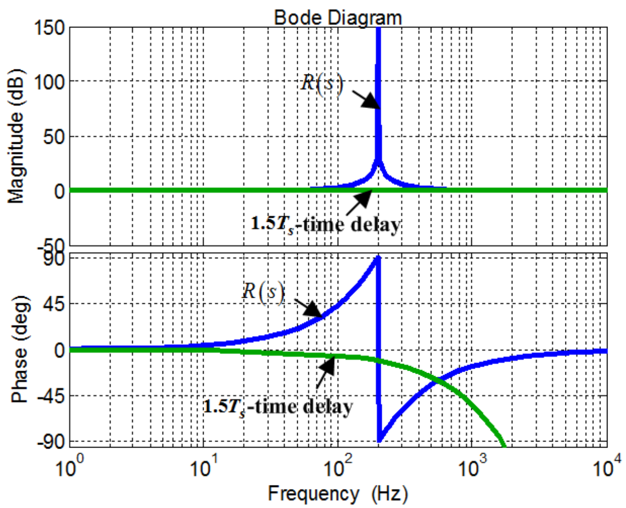
Capacitor Current Feedback AD

How to enhance the stability of the dual-loop GCF?



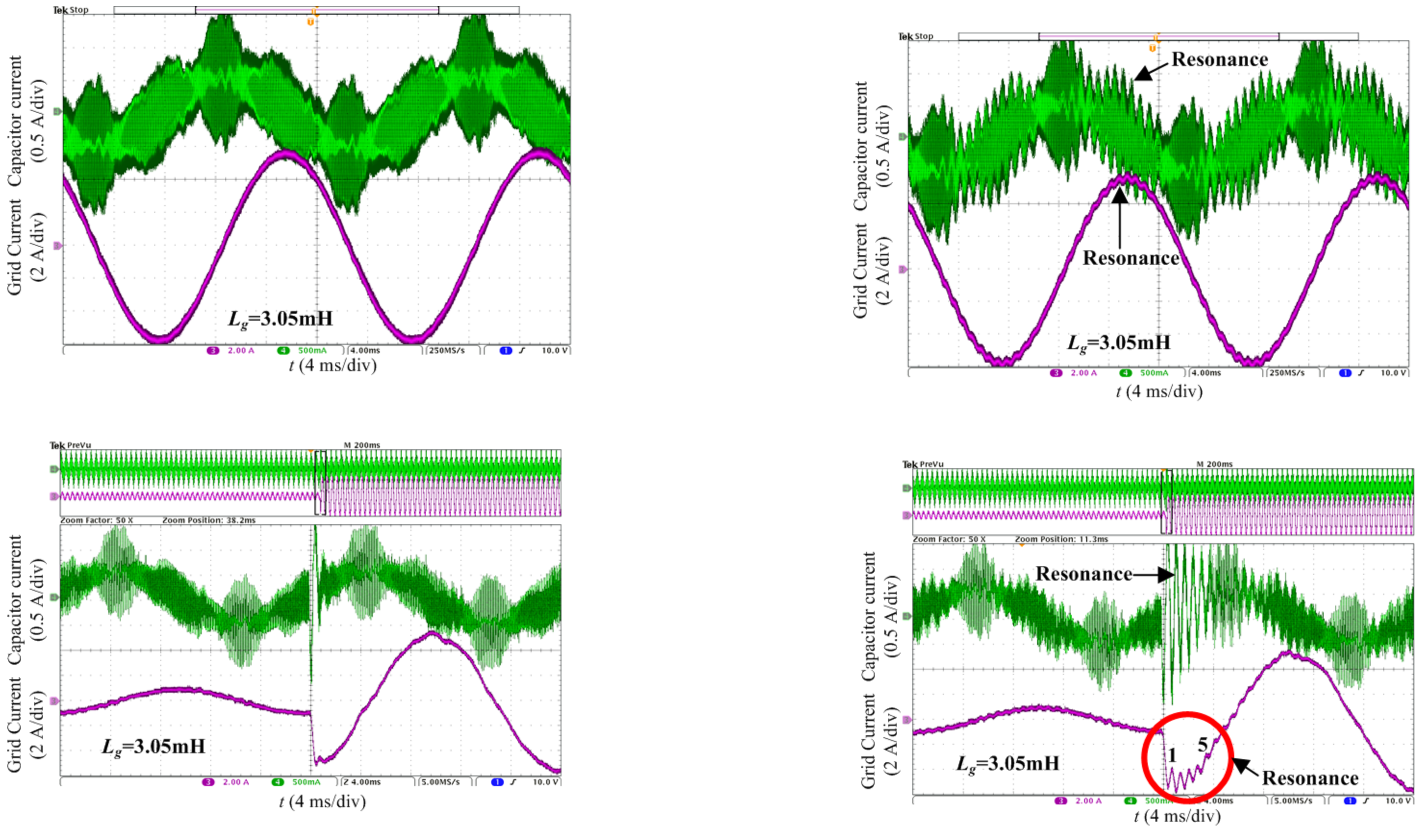
Proposed SOGI-based AD:





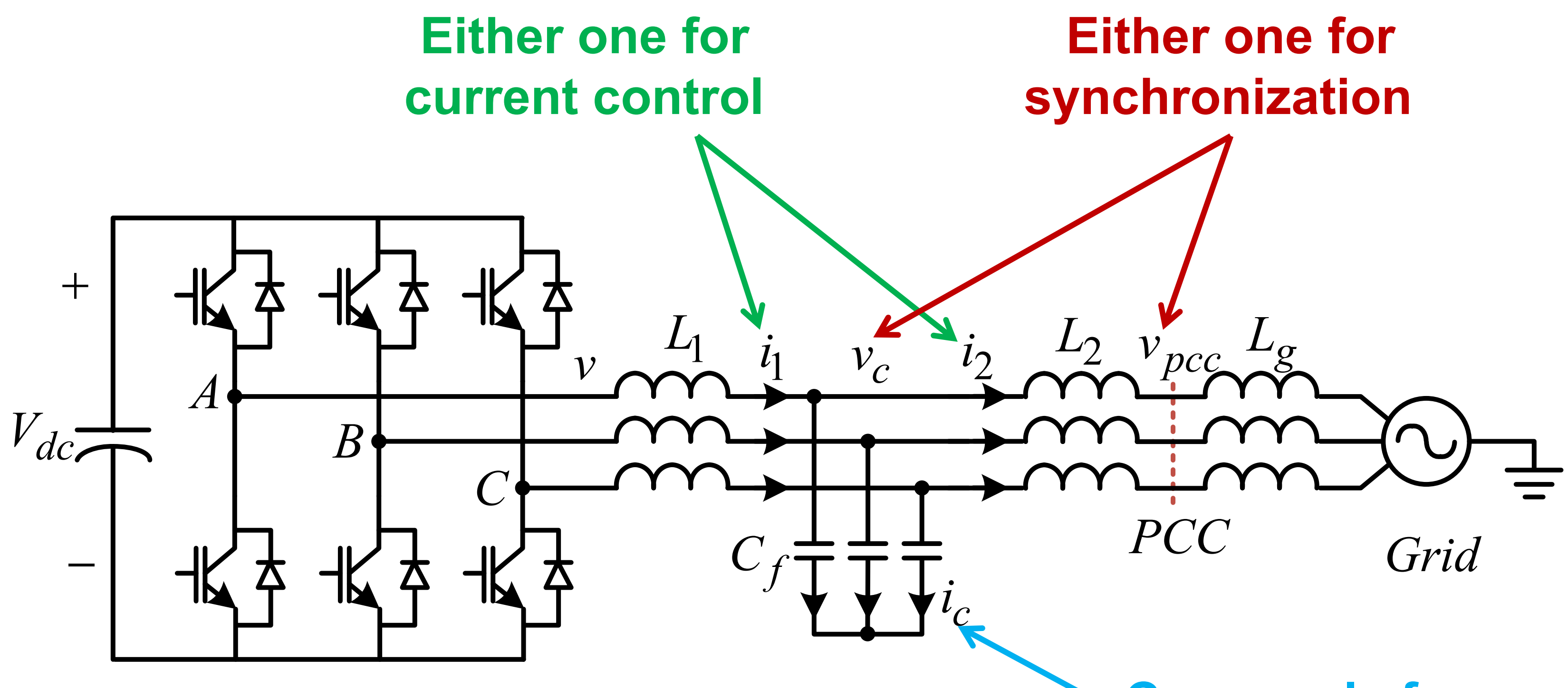
Capacitor Current Feedback AD

Experimental results:



Z. Xin, X. Wang, P. C. Loh, and F. Blaabjerg, "Robust active damping design for grid-current feedback control in grid-connected converters," *IEEE Trans. Power Electron.*, To be published.

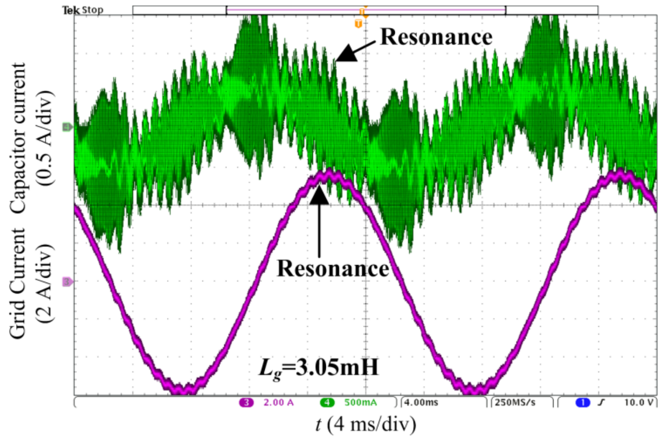
Background



Grid-Tied Converter

Capacitor Voltage Feedback AD

- **Capacitor Current ----** Difficult to extract perfectly due to the influence of switching-frequency harmonics



- **Cost----** Additional current sensors for sensing capacitor current

Price: £14.34 ~~£14.80~~

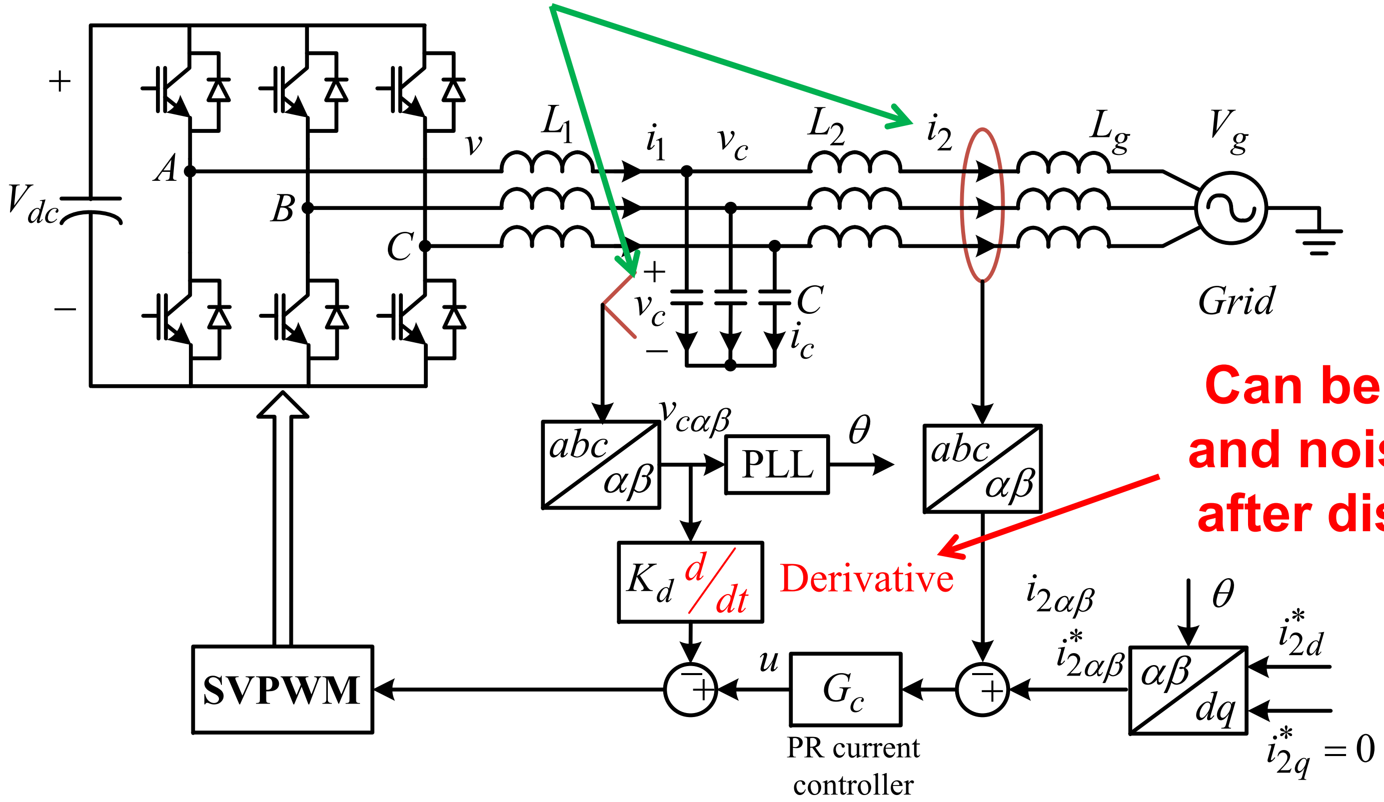
Price: £14.39 ~~£14.85~~

Price: £10.85 ~~£12.80~~

Capacitor Voltage Feedback AD

One Possibility

Measure one voltage and one current only



Can be inaccurate and noise sensitive after discretization

Existing Differentiation Problems

Direct Digital Differentiation

Method	Tustin	Forward Euler	Backward Euler
Rule	$s = \frac{2}{T_s}\frac{z-1}{z+1}$	$s = \frac{z-1}{T_s}$	$s = \frac{z-1}{zT_s}$

Indirect Digital Differentiation

Method	High-Pass Filter	Lead-Lag Function
Rule	$\frac{\omega_{HP}s}{s+\omega_{HP}}$	$\omega_{max}\frac{s+k_f\omega_{HP}}{k_f s+\omega_{max}}$

Z. Xin, P. C. Loh, X. Wang, F. Blaabjerg, and Y. Tang, "Highly Accurate Derivatives for LCL-Filtered Grid Converter With Capacitor Voltage Active Damping," *IEEE Trans. Power Electron.*, 2015, DOI: 10.1109/TPEL.2015.2467313.

Recommended Solutions

Differentiation with :
Nonideal Generalized Integrator (GI)
and
Second-Order Generalized Integrator (SOGI)

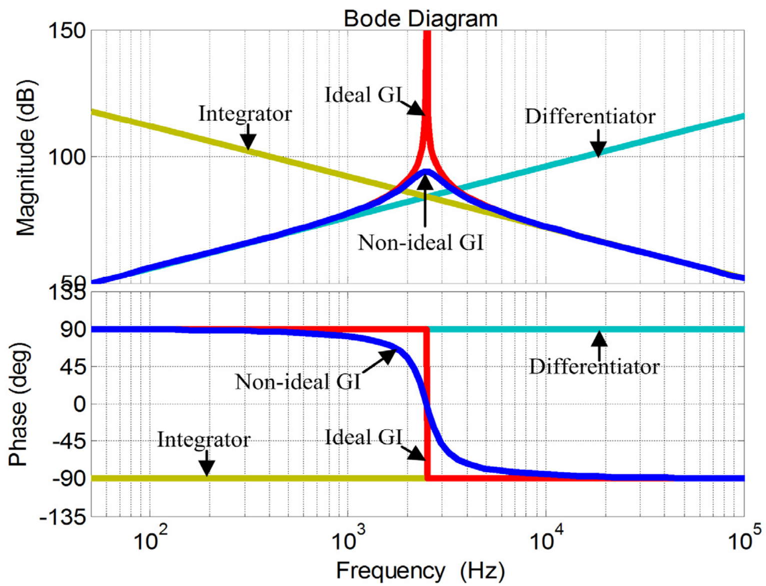
Question

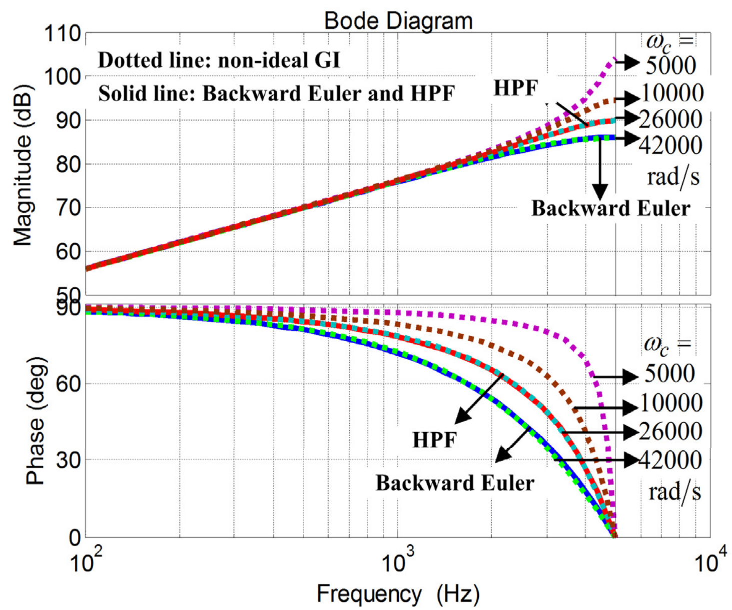
-- How can they differentiate?

Non-ideal Generalized Integrator

$$GI(s)=\frac{\omega''^2 s}{s^2+\omega''^2}$$

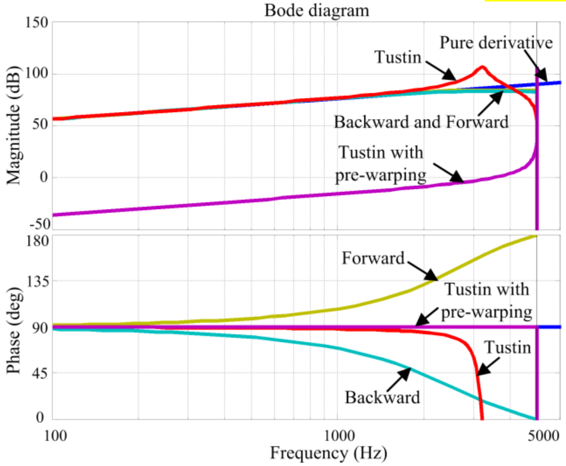
$$GI'(s)=\frac{\omega''^2 s}{s^2+\omega_c s+\omega''^2}$$

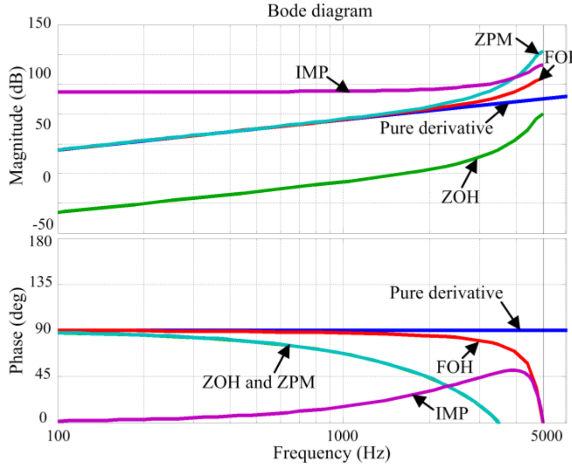




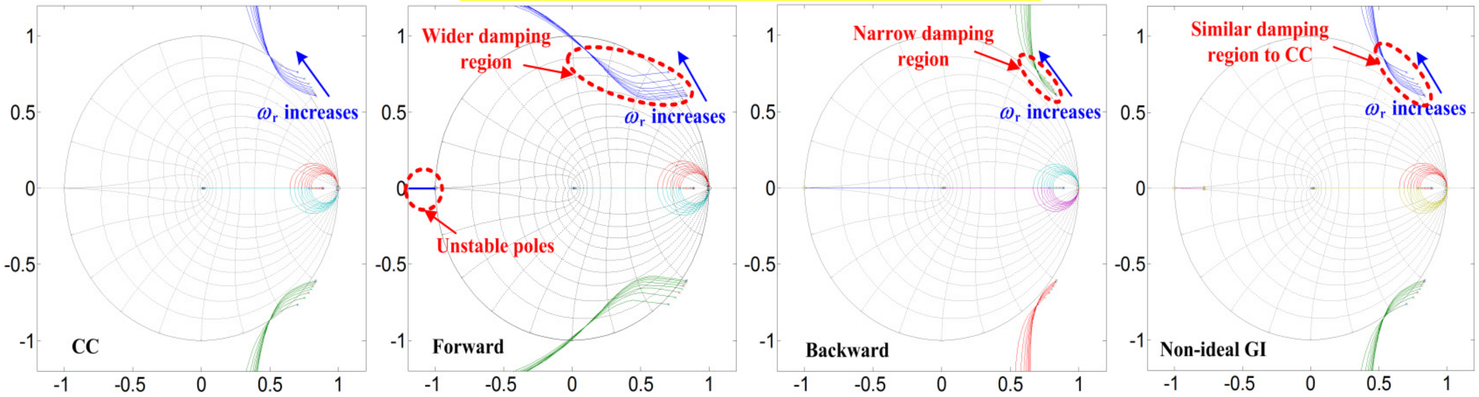
Non-ideal Generalized Integrator

Discretization





For active damping



Z. Xin, X. Wang, P. C. Loh, and F. Blaabjerg, “Realization of Digital Differentiator Using Generalized Integrator for Power Converters,” *IEEE Trans. Power Electron.*, 2015, 10.1109/TPEL.2015.2442414.

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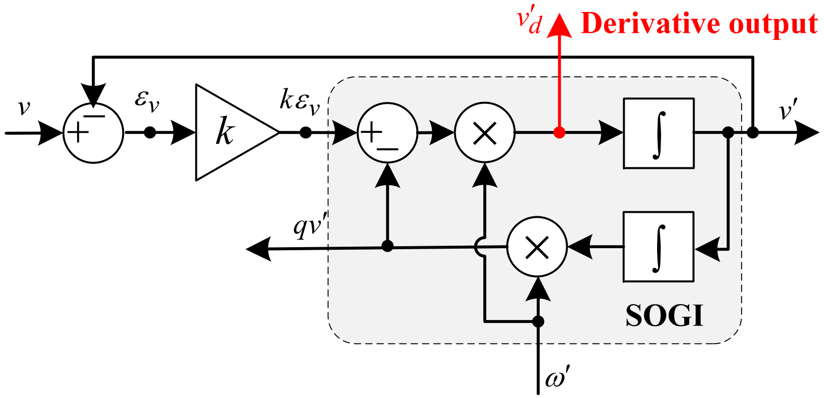
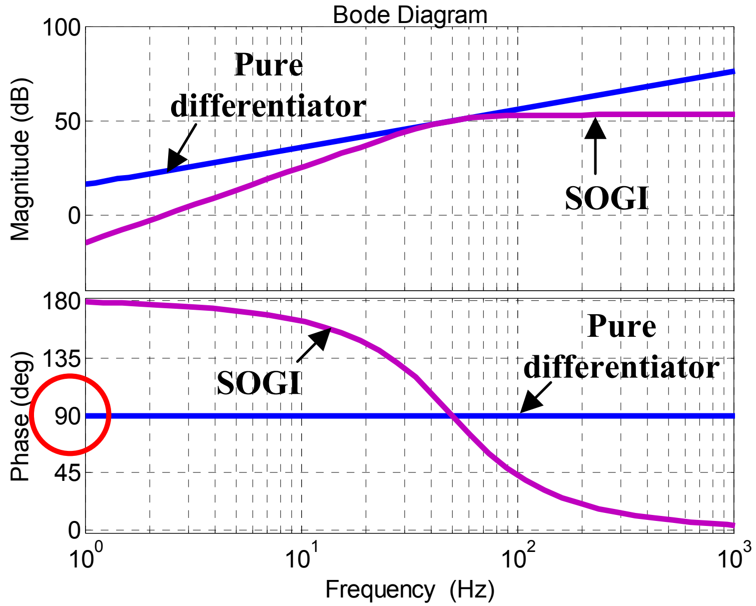
Second Order Generalized Integrator

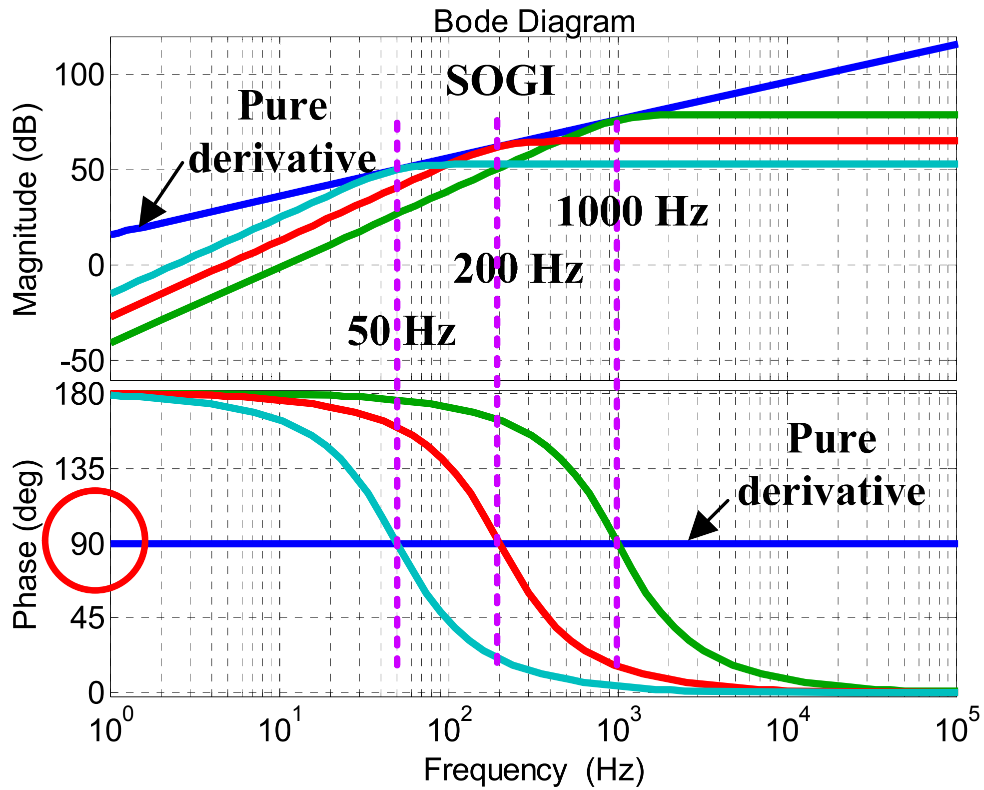
How can "SOGI" differentiate?



$$G_{v'_d}(s) = \frac{v'_d}{v} = \frac{k\omega' s^2}{s^2 + k\omega' s + \omega'^2}$$

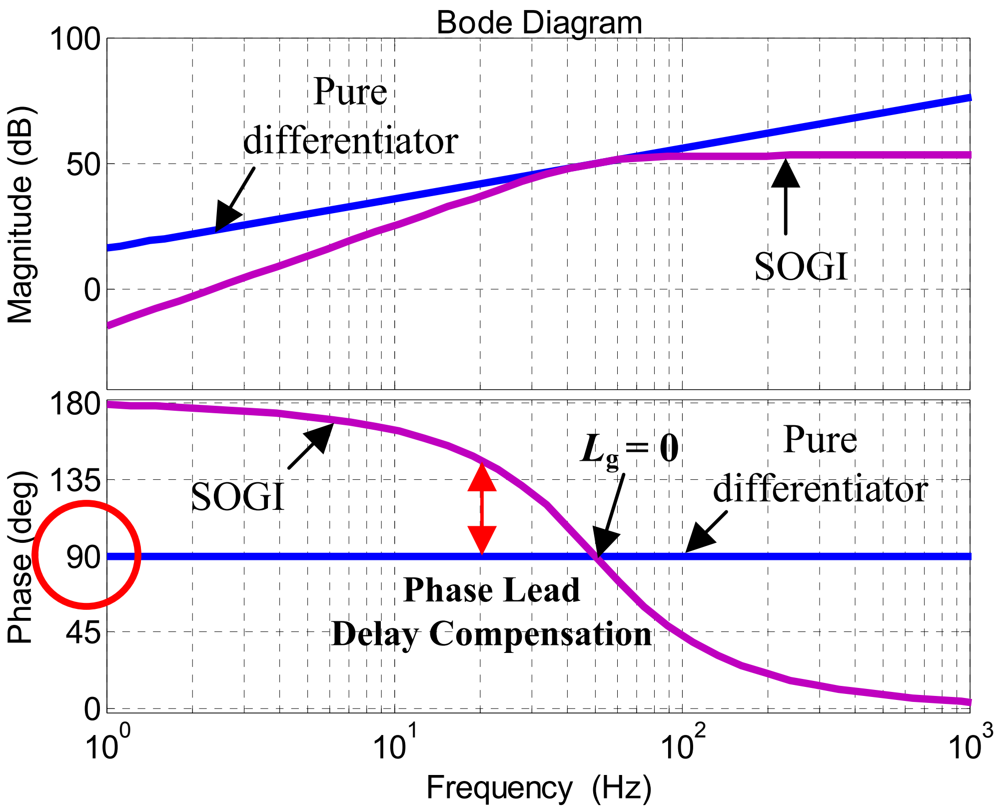


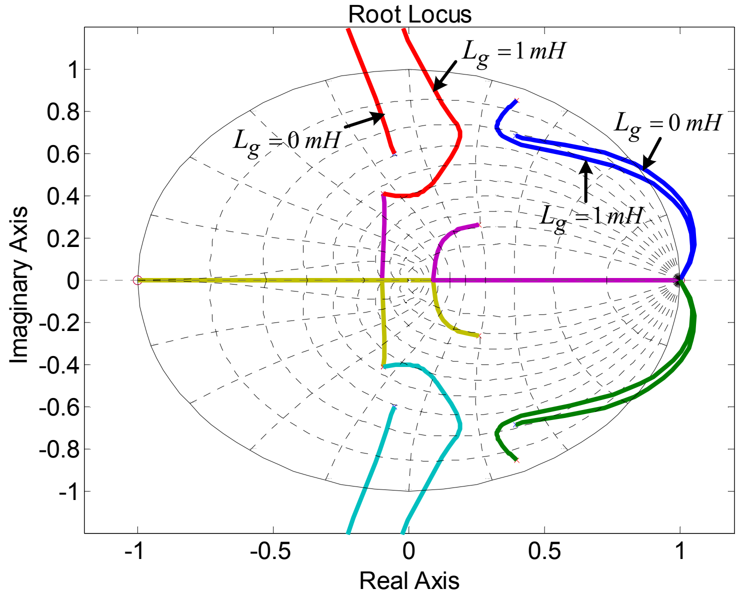
Usage 1: frequency-adaptive differentiator



- Need additional frequency detection algorithm or grid inductance estimation algorithm to obtain the required frequency
- Can also be used where resonance frequency does not vary greatly.

Usage 2: frequency-fixed differentiator

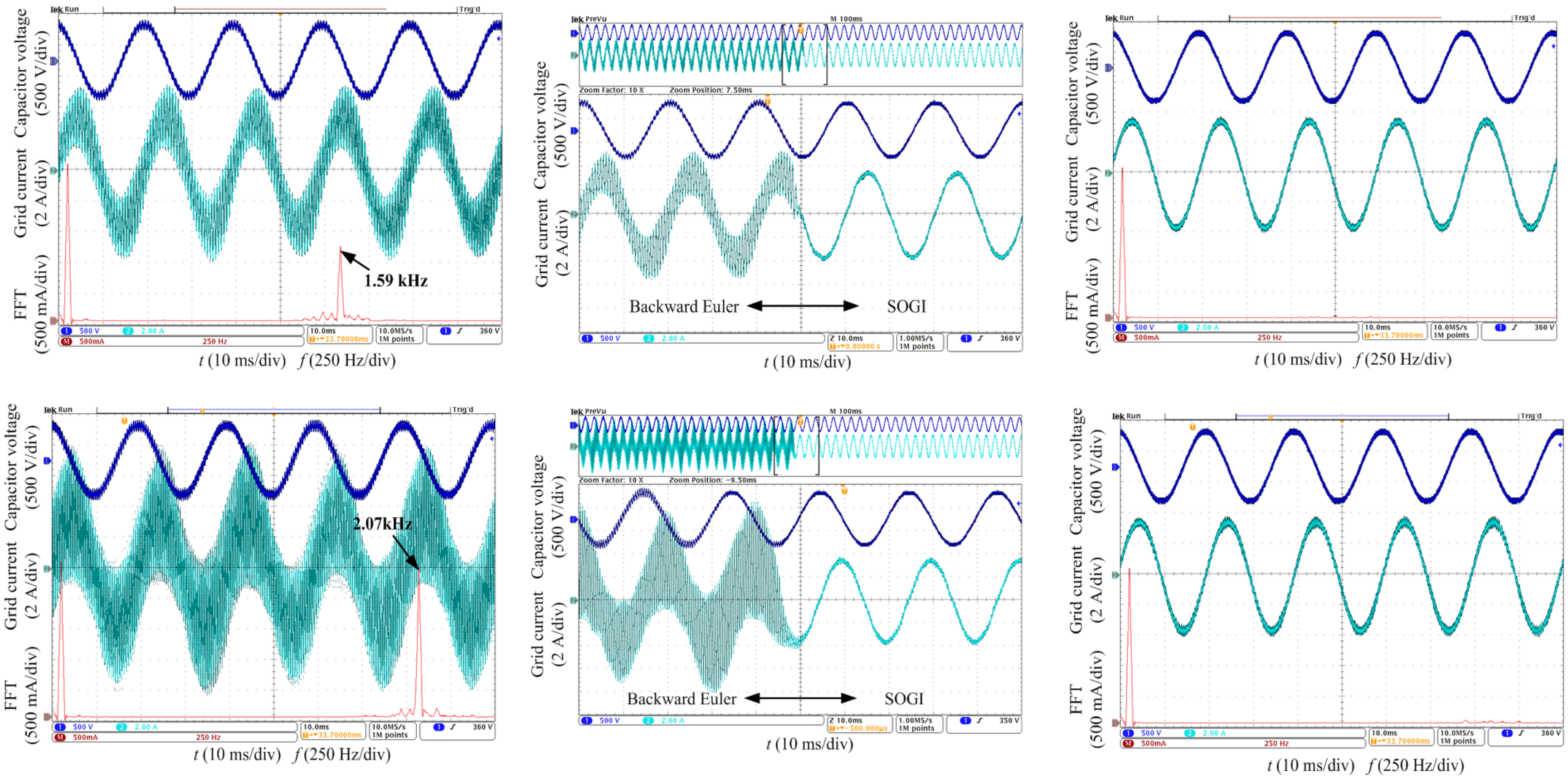




- ❑ **Does not need any frequency detection algorithm**
- ❑ **Can realize time delay compensation**

Second Order Generalized Integrator

Experimental Results



Thank You! Questions?

“ THE HIDDEN HARMONY IS BETTER THAN THE OBVIOUS ”

- P. PICASSO

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