Current Control of Grid Converters Connected with Series AC Capacitor

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Outline

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- Background and Challenges
- Proposed Current Control
- Performance Validation
- Conclusions

Background and Challenges

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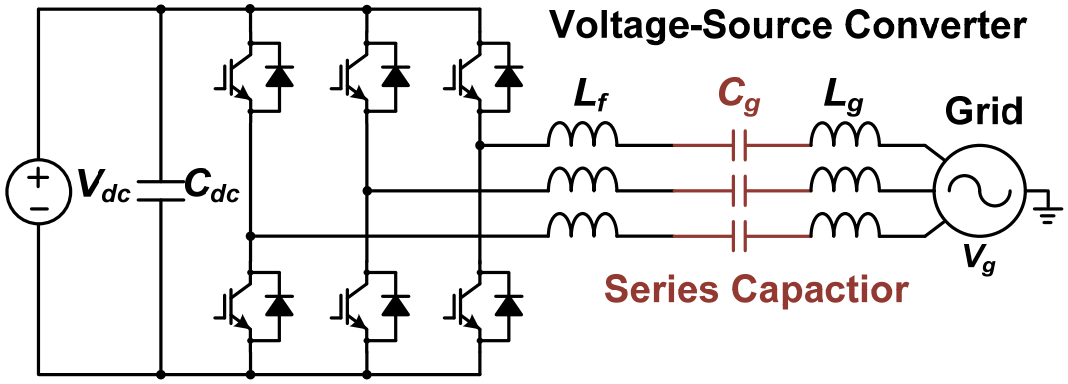
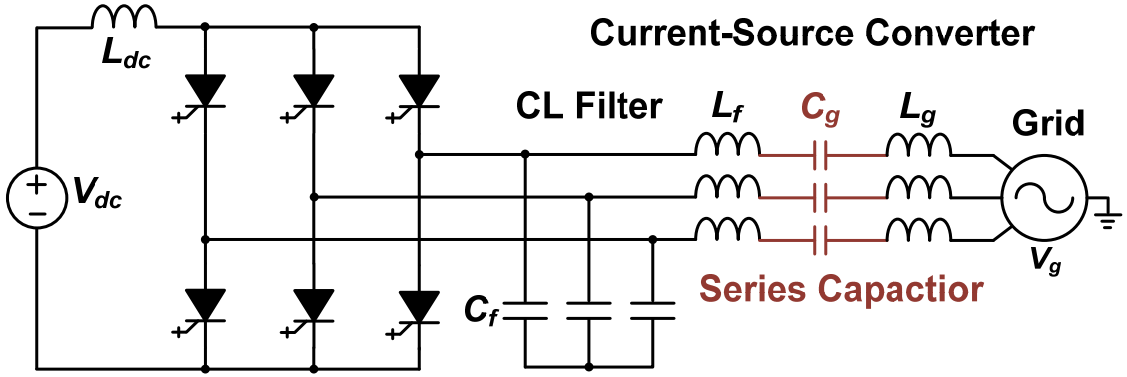
Grid converters with series ac capacitor

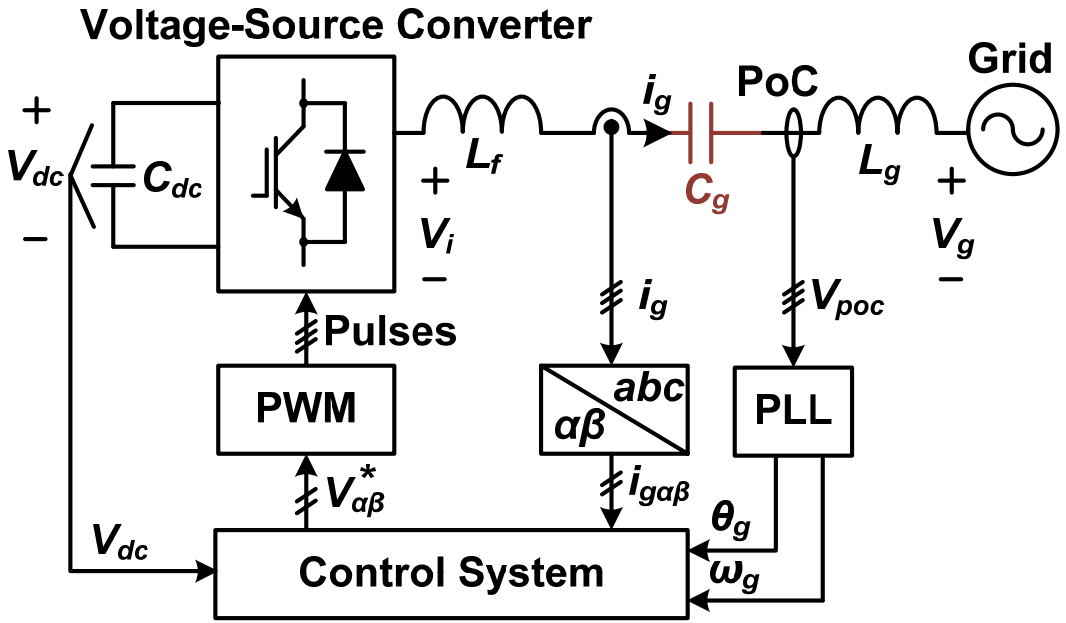




Reduced Voltage Stress and Power Rating

Background and Challenges

Challenges with Series-LC-Filter



- Capacitive behavior of series-LC-filter
  - ✓ Prevents the use of integral current controllers
  - ✓ Coupling between dc-link voltage and reactive power control

Background and Challenges

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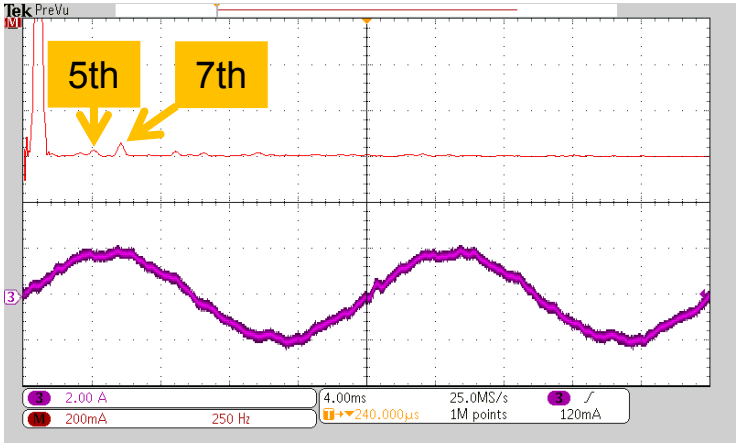
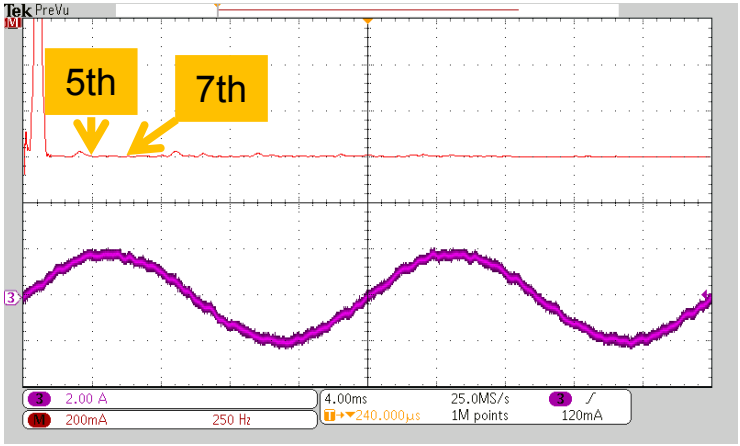
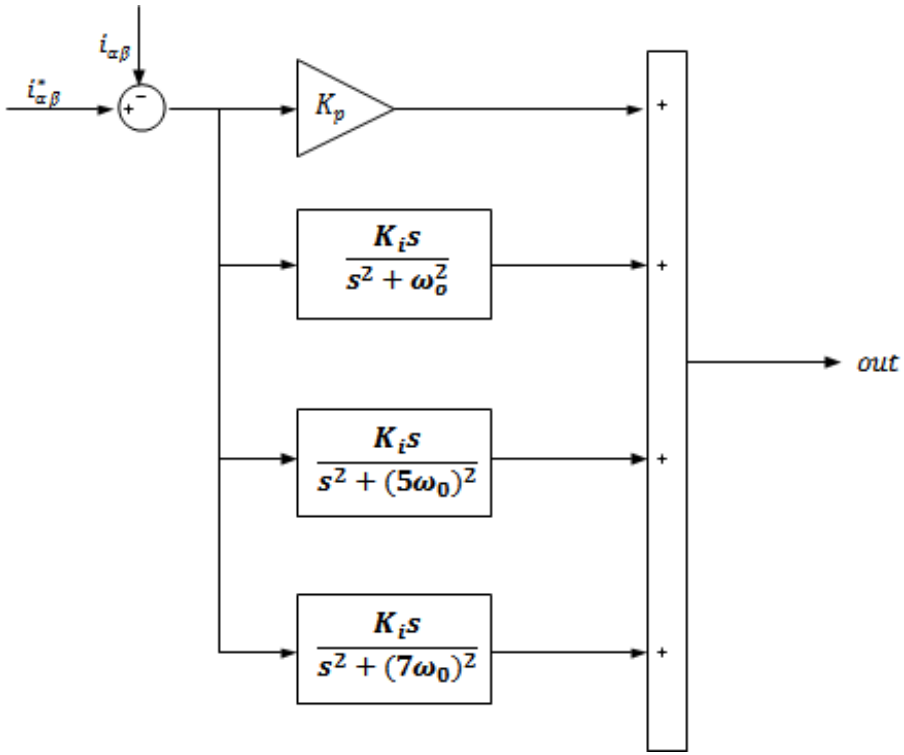
Resonant Current Controllers for L-Filtered VSC



Grid current without harmonic control



Grid current with harmonic control



Background and Challenges

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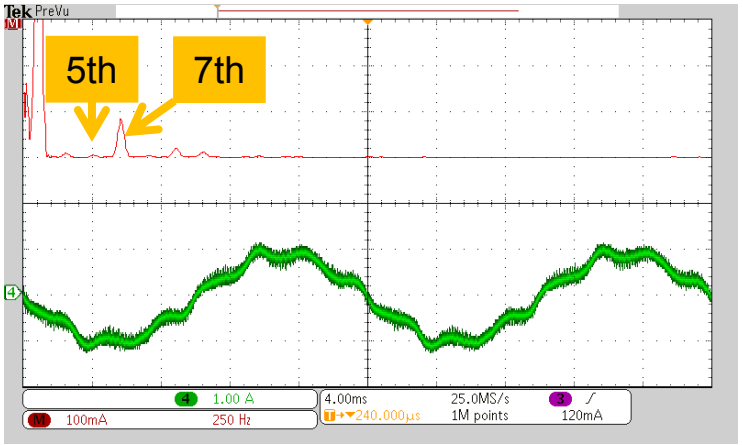
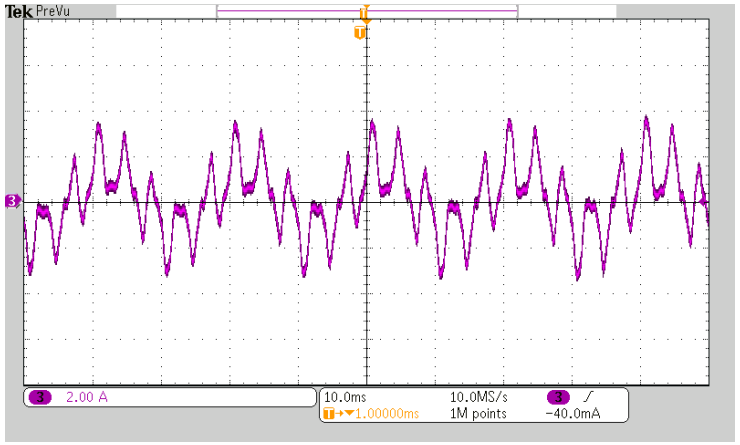
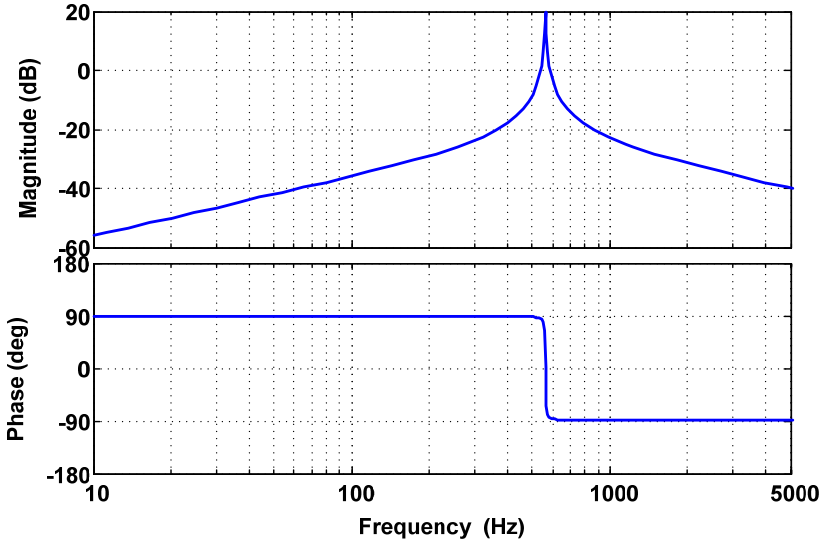
Resonant Current Controllers for LC-Filtered VSC



Grid current without harmonic control



Grid current with harmonic control



Current controller of capacitive filter is required for low-order harmonics rejection.

Proposed Current Control

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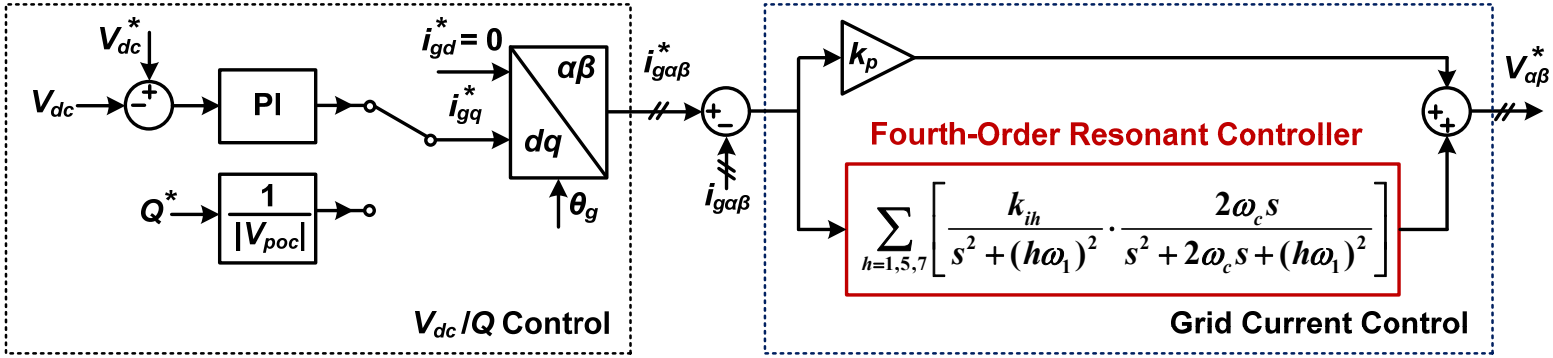
A Fourth-Order Integral Controller



$$Y_{op}(s) = C_{eq}s \Rightarrow Y_{rp}(s) = \frac{2h\omega_c}{s^2+2h\omega_c s+(h\omega_1)^2}C_{eq}s = \frac{2h\omega_c s}{s^2+2h\omega_c s+(h\omega_1)^2}C_{eq}$$

$$G_{2R}(s)\times Y_{rp}(s) = G_{4R}(s)\times Y_{op}(s)$$

$$= \sum_{h=1,5,7}\left\{\left[\frac{k_{ih}s}{s^2+(h\omega_1)^2}\right]\times\left[\frac{2h\omega_c s}{s^2+2h\omega_c s+(h\omega_1)^2}\times C_{eq}\right]\right\}$$

$$= \sum_{h=1,5,7}\left\{\frac{k_{ih}s}{s^2+(h\omega_1)^2}\times\frac{2h\omega_c}{s^2+2h\omega_c s+(h\omega_1)^2}\right\}\times sC_{eq}$$

Proposed Current Control

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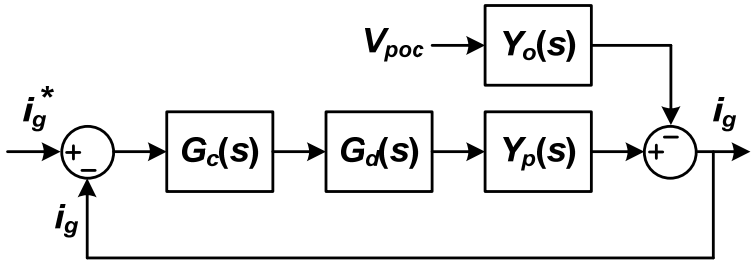
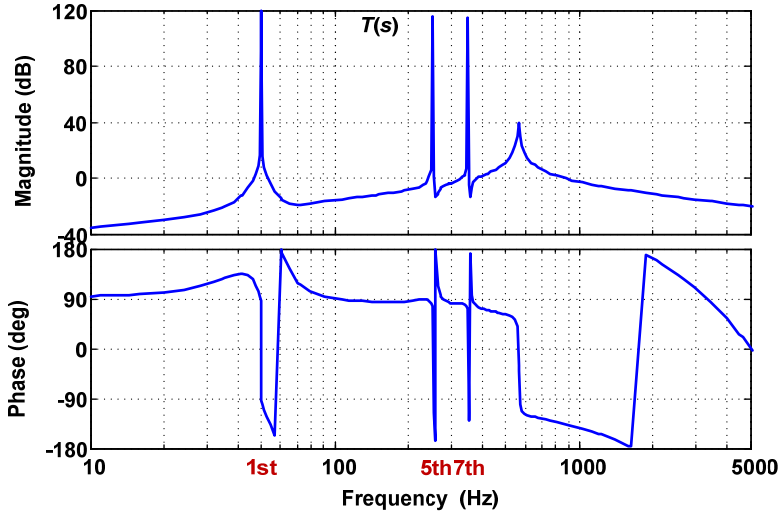
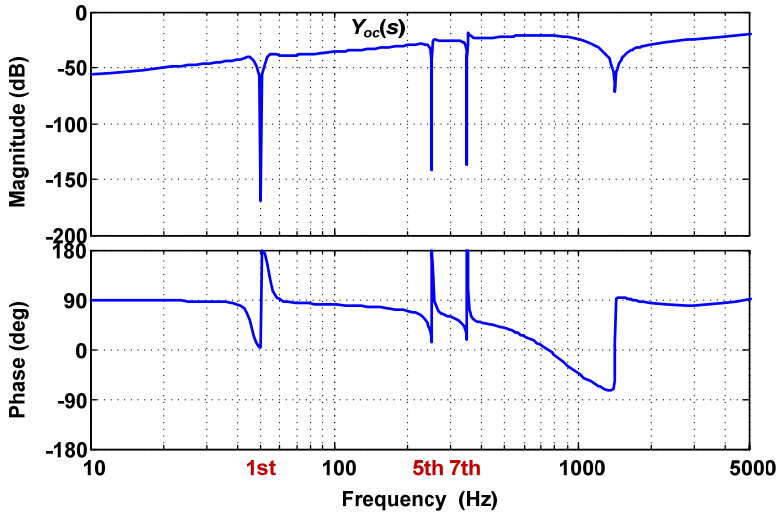
Frequency-Domain Analysis



Current Control Loop





$$T(s) = G_c(s)G_d(s)Y_p(s)$$

$$Y_{oc}(s) = \frac{Y_o(s)}{1+T(s)}$$

Performance Validation

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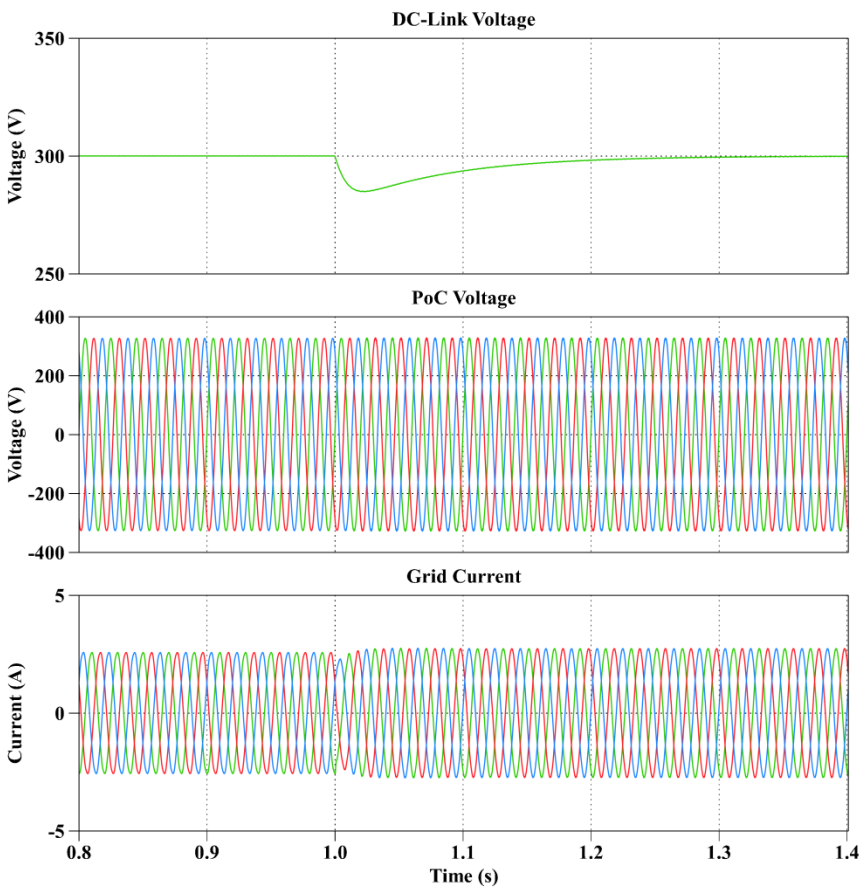
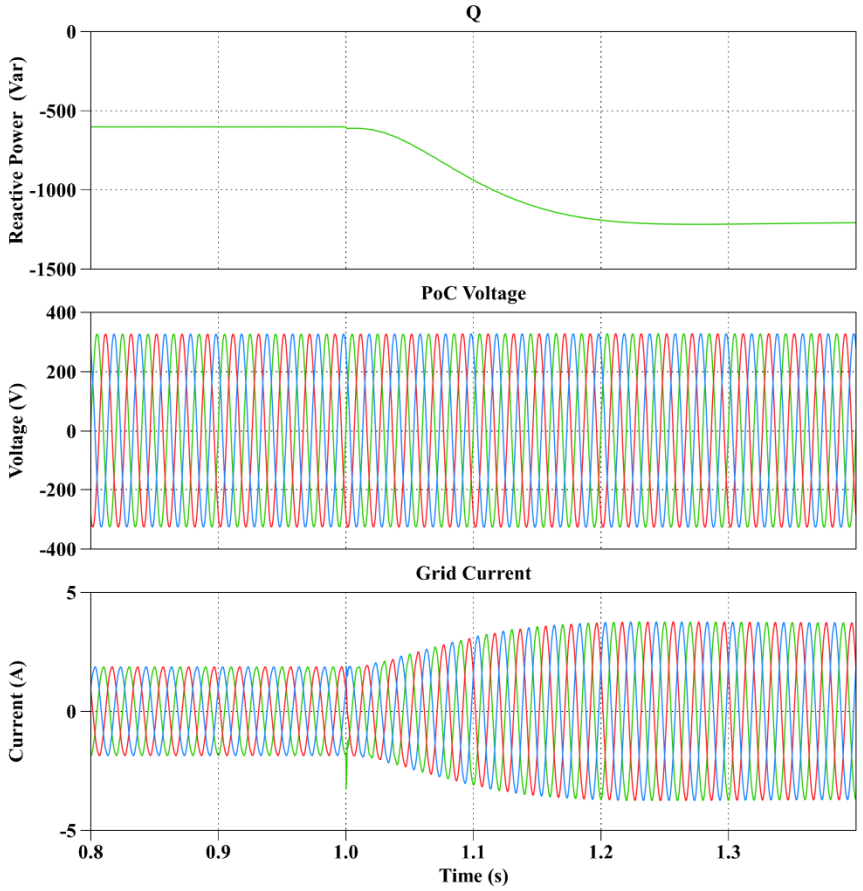
- **Simulation Results – Power Control**



DC-link voltage regulation (with dc load)



Reactive power regulation

Performance Validation

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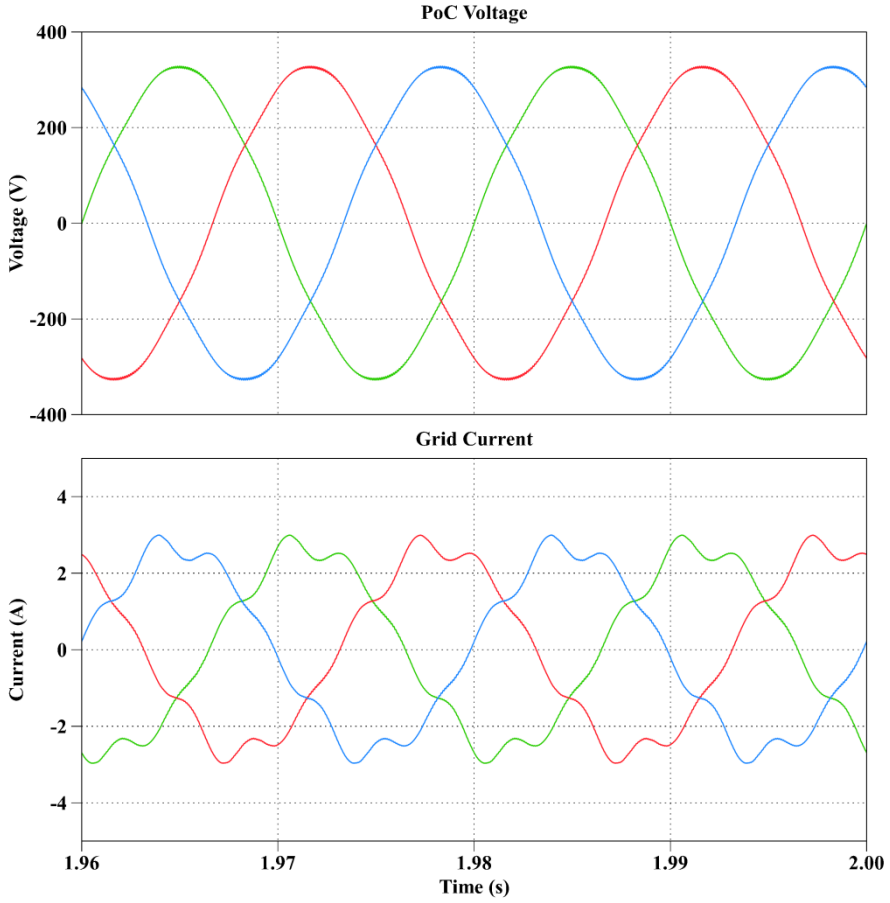
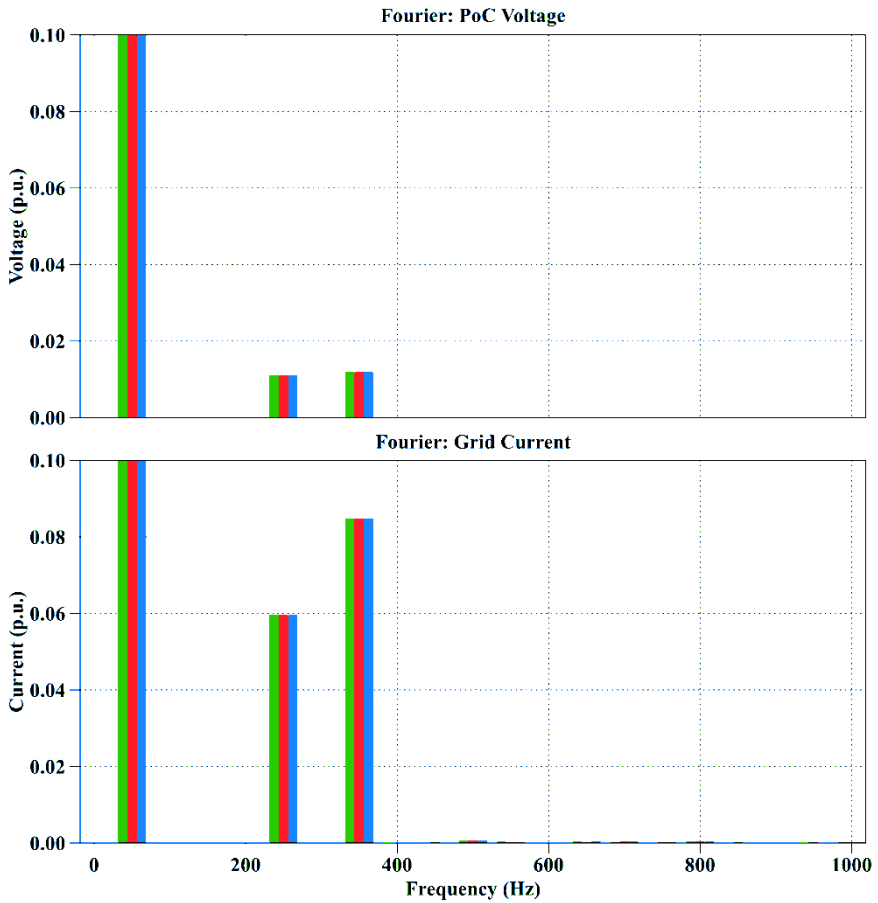
- **Simulation Results – With proportional control only**



Voltage and Current



Harmonic Spectra

Performance Validation

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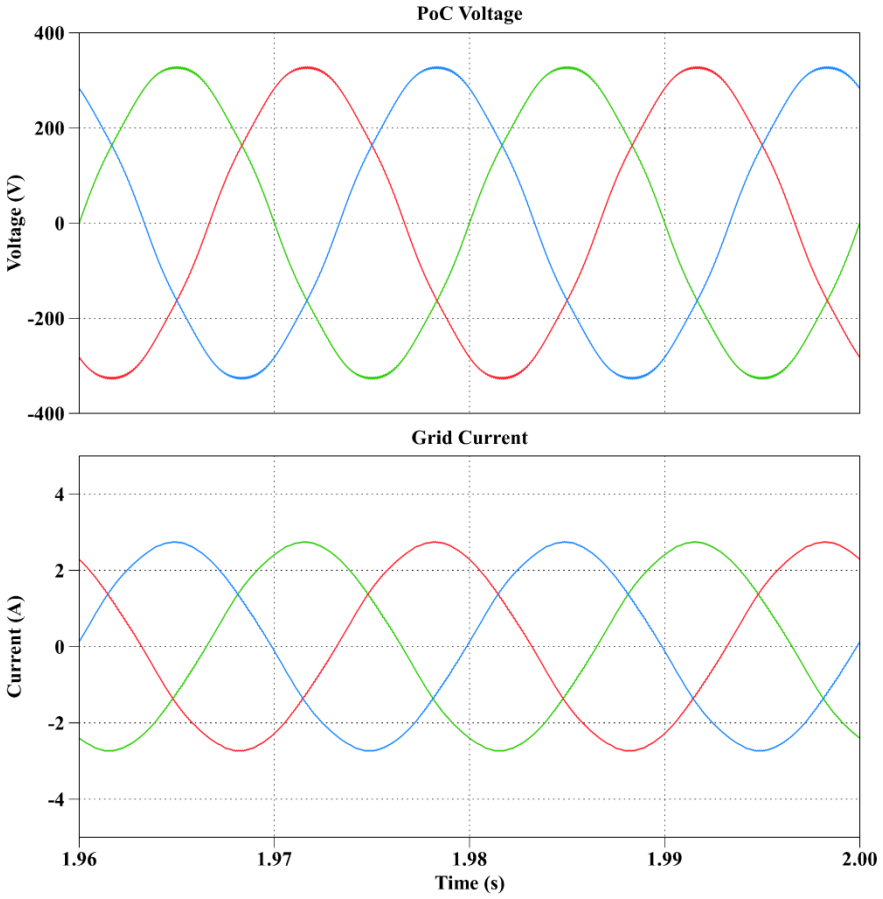
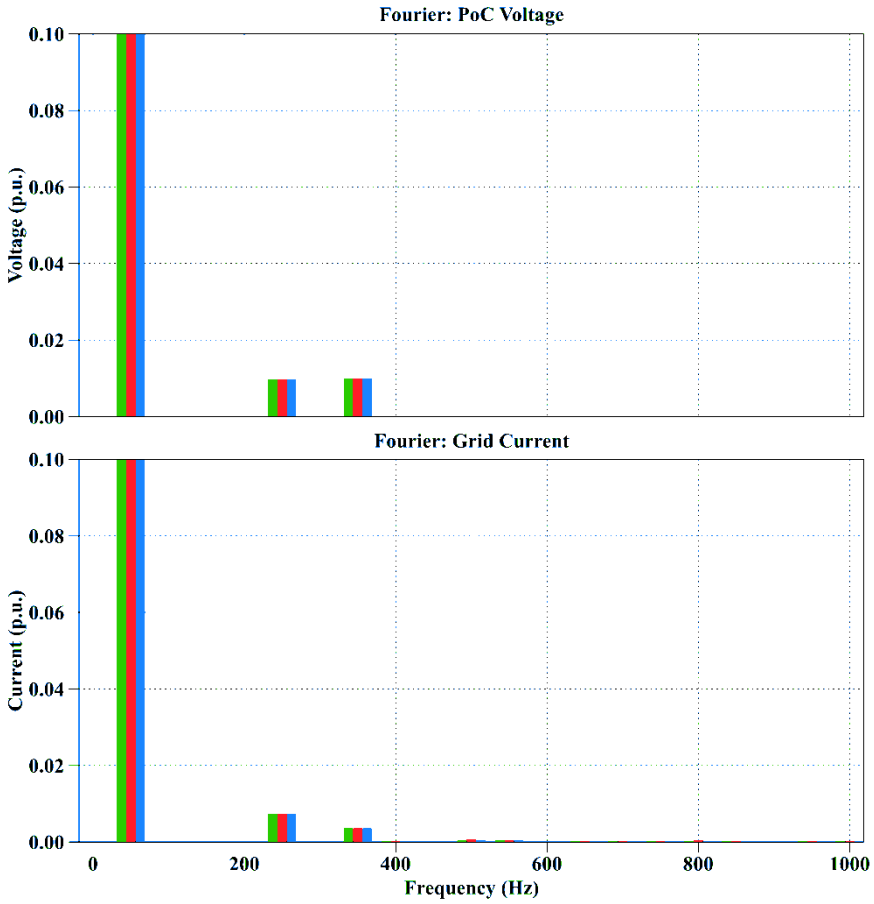
- **Simulation Results – With proposed current control**



Voltage and Current



Harmonic Spectra

Performance Validation

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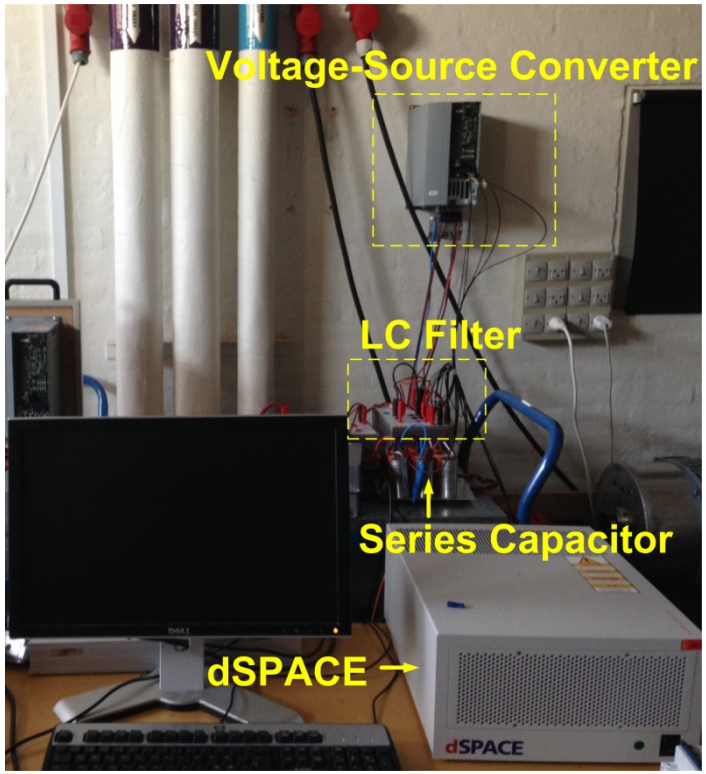
- **Experimental Results**



Hardware Picture

TABLE I Main Electrical Parameters

Symbol	QUANTITY	Value
V_g	Grid voltage	400 V
L_g	Grid inductance	1.8 mH
C_g	Series coupling capacitor	25 μF
V_{dc}	DC-link voltage	300 V
C_{dc}	DC-link capacitor	1600 μF
L_f	LC-filter inductor	2.7 mH
C_f	LC-filter capacitor	4.7 μF
f_{sw}	Switching frequency	10 kHz

TABLE II Main Controller Parameters

Symbol	QUANTITY	Value
T_s	System sampling period	100 μs
k_p	Proportional current controller	10
k_{i1}	Fourth-order resonant controller at the fundamental frequency	$1 \cdot 10^6$
k_{i5}	Fourth-order resonant controller at the 5th harmonic frequency	$1 \cdot 10^6$
k_{i7}	Fourth-order resonant controller at the 7th harmonic frequency	$4 \cdot 10^6$
ω_c	Cut-off frequency of the fourth-order resonant controller	31.4 rad/s

Performance Validation

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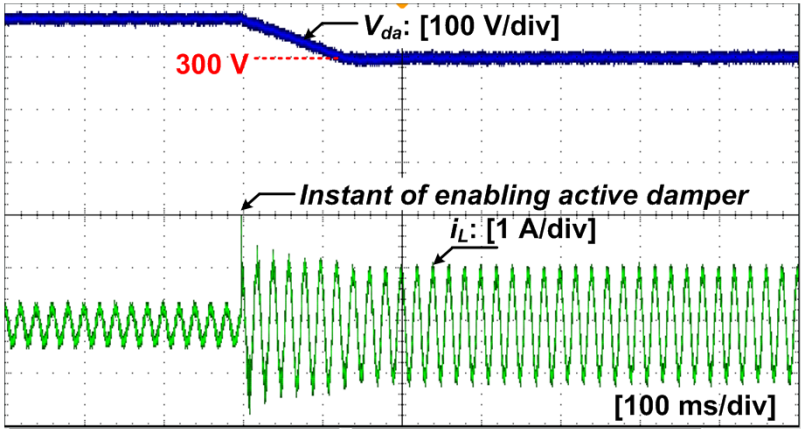
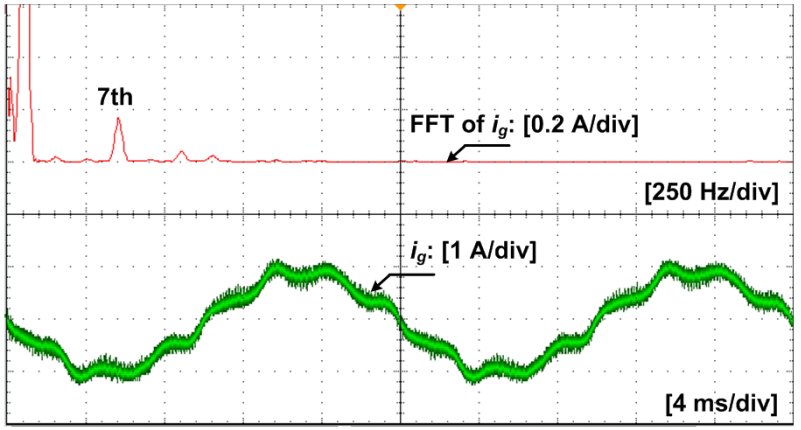
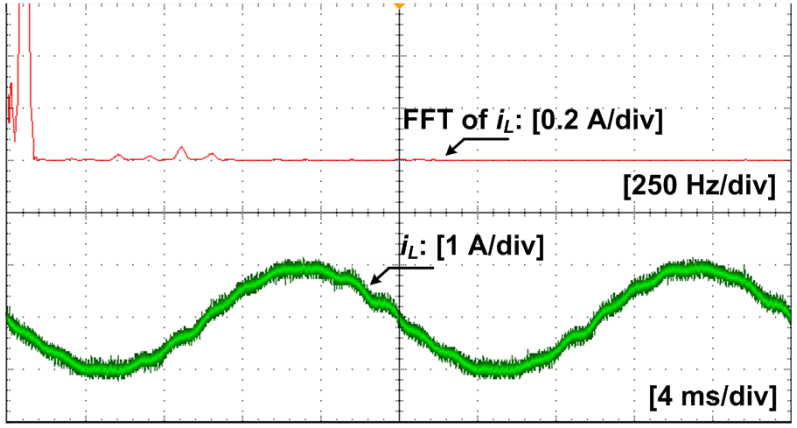
- **Experimental Results**



DC-link voltage and grid current



Proportional control only



Proposed current controller

Conclusions

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- A fourth-order resonant current controller has been proposed for grid converter with capacitive filters.
- Frequency-domain analysis with Bode diagrams confirm the stability of current control loop.
- Simulations and experimental results validate the performance of the proposed current controller.

Acknowledgement

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Extended Deadline: May 15, 2015

Thank You! Questions?

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