APSC
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消除电网电压谐波对并网逆变器并网电流影响的电网电压前馈方法

阮新波

南京航空航天大学
航空电源重点实验室

报告内容

- 研究背景
- LCL并网滤波器
- 电网电压全前馈方法
- 实验结果
- 结论

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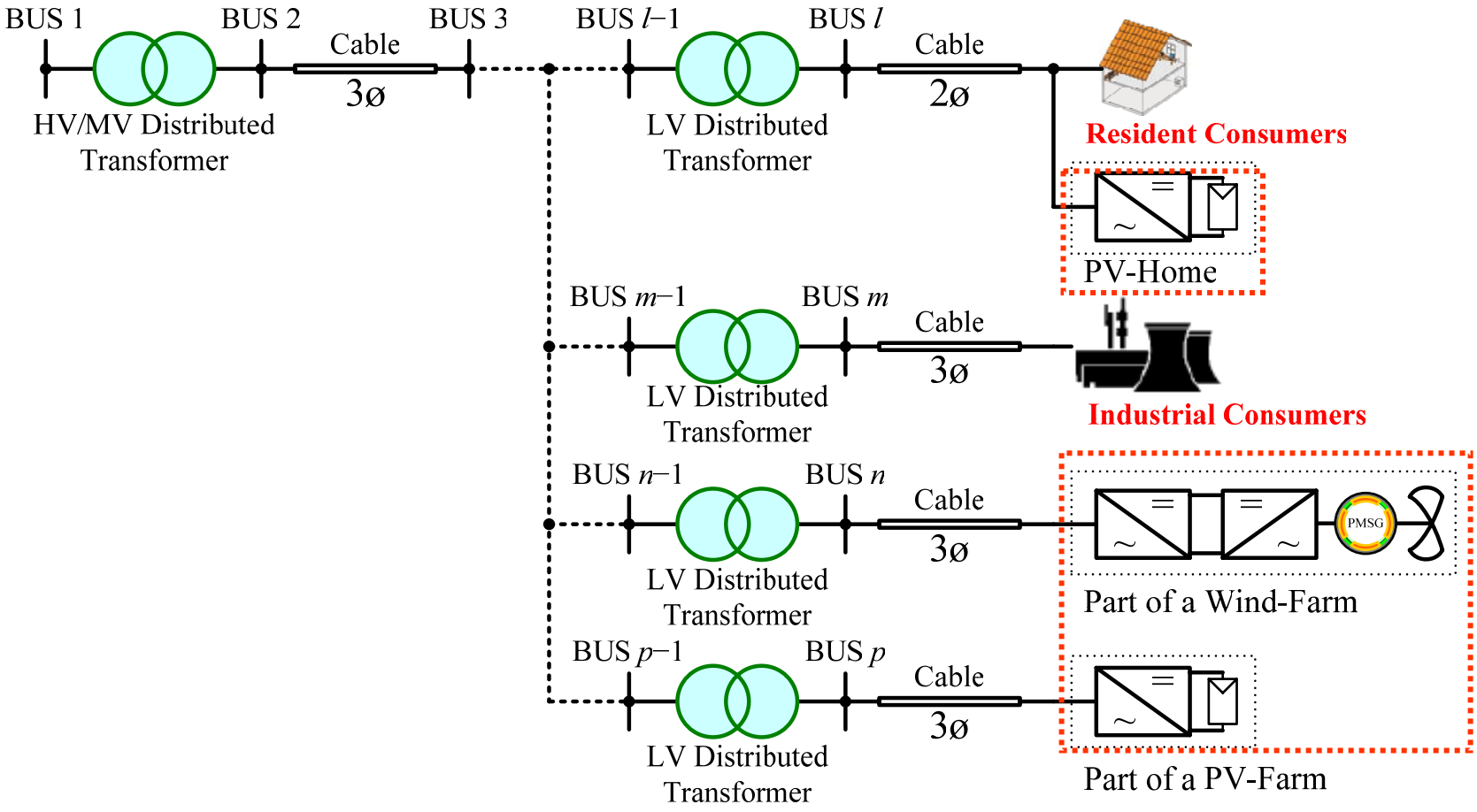
可再生能源的应用

☺ 可再生
☺ 无污染

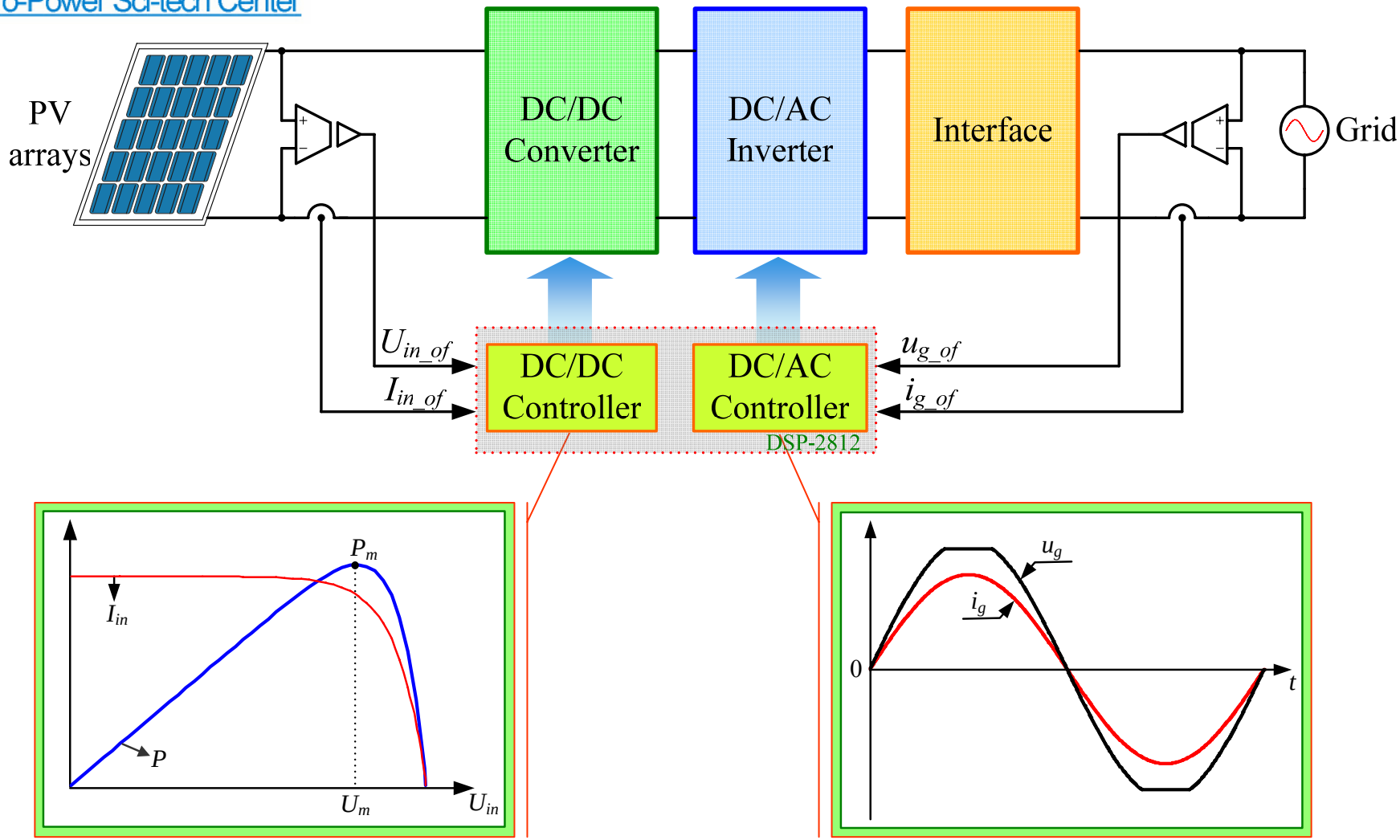
☹ 间歇性
☹ 随机性

分布式发电系统



Source: M. Liserre, *et al*. Stability of photovoltaic and wind turbine grid-connected inverters for a large set of grid impedance values. *IEEE Trans. on PE*., 2006 , 21(1): 888-895.

PV并网系统



MPPT **Grid Connected**

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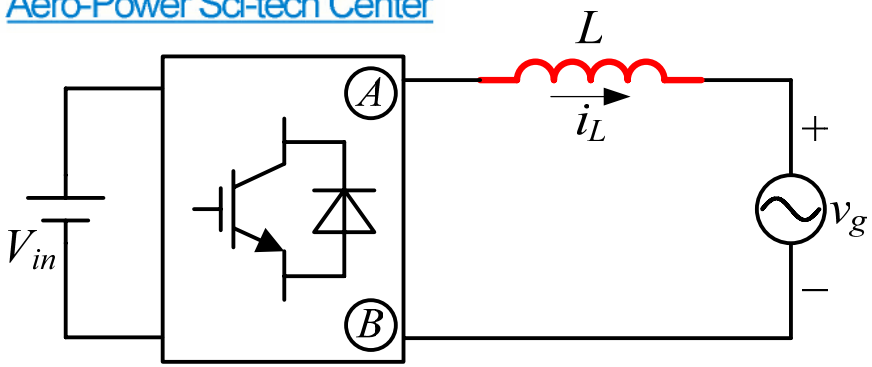
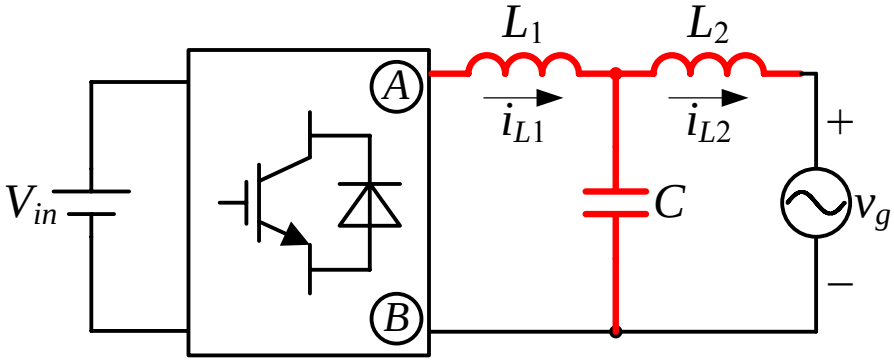
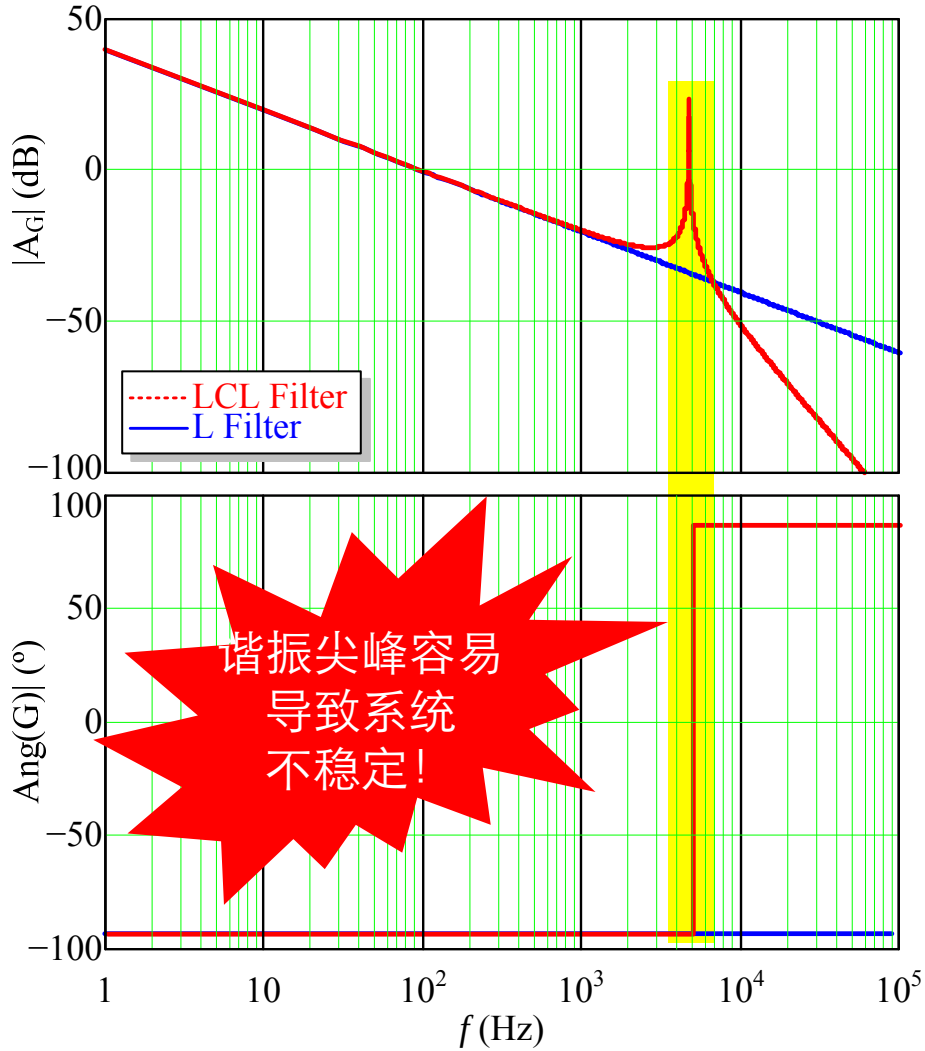
并网逆变器的LCL滤波器的提出



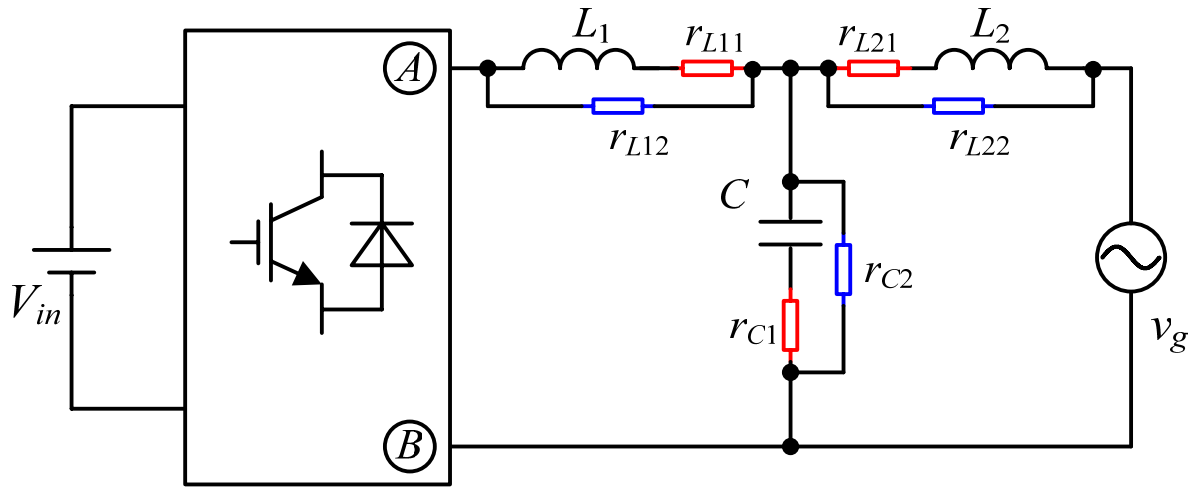
$$G_L(s) = \frac{i_L(s)}{v_{AB}(s)} = \frac{1}{sL}$$



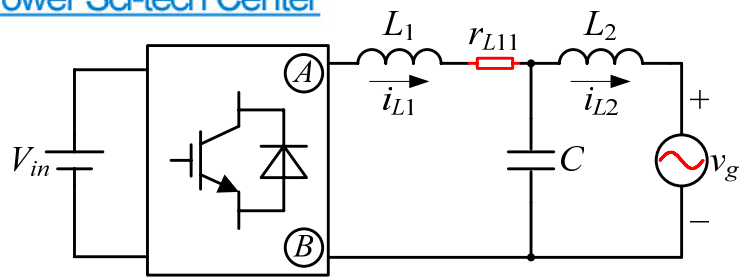
$$G_{LCL}(s) = \frac{i_{L2}(s)}{v_{AB}(s)} = \frac{1}{sL_1L_2C} \cdot \frac{1}{s^2 + \frac{L_1 + L_2}{L_1L_2C}}$$

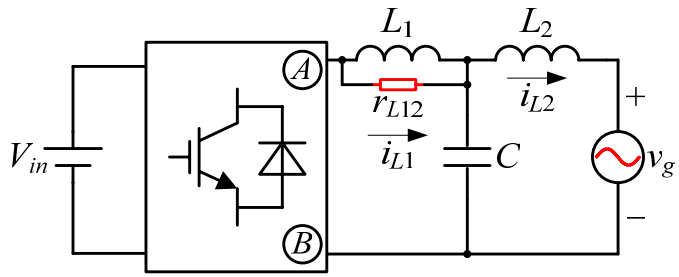


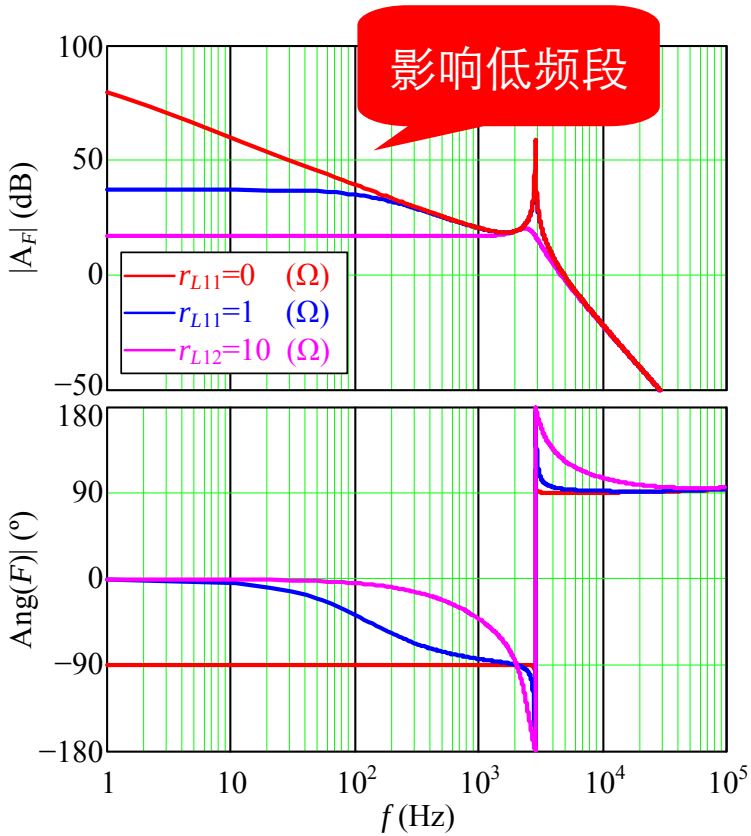
阻尼谐振峰的方法

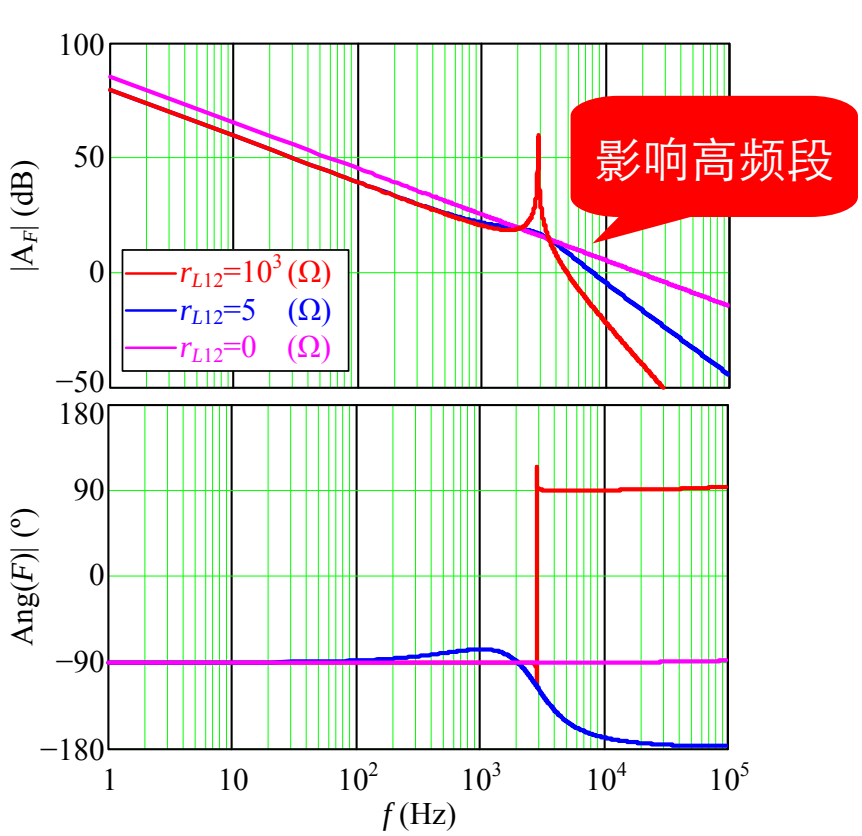


L_1串联或并联阻尼电阻

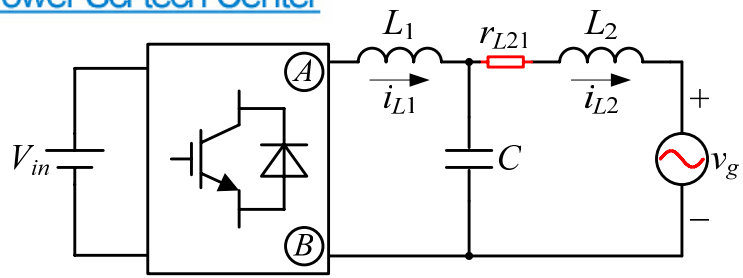


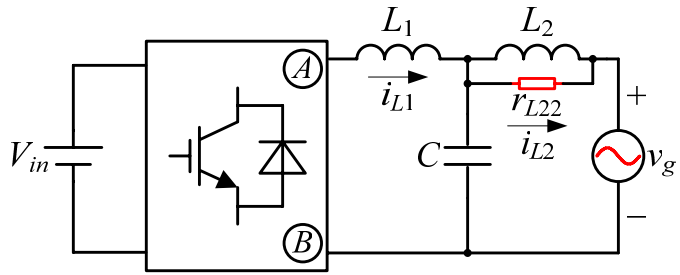


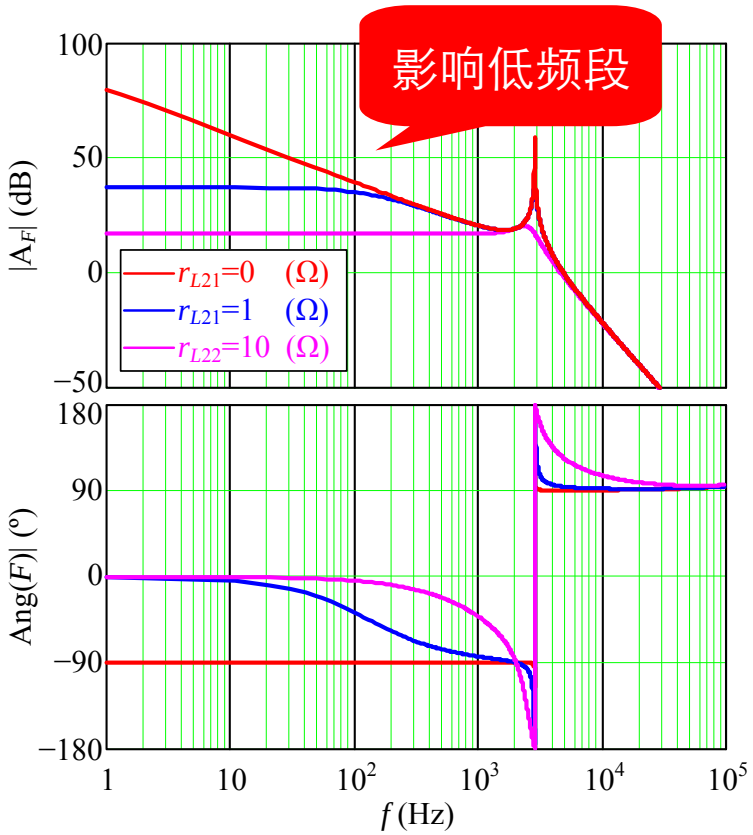


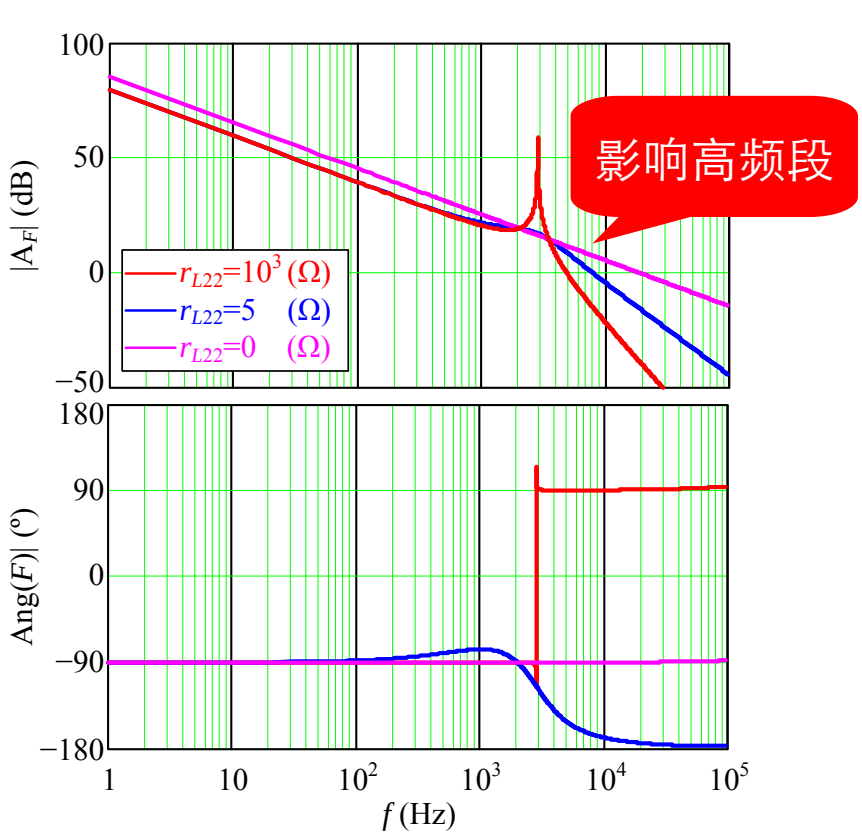


L_2串联或并联阻尼电阻

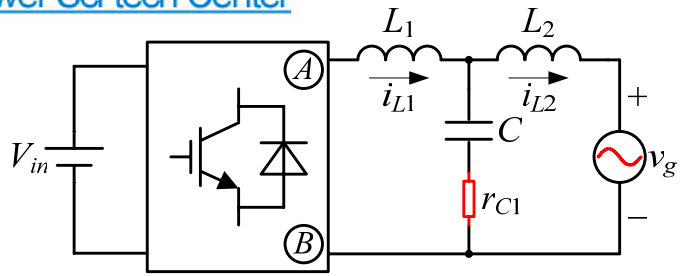


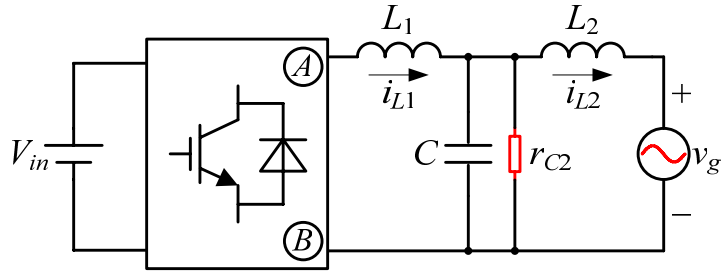


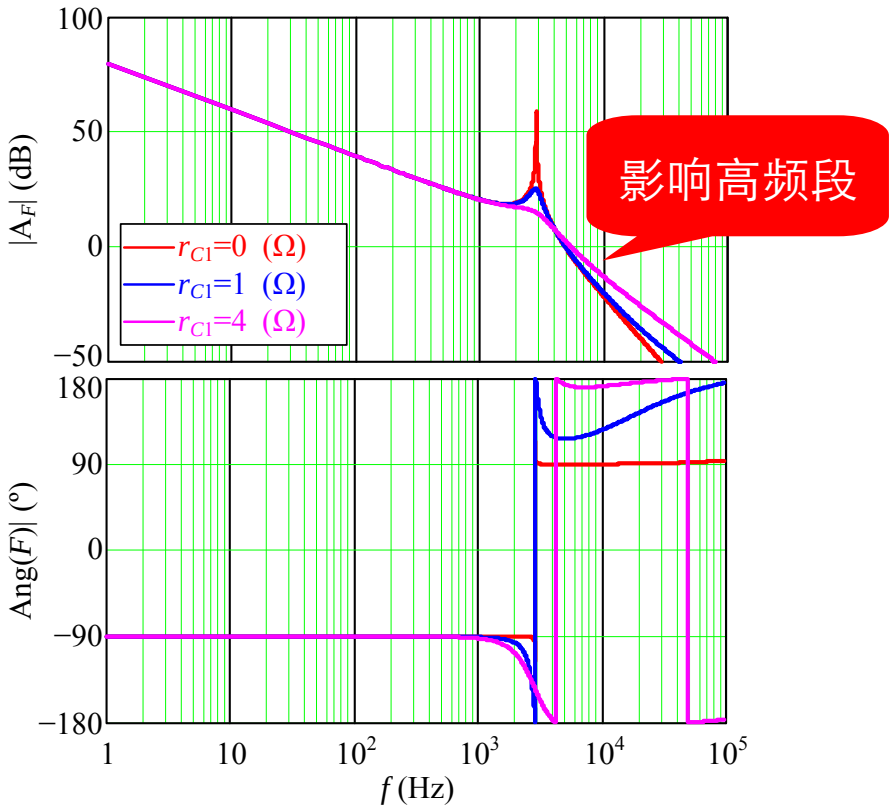




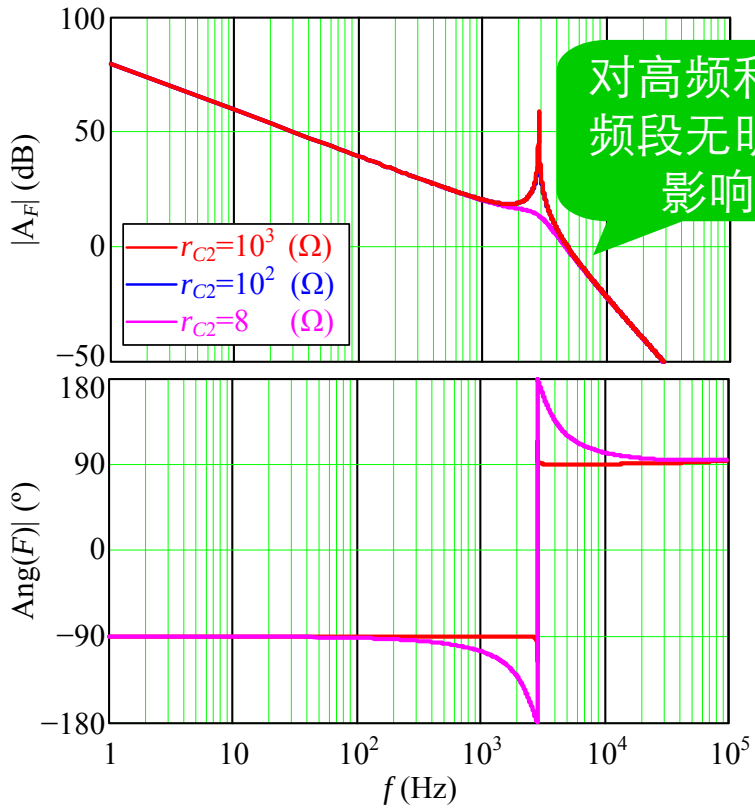
C串联或并联阻尼电阻





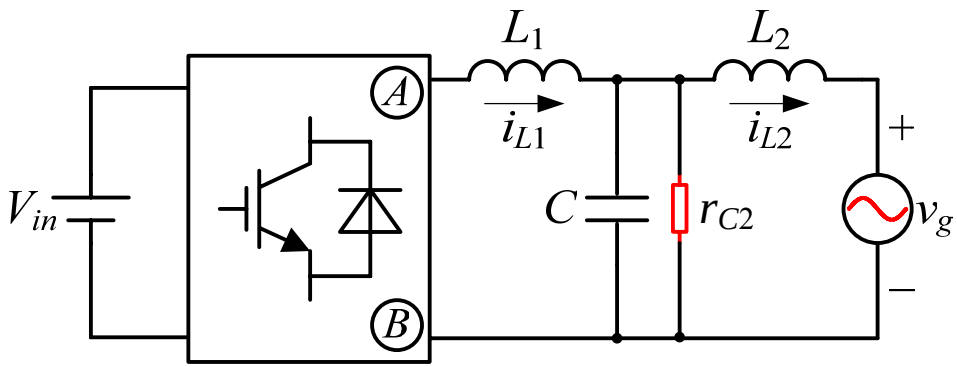


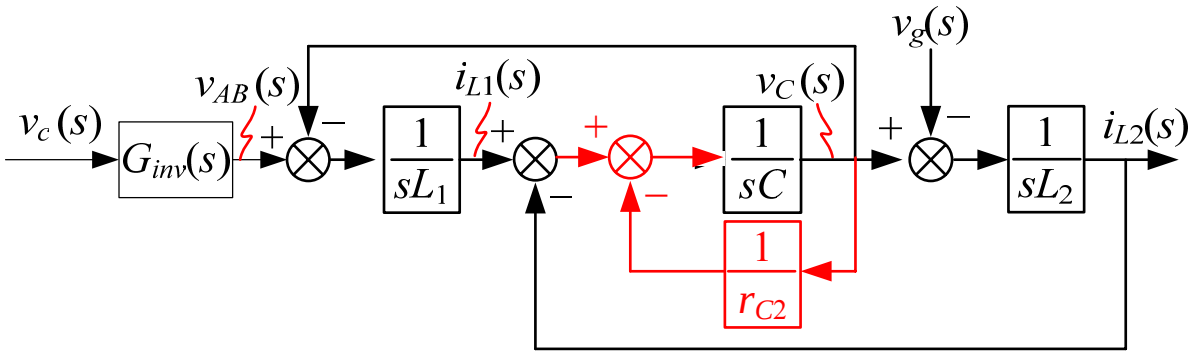
影响高频段

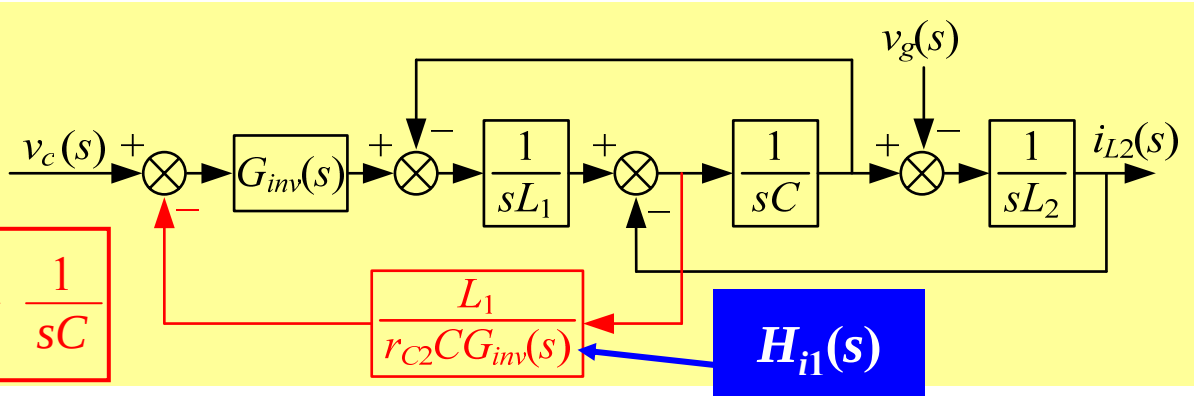


对高频和低频段无明显影响

电容电流反馈有源阻尼方法

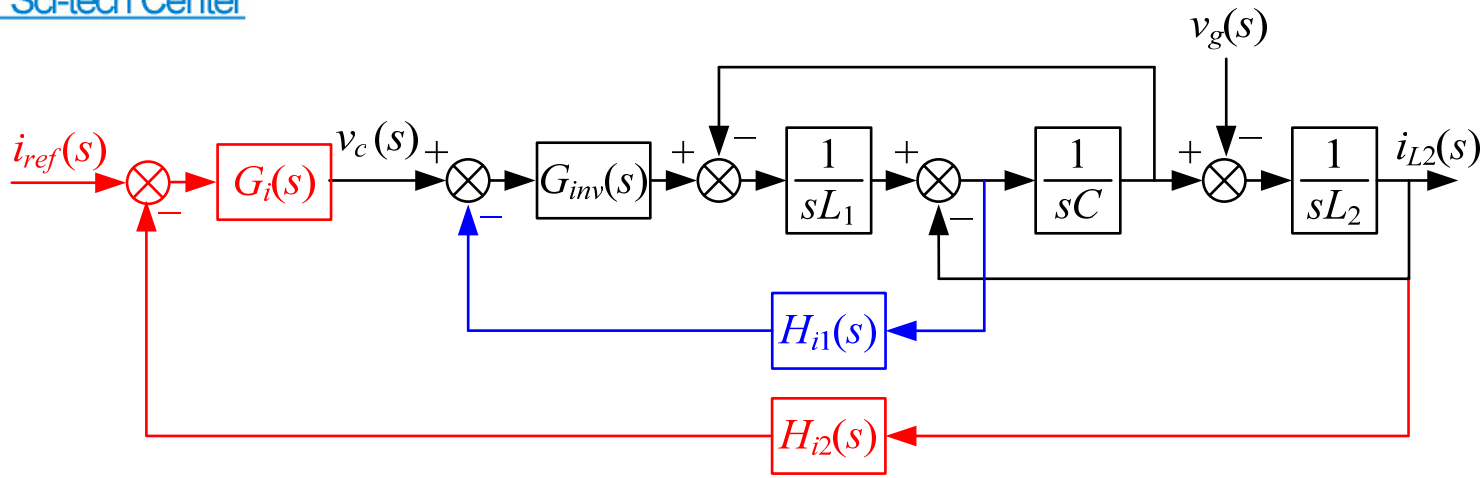


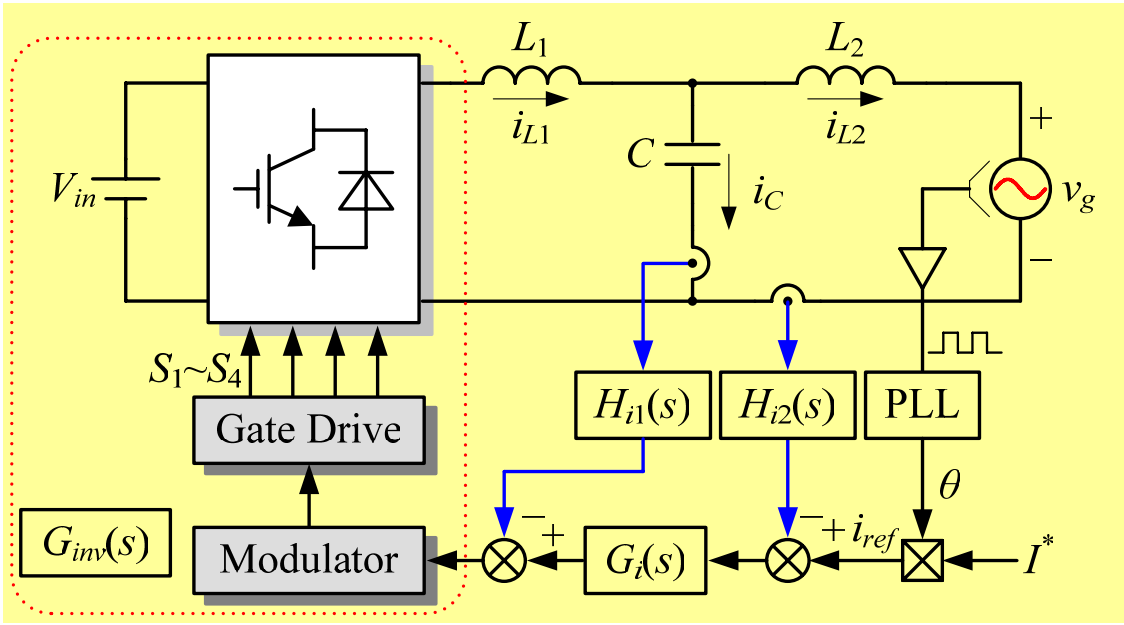




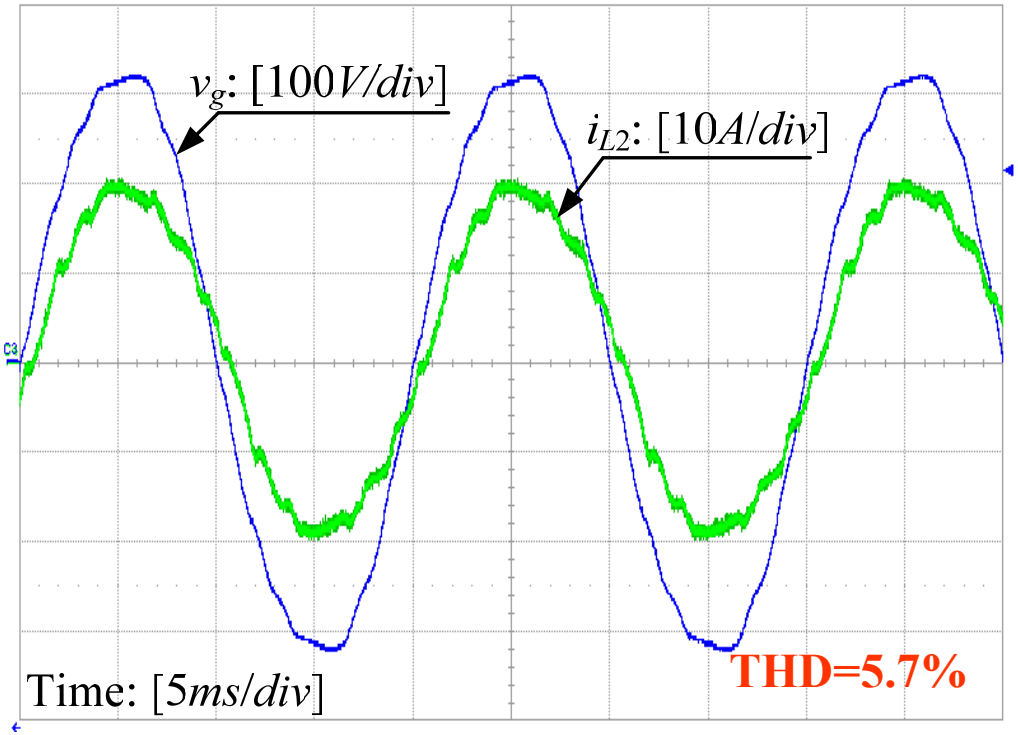
$$\frac{1}{G_{inv}(s)}\ sL_1\ \frac{1}{r_{C2}}\ \frac{1}{sC}$$

双闭环控制策略


$v_g(s)$
$i_{ref}(s)$
$G_i(s)$
$v_c(s)$
$G_{inv}(s)$
$\frac{1}{sL_1}$
$\frac{1}{sC}$
$\frac{1}{sL_2}$
$i_{L2}(s)$
$H_{i1}(s)$
$H_{i2}(s)$


L_1
L_2
i_{L1}
i_{L2}
C
i_C
V_{in}
v_g
S_1~S_4
Gate Drive
$H_{i1}(s)$
$H_{i2}(s)$
PLL
θ
$G_{inv}(s)$
Modulator
$G_i(s)$
i_{ref}
I^*

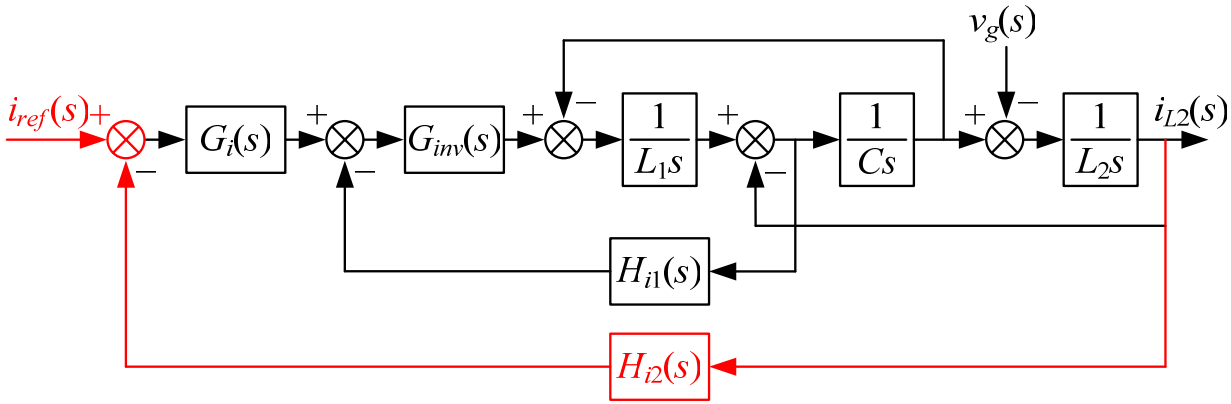
双闭环控制策略的实验结果

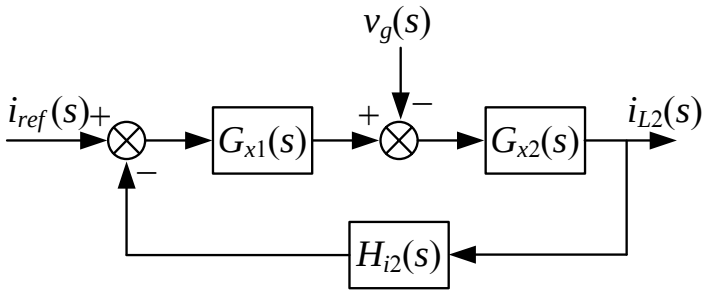


☹ 并网电流滞后于电网电压；

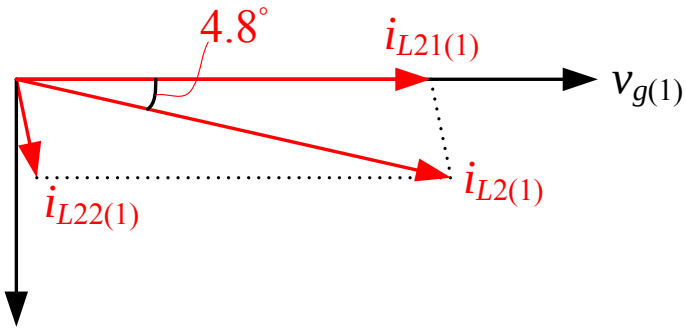
☹ 电网电压背景谐波导致并网电流畸变。

双闭环控制策略的不足之处





$$i_{L2} = \frac{T}{1+T}\cdot\frac{1}{H_{i2}}\cdot i_{ref} - \frac{G_{x2}}{1+T}\cdot v_g$$



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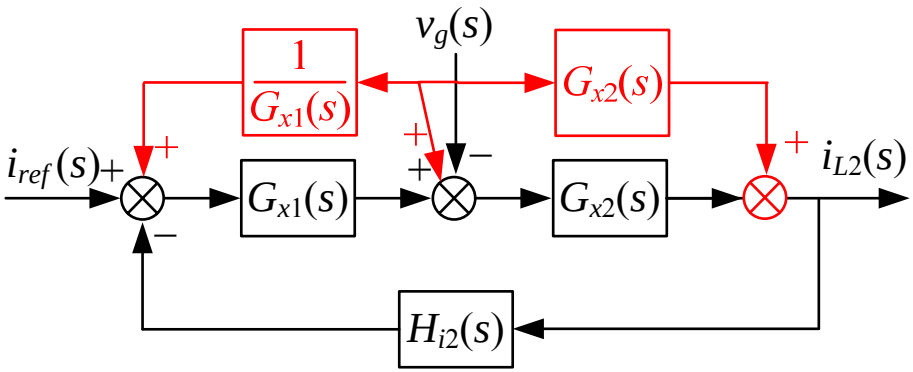
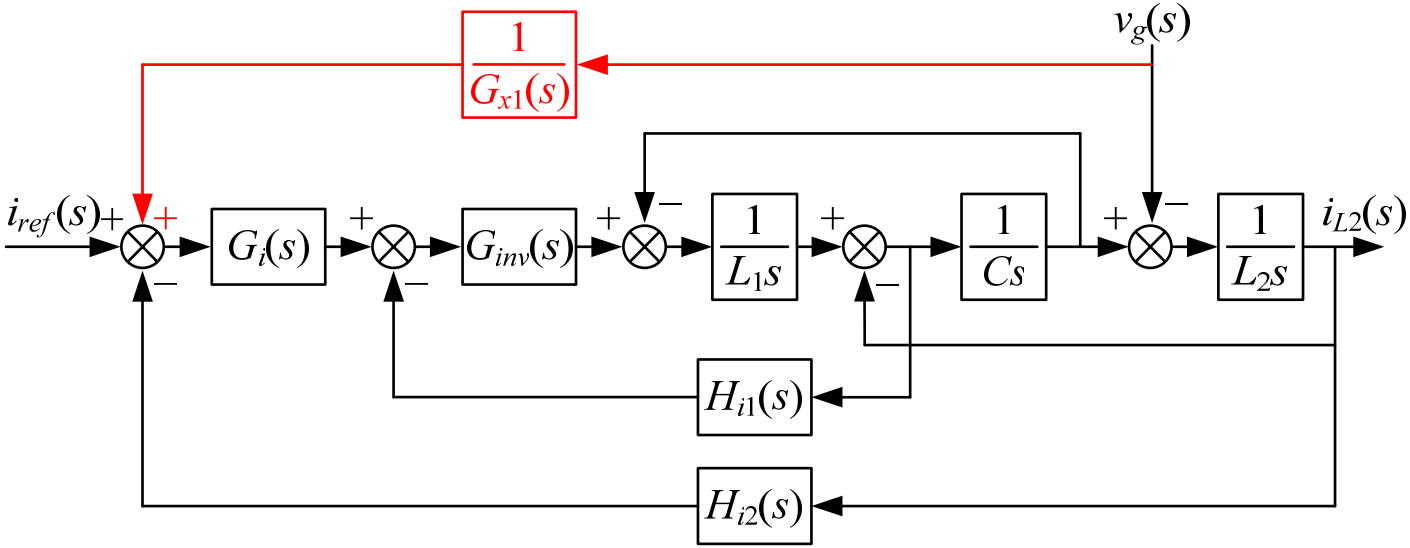
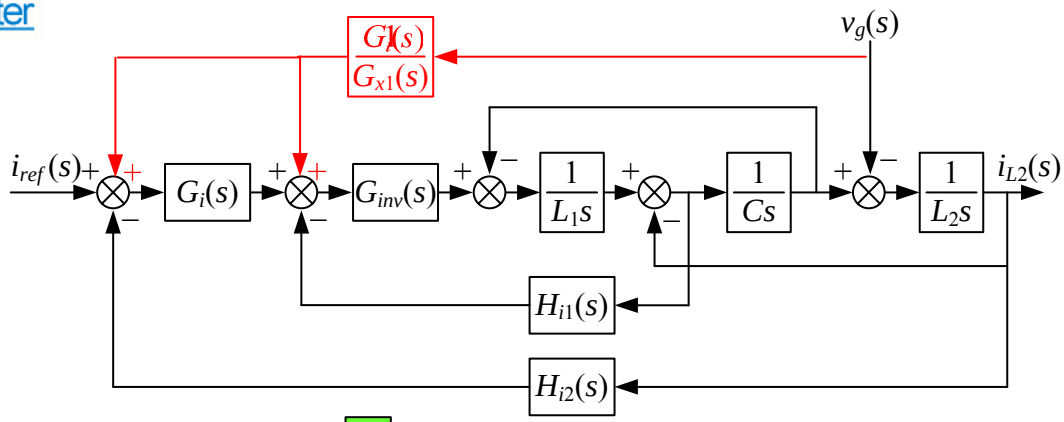
消除电网电压对并网电流的影响



$$i_{L2} = \frac{T}{1+T} \cdot \frac{1}{H_{i2}} \cdot i_{ref}$$



电网电压前馈方法

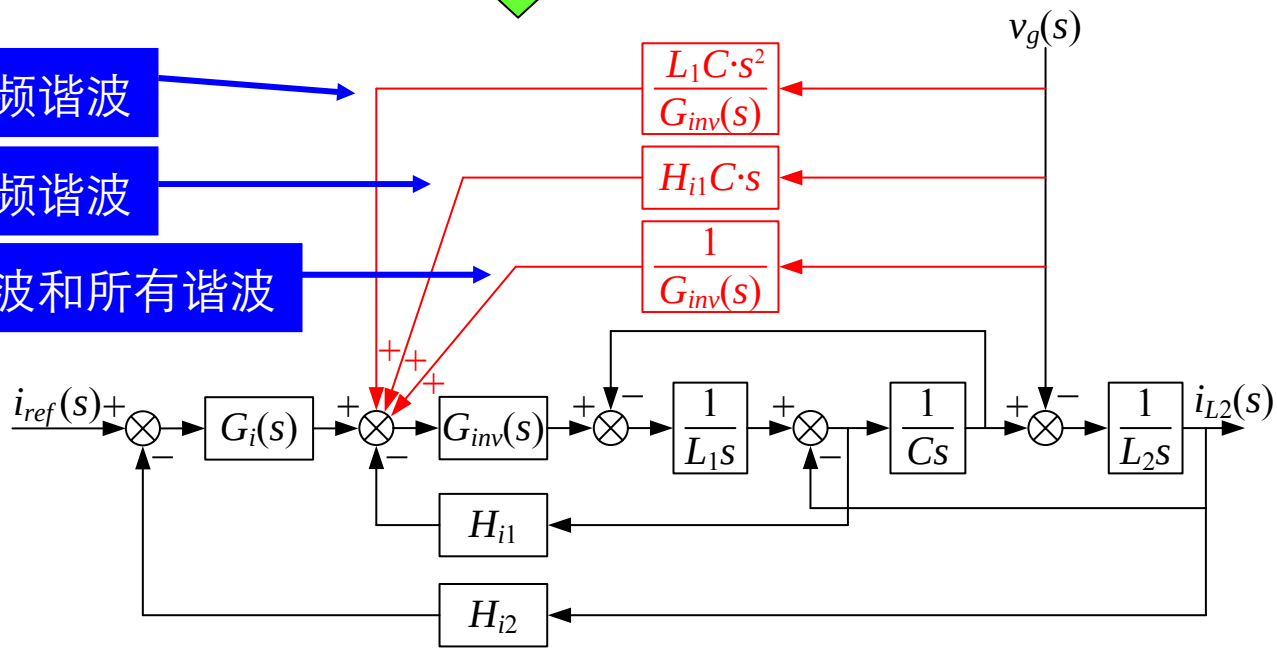


$$\frac{G_i(s)}{G_{x1}(s)} = \frac{1}{G_{inv}(s)} + H_{i1}Cs + \frac{L_1Cs^2}{G_{inv}(s)}$$

消除高频谐波

消除中频谐波

消除基波和所有谐波

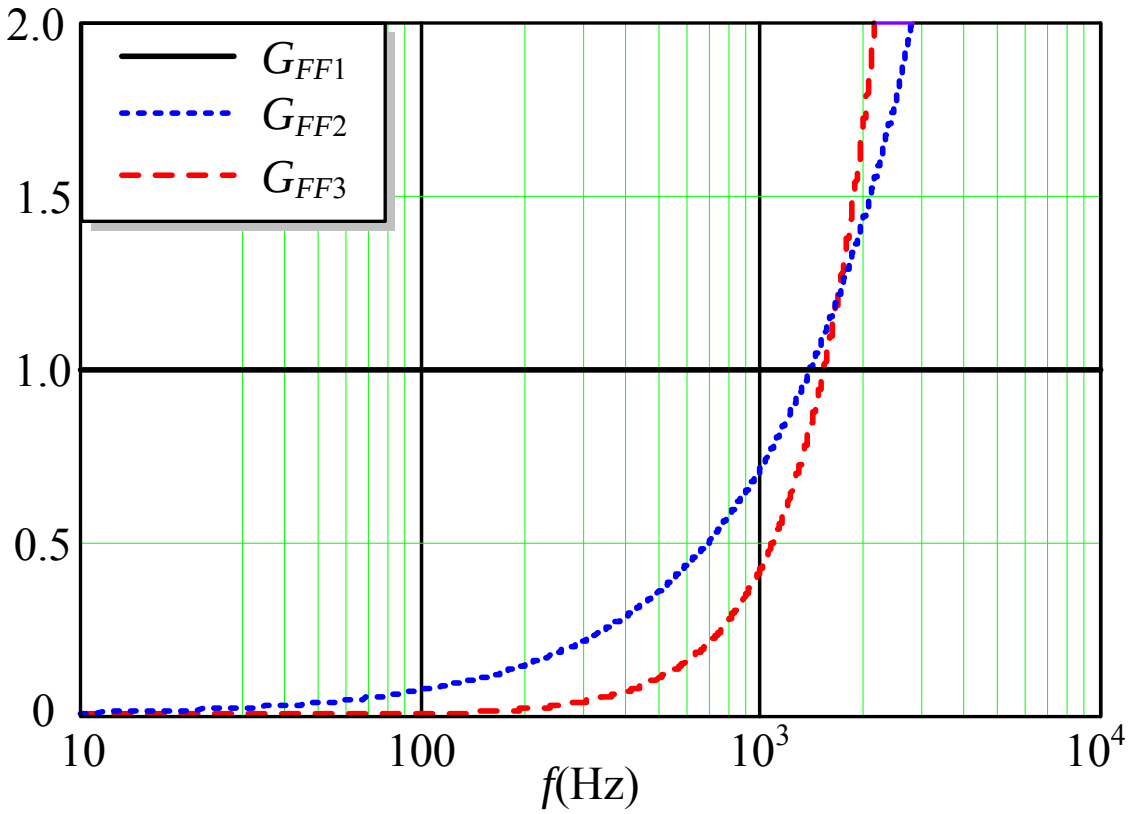


电网电压前馈分量的比较

$$G_{FF1} = \frac{1}{G_{pwm}(s)}$$

$$G_{FF2} = sH_{i1}C_f$$

$$G_{FF3} = \frac{s^2 L_{f1} C_f}{G_{pwm}(s)}$$



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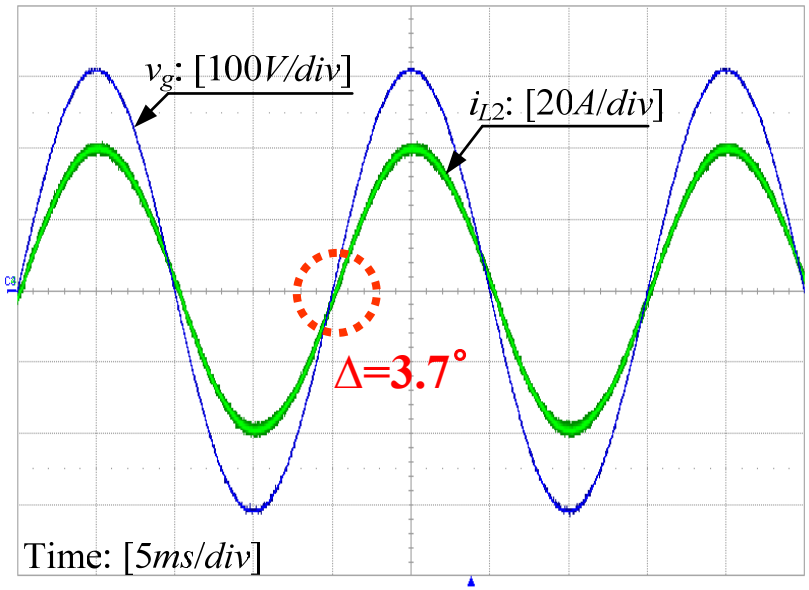
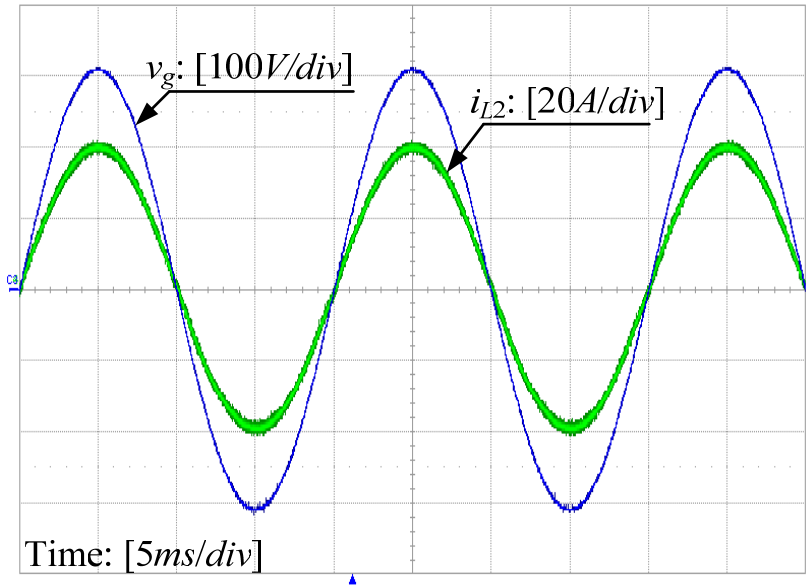
实验波形：v_g纯正弦



无前馈



只有比例前馈

Note: these waveforms are based on a simulated grid voltage with *Chroma programmable AC Source 6590*.

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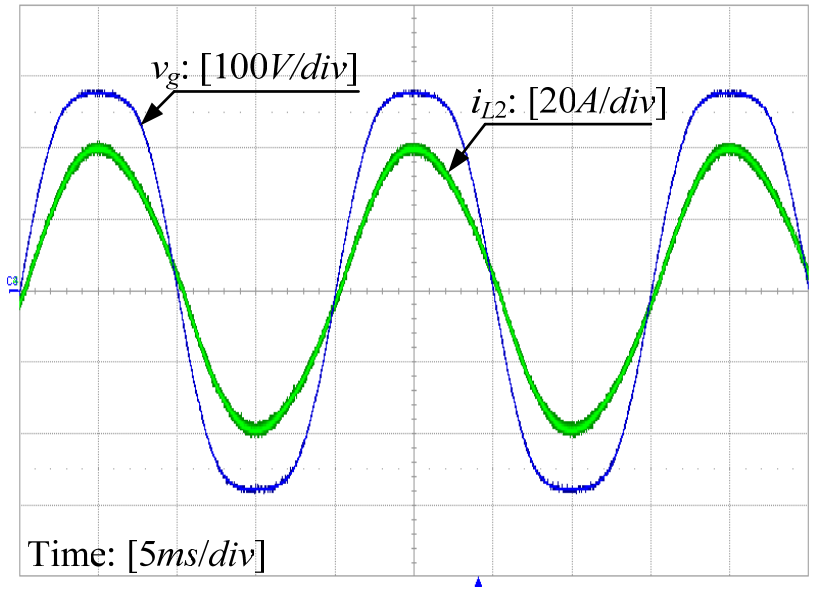
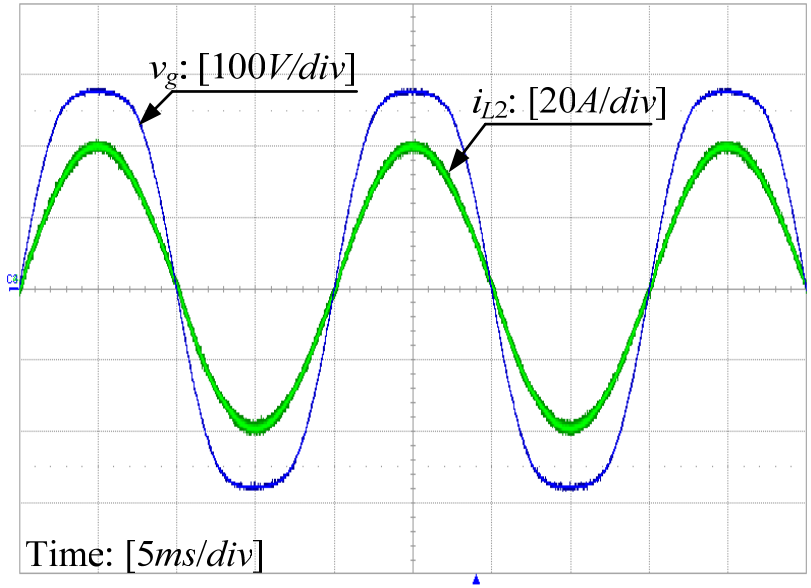
实验波形：v_g中含有10% 3次谐波



无前馈



只有比例前馈

Note: these waveforms are based on a simulated grid voltage with *Chroma programmable AC Source 6590*.

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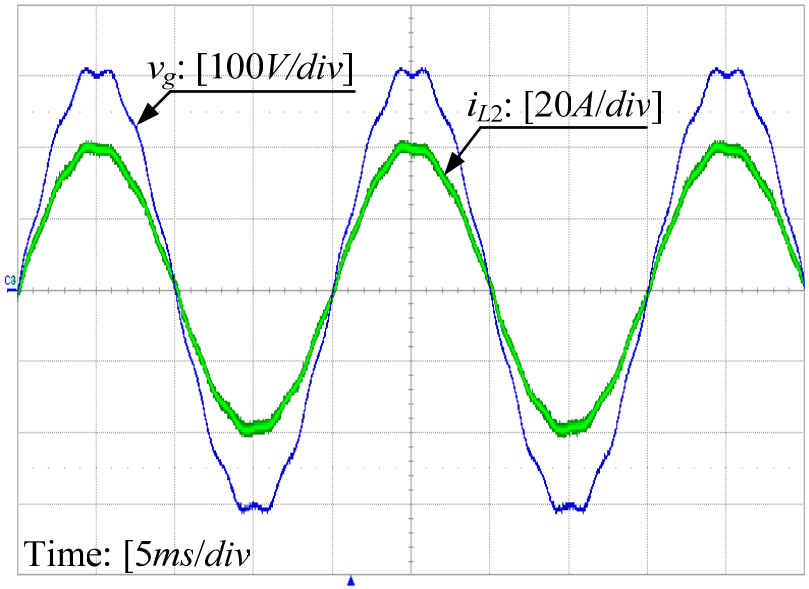
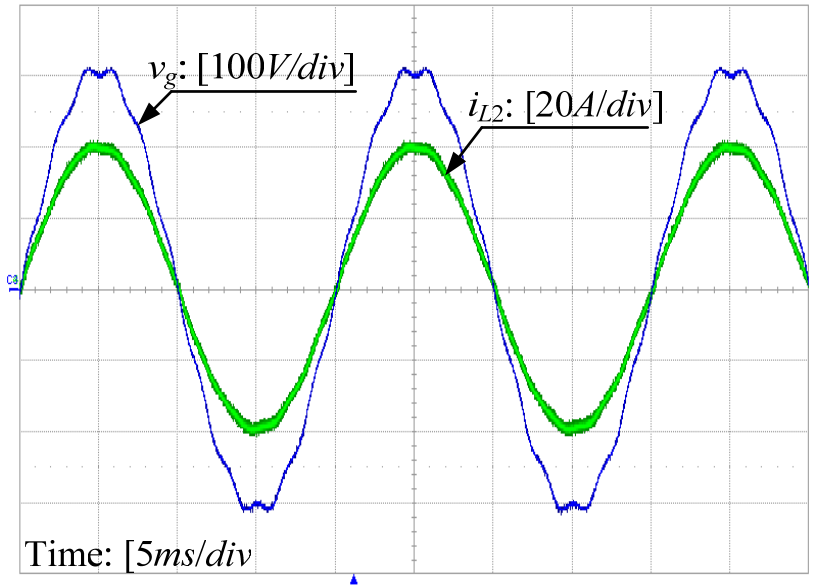
实验波形：v_g中含有3%11次谐波



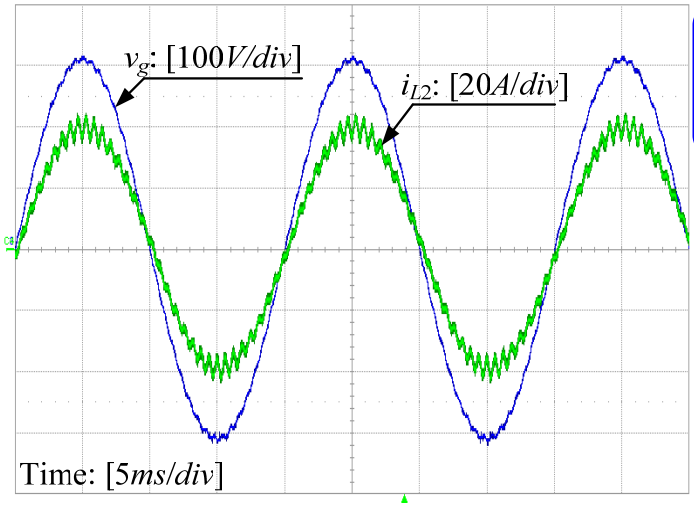
只有比例前馈



比例+一次微分前馈

Note: these waveforms are based on a simulated grid voltage with *Chroma programmable AC Source 6590*.

实验波形：v_g中含有1%33次谐波



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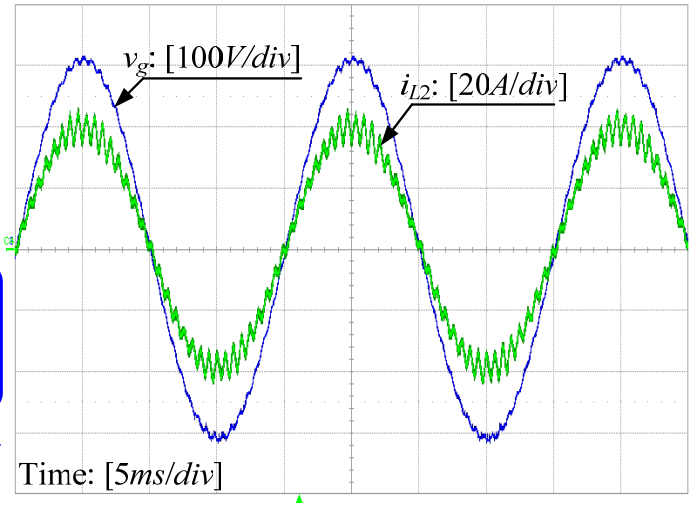
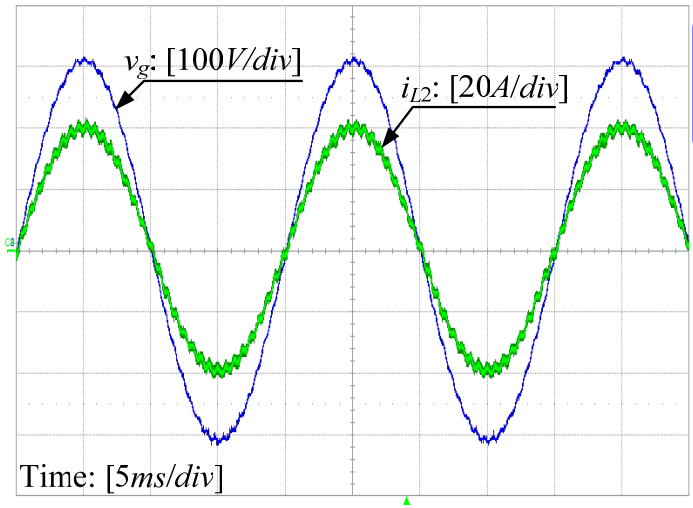
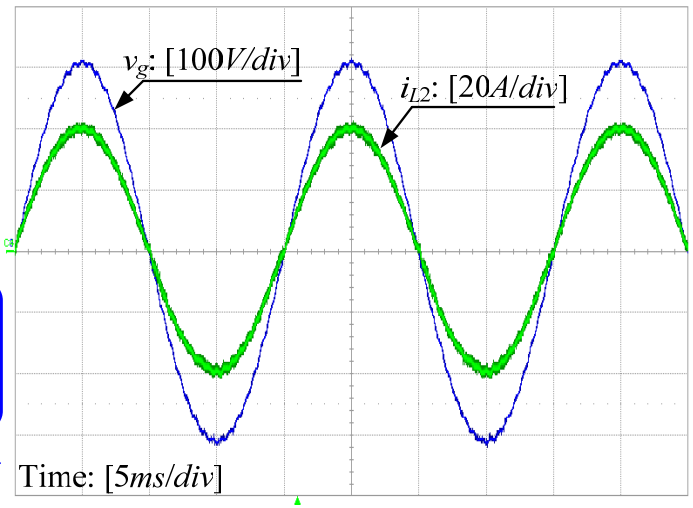


只有比例前馈

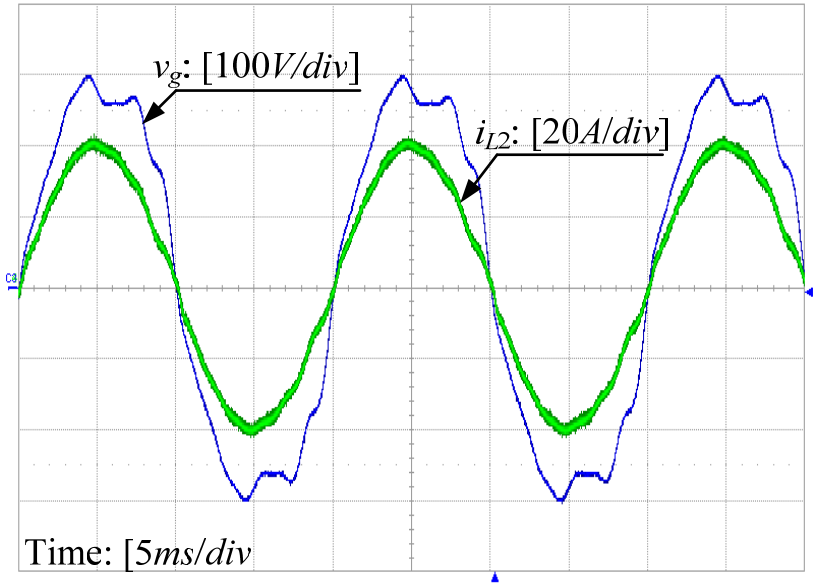


比例+一次微分前馈

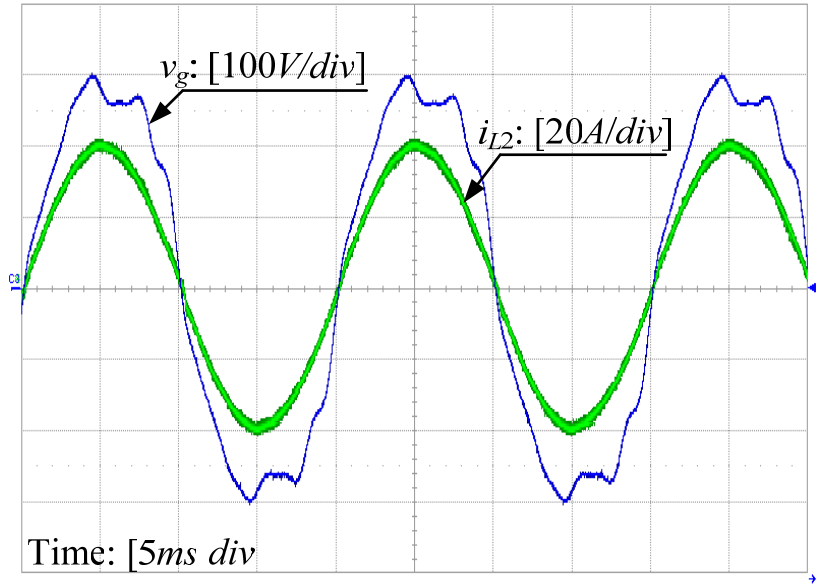


全前馈

实验波形：v_g中含有各次谐波



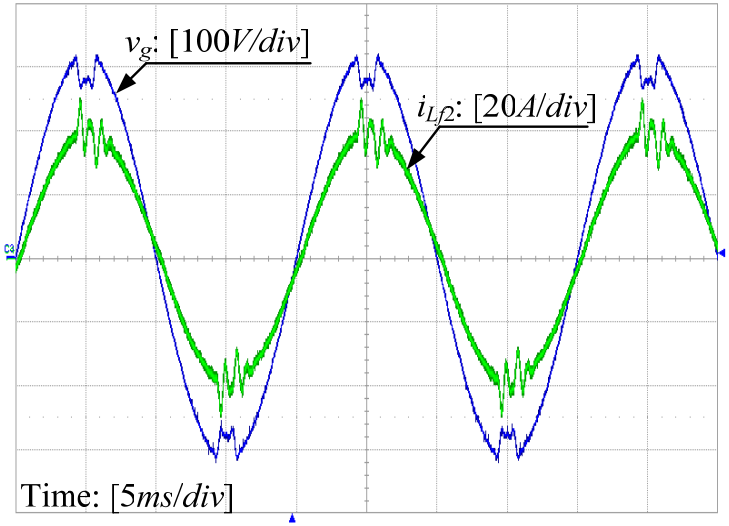
只有比例前馈



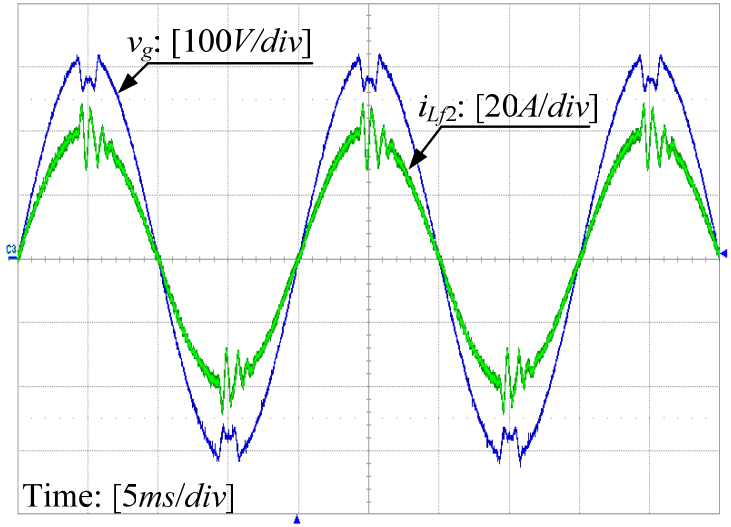
比例加一次微分前馈

	3rd	5th	7th	9th	11th	13th	15th
p.u (%)	10	5	3	3	2	2	0
angle (°)	0	90	0	0	0	0	0

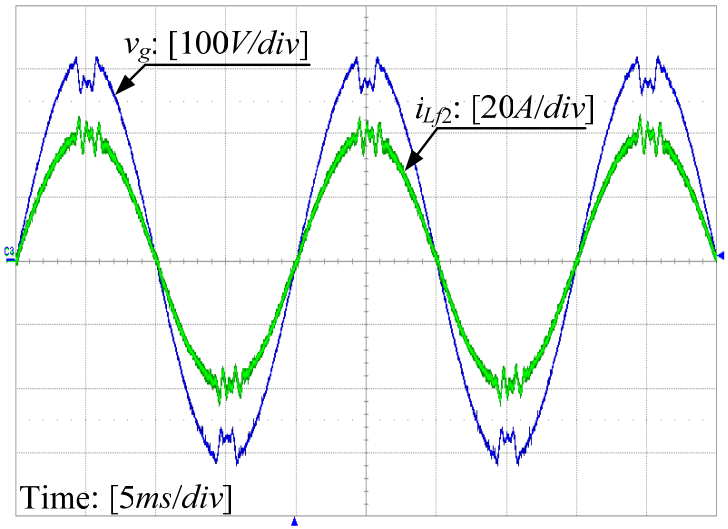
实验波形：v_g存在突降



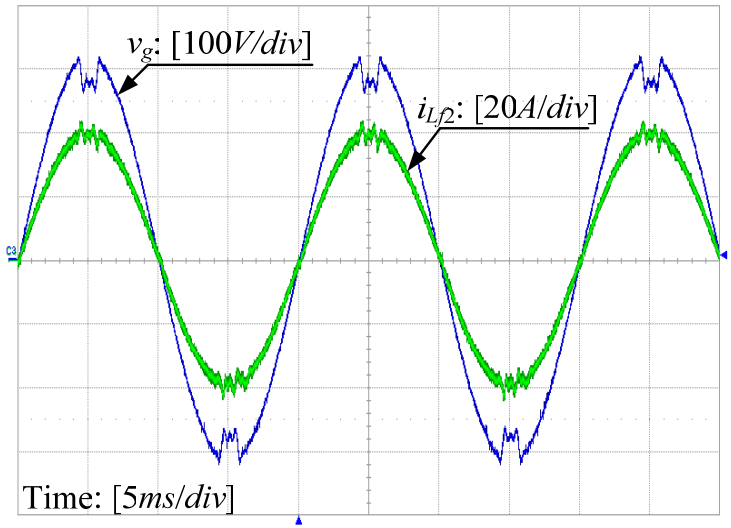
无前馈



只有比例前馈

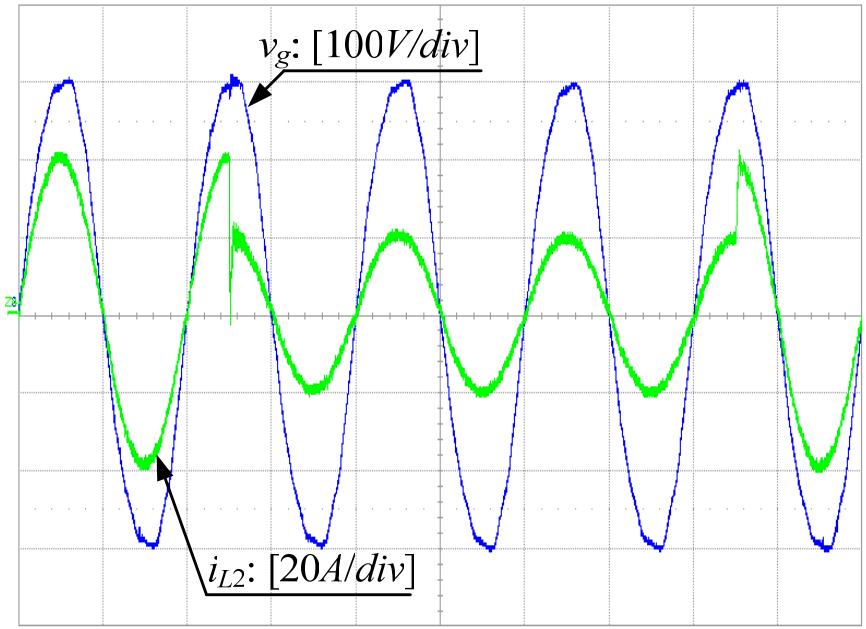


比例+一次微分前馈

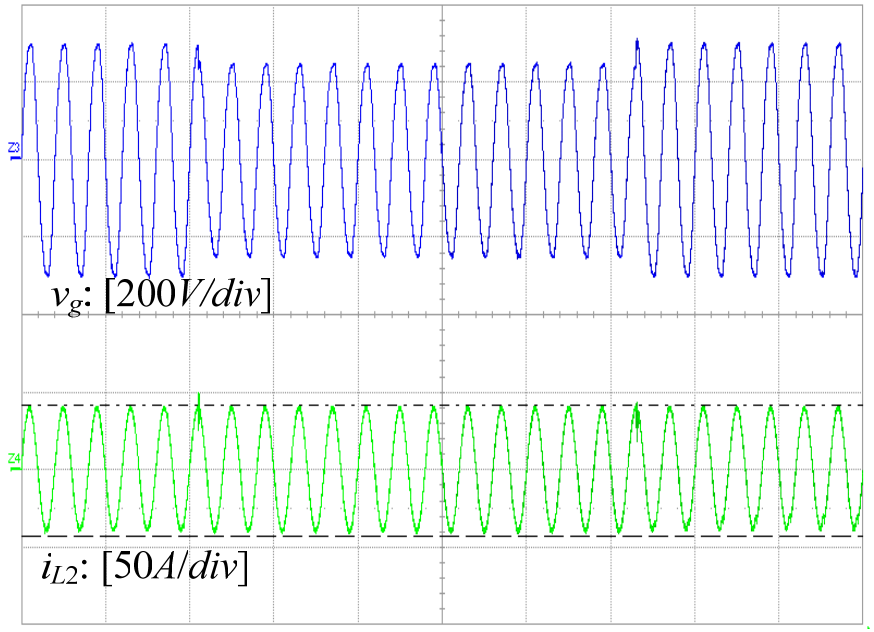


全前馈

动态特性



电流基准突变



电网电压突变

- 研究背景
- LCL并网滤波器
- 电网电压全前馈方法
- 实验结果
- **结论**

结论

- 与L滤波器相比，LCL滤波器具有更好的高频谐波抑制作用；
- LCL具有谐振峰，容易导致系统不稳定。在滤波电感或电容上串联或并联电阻可以阻尼谐振峰，其中在电容上并联电阻具有较好的阻尼作用，且对低频和高频谐波的抑制影响较小；
- 采用电容电流反馈可以实现电容上并联电阻的阻尼作用，且不存在损耗；
- 提出了一种电网电压全前馈方法，有效抑制了电网电压谐波对并网电流的影响，减小了并网电流的谐波，并提高了并网电流的跟随性。
- 研制了一台6kW的原理样机，验证了所提出的电网电压全前馈方法。

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请各位提出意见和建议！