pcim ASIA *Hybrid Platform*

A DC-link Voltage Estimation Based Active Damping Control Method of Single-phase Reduced DC-link Capacitance Motor Drives

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I received the B.S. and M.S. degrees in control science and engineering in 2013 and 2015, and the Ph.D. degree in electrical engineering in 2019, all from Harbin Institute of Technology. Currently I am a Postdoctoral Fellow and a Lecturer in the School of Electrical Engineering and Automation, Harbin Institute of Technology. My current research interests include advanced control of permanent magnet synchronous motor drives and position sensor-less control of ac motors. I am a member of IEEE and currently supported by Postdoctoral Innovative Talent Support Program of China

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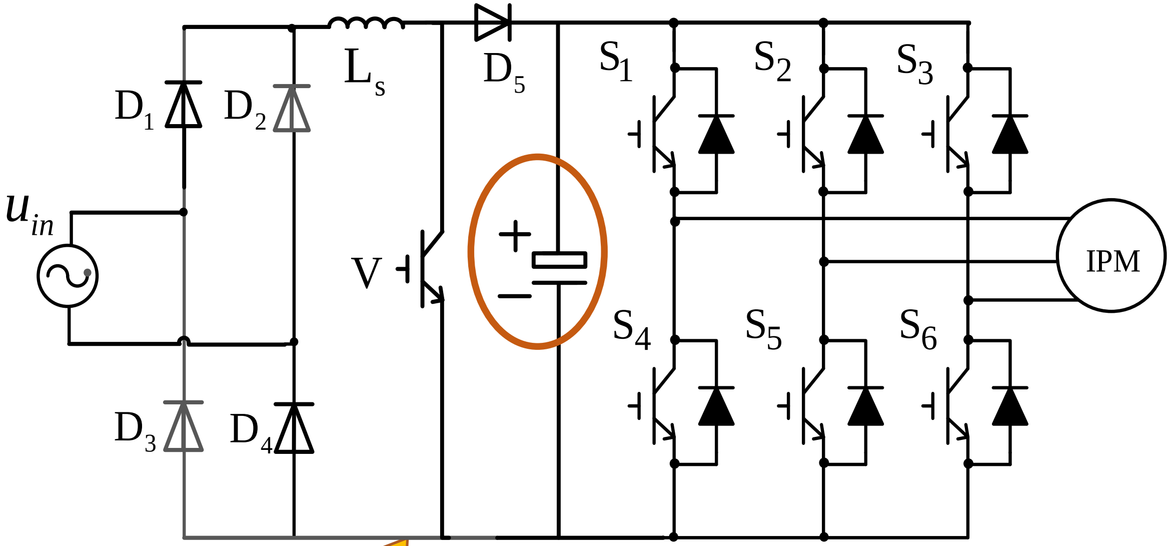
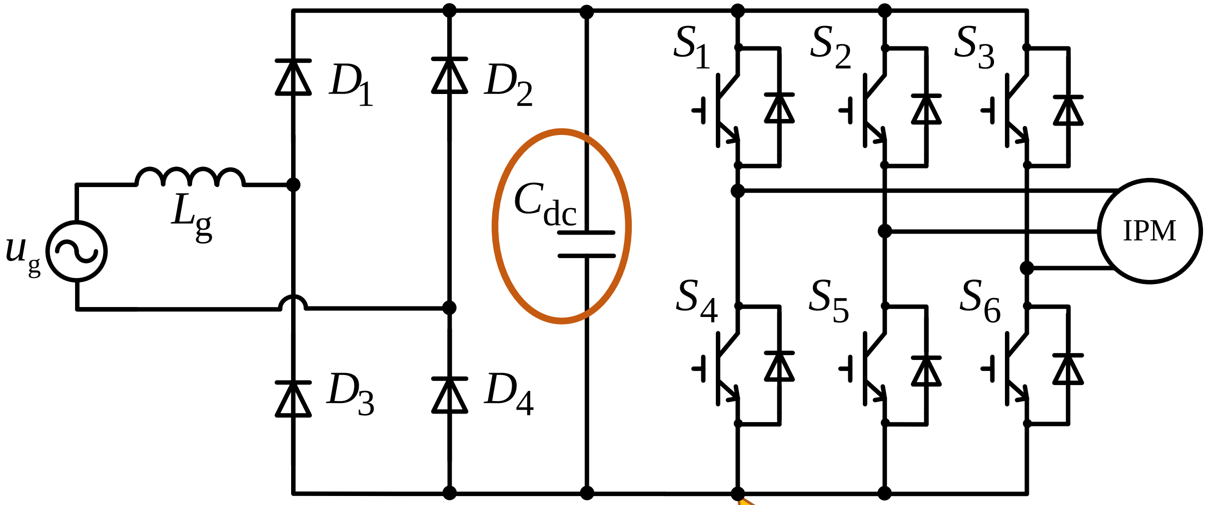
- Introduction
- Impedance model of IPMSM
- Drive system impedance model
- Drive system performance evaluation
- Experimental Results

Introduction

Topology analysis



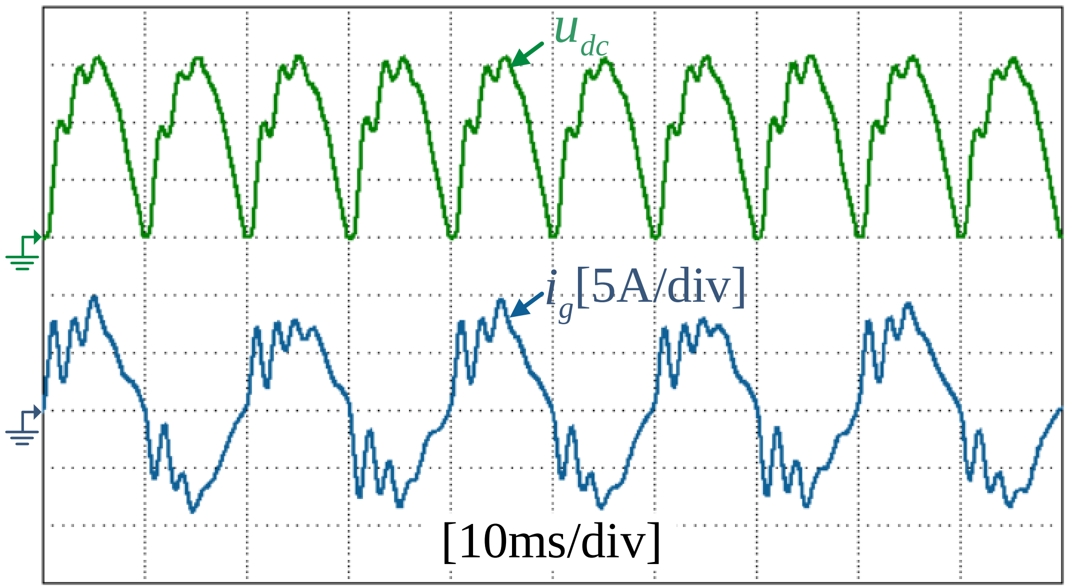


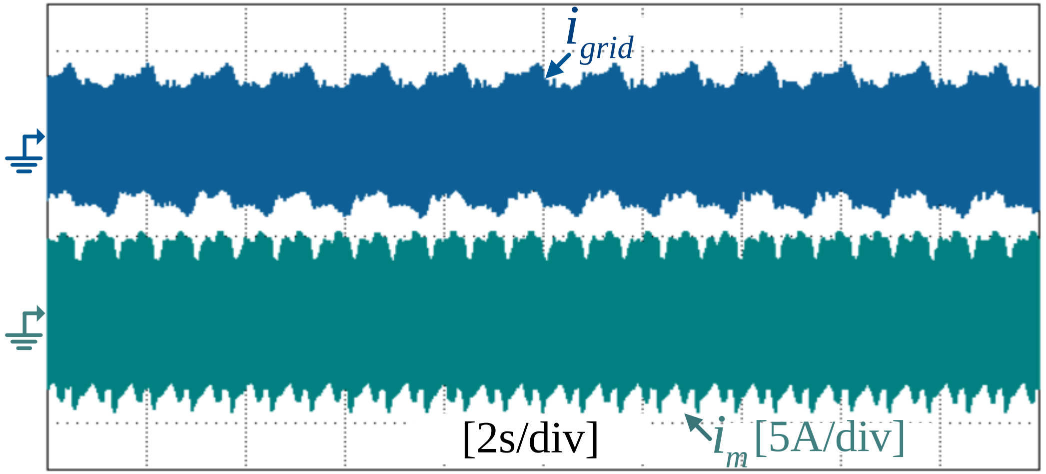
Electrolytic capacitor
- ✓ Short lifetime
- ✓ Large volume
- ✓ Need PFC circuit

Film capacitor
- ✓ High reliability
- ✓ Small volume
- ✓ Without PFC circuit

Introduction

Practical issues





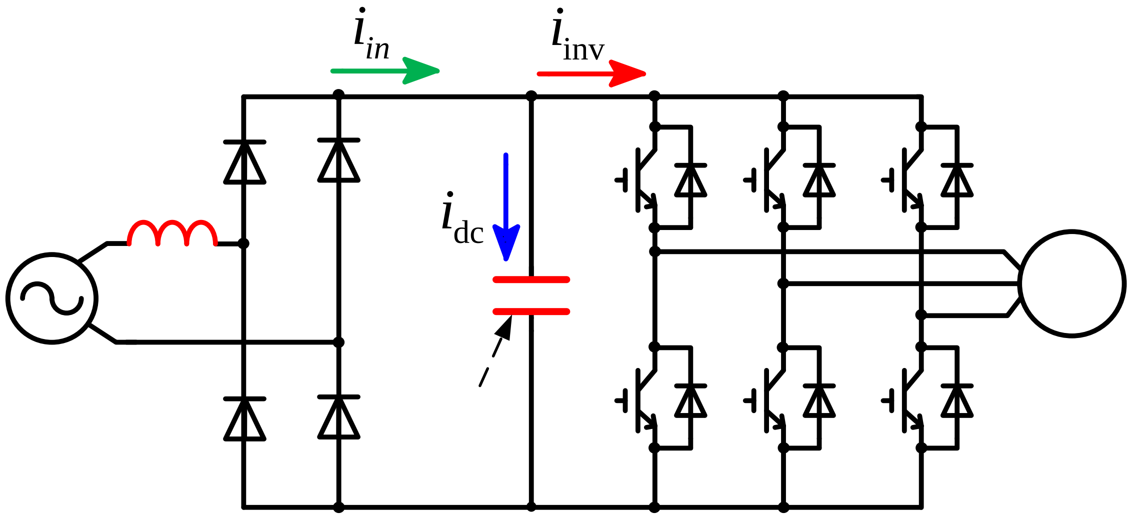
- LC resonance
- Obvious grid current harmonics
- Drive system stability

- Beat phenomenon
- Obvious grid current harmonics
- Drive system stability

Grid current performance improvement

Grid side performance

- **Conduction angle of diode rectifier** → **back electromotive force** → **Flux weakening current**
- **Grid current harmonics** →
  - **Stator current harmonics**
  - **Harmonics caused by LC resonance**



Grid current analysis

Grid current

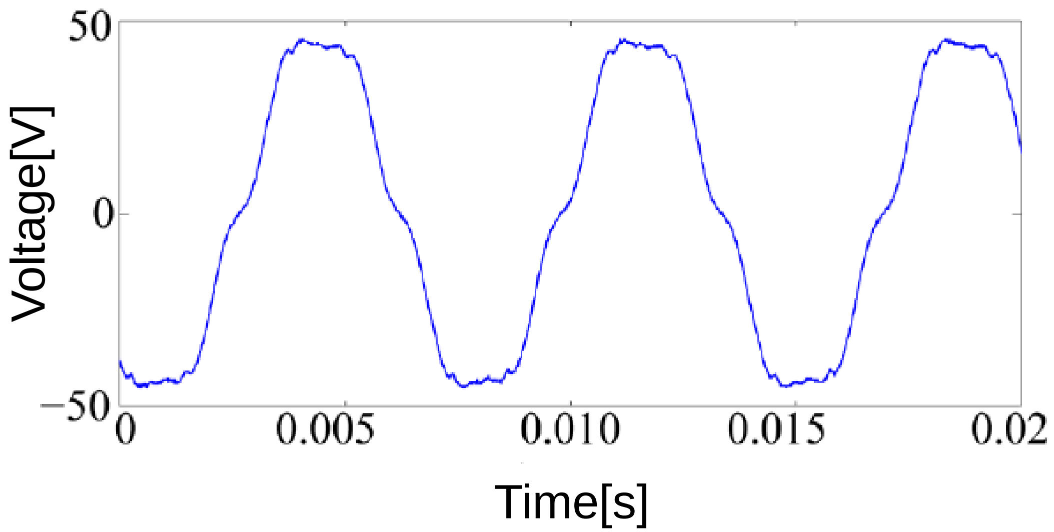
$$i_{\text{g}} = i_{\text{dc}} + i_{\text{inv}}$$

Introduction

Grid current performance improvement

Harmonics caused by stator currents

- □ **Stator current suppression loop**
- □ **Repetitive controller of specified frequency**



back electromotive force

Harmonics caused by LC resonance

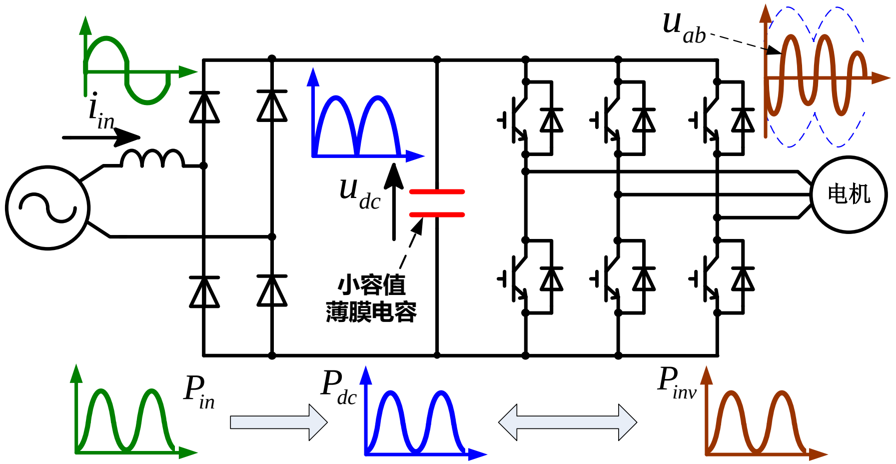
- □ **Grid side resonance information detection**
- □ **Power exchange between line inductor and film capacitor**
- □ **Voltage and current command**

Introduction

LC resonance suppression method to enhance drive system stability

Drive system characteristic equation:

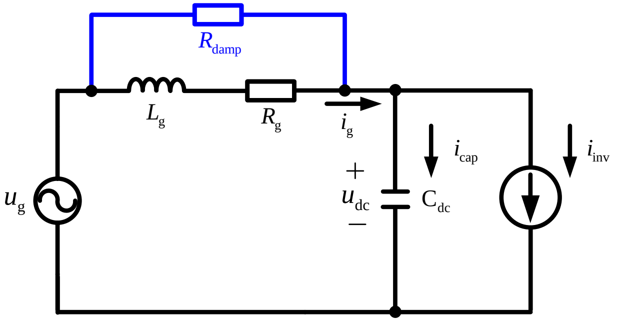
$$s^2+\left(\frac{R_\mathrm{g}}{L_\mathrm{g}}-\frac{P_\mathrm{L}}{C_\mathrm{dc}u_{\mathrm{dc},0}^2}\right)s+\frac{1}{L_\mathrm{g}C_\mathrm{dc}}\left(1-\frac{P_\mathrm{L}R_\mathrm{g}}{u_{\mathrm{dc},0}^2}\right)=0$$



Power coupling characteristic

Stability control methods:

- Change coefficients
  - Increase positive term
  - Reduce negative term
- Virtual impedance control
  - Virtual capacitance
  - Virtual resistance



Virtual resistor based stability control method

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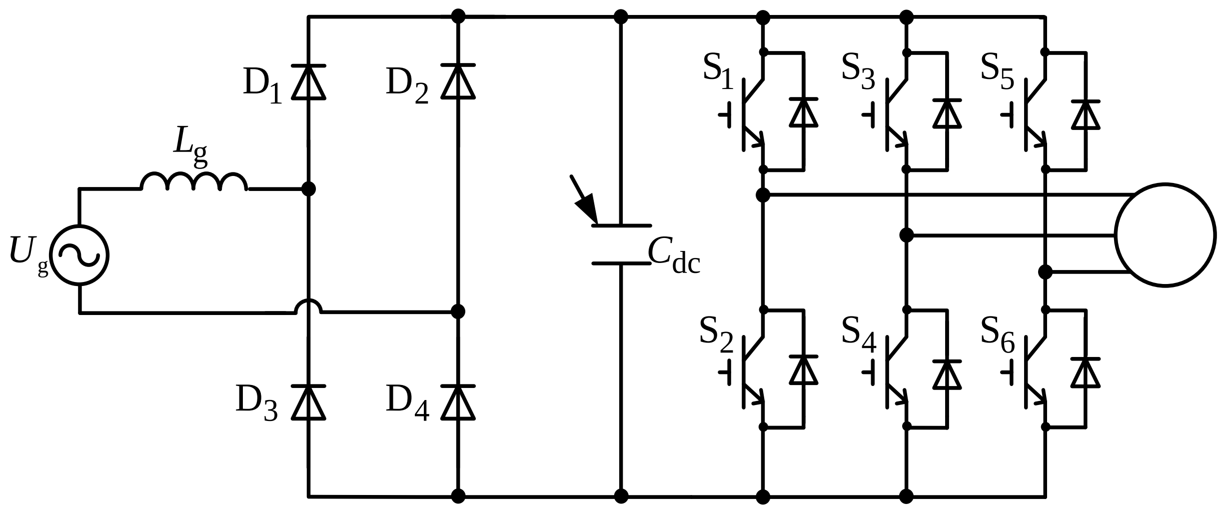
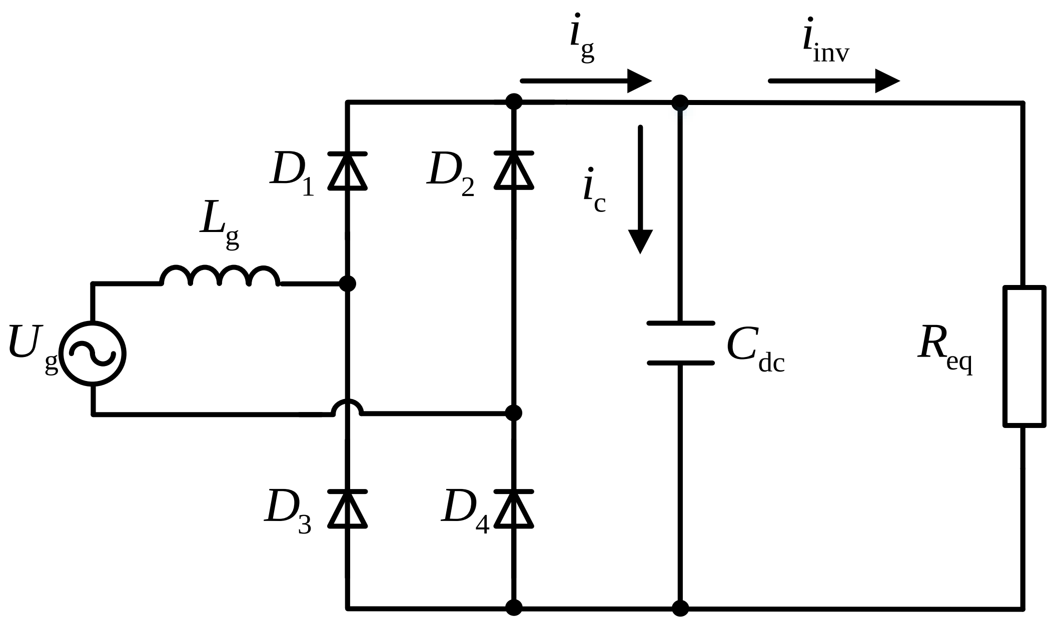
Introduction

Drive system equipped with small line inductance



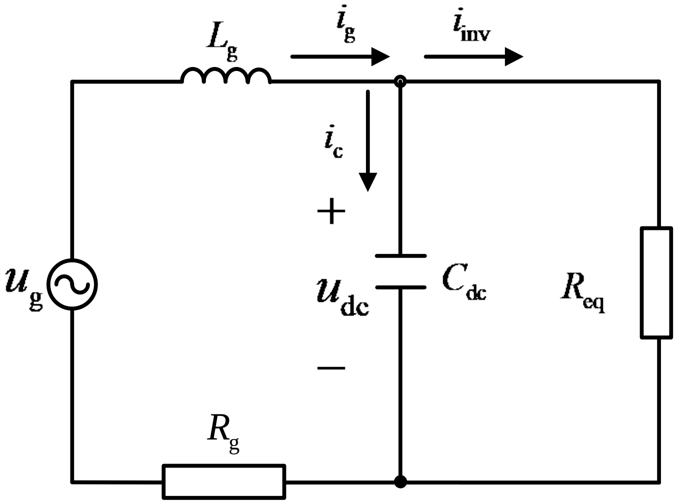
Drive system with small line inductance

Resonance characteristic analysis



Drive system characteristic analysis

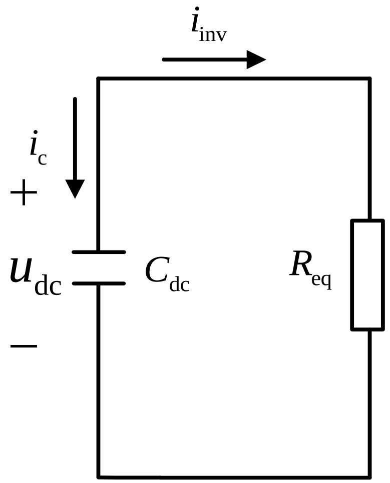
Forward-biased mode



$$
\begin{cases}
U_g \sin\left(\omega_g t + \delta\right) = L_g \dfrac{di_g}{dt} + R_g i_g + u_{dc1} \\
i_g = i_c + i_{inv} \\
i_c = C_{dc} \dfrac{du_{dc1}}{dt} \\
R_{eq} i_{inv} = u_{dc1}
\end{cases}
$$

LC resonance occurs

Reverse-biased mode

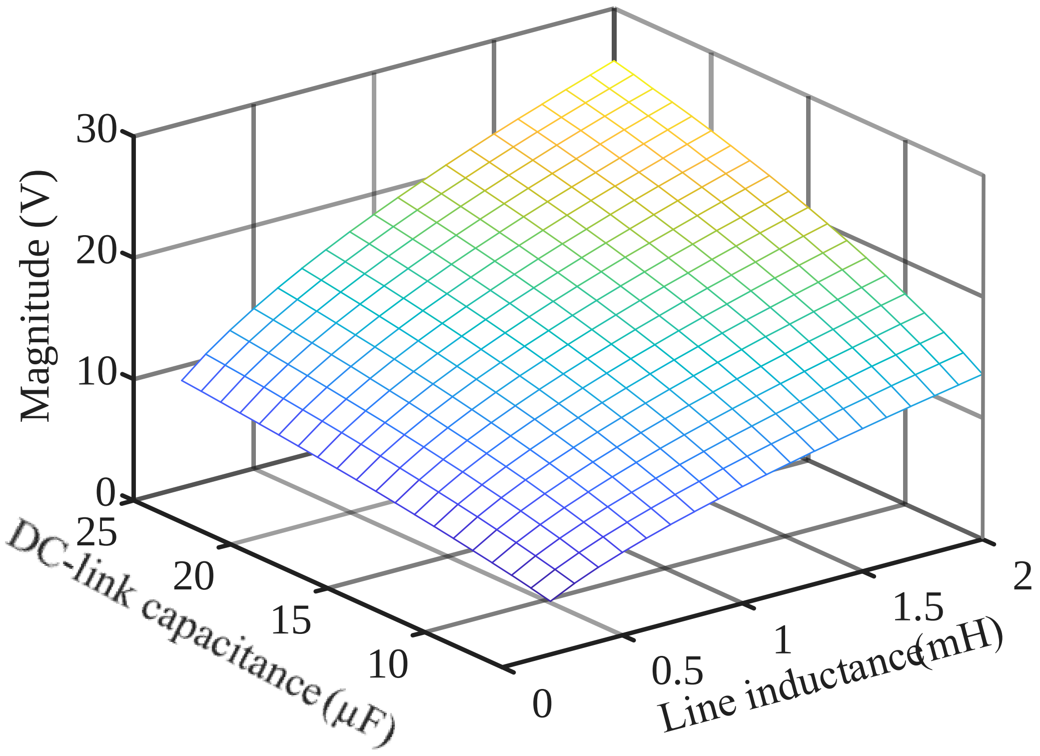


$$
\begin{cases}
i_c = C_{dc} \dfrac{du_{dc2}}{dt} \\
R_{eq} i_{inv} = u_{dc2} \\
i_c + i_{inv} = 0
\end{cases}
$$

Discharge process

Introduction

Drive system characteristic analysis



Magnitude of DC-link voltage

As line inductance decreases:

- **the LC resonant frequency increases**
- **the magnitude of the resonant DC-link voltage decreases**
- **Make it more difficult to suppress the LC resonance**

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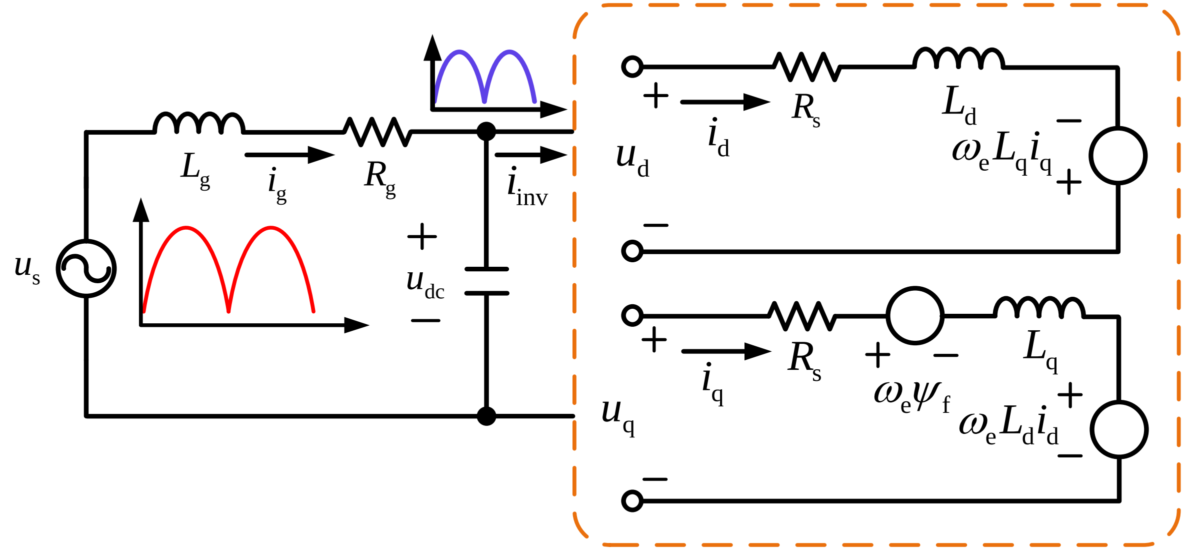
Impedance model of IPMSM

Impedance model construction



Drive system model

- **Small signal of motor voltage:**

$$\begin{bmatrix} \Delta u_d \\ \Delta u_q \end{bmatrix} = \frac{\Delta u_{dc}}{u_{dc,0}} \begin{bmatrix} u_{d,0} \\ u_{q,0} \end{bmatrix} + \begin{bmatrix} \Delta u_{dref} \\ \Delta u_{qref} \end{bmatrix}$$

- **Inverter power:**

$$u_{dc} i_{inv} = \frac{3}{2}\left(u_d i_d + u_q i_q\right)$$

- **Motor admittance:**

$$\boldsymbol{Y}_m(s) = -\frac{i_{inv,0}}{u_{dc,0}} + \frac{3}{2}\frac{u_{d,0}}{u_{dc,0}^2}\frac{u_{d,0} + \omega_e L_d i_{q,0} + L_d i_{d,0} s + i_{d,0} R_s}{R_s + L_d s + \boldsymbol{G}_d} + \frac{3}{2}\frac{u_{q,0}}{u_{dc,0}^2}\frac{u_{q,0} - \omega_e L_q i_{d,0} + L_q i_{q,0} s + i_{q,0} R_s}{R_s + L_q s + \boldsymbol{G}_q}$$

- **LC filter admittance:**

$$\boldsymbol{Y}_{LC}(s) = \frac{L_g C_{dc} s^2 + R_g C_{dc} s + 1}{L_g s + R_g}$$

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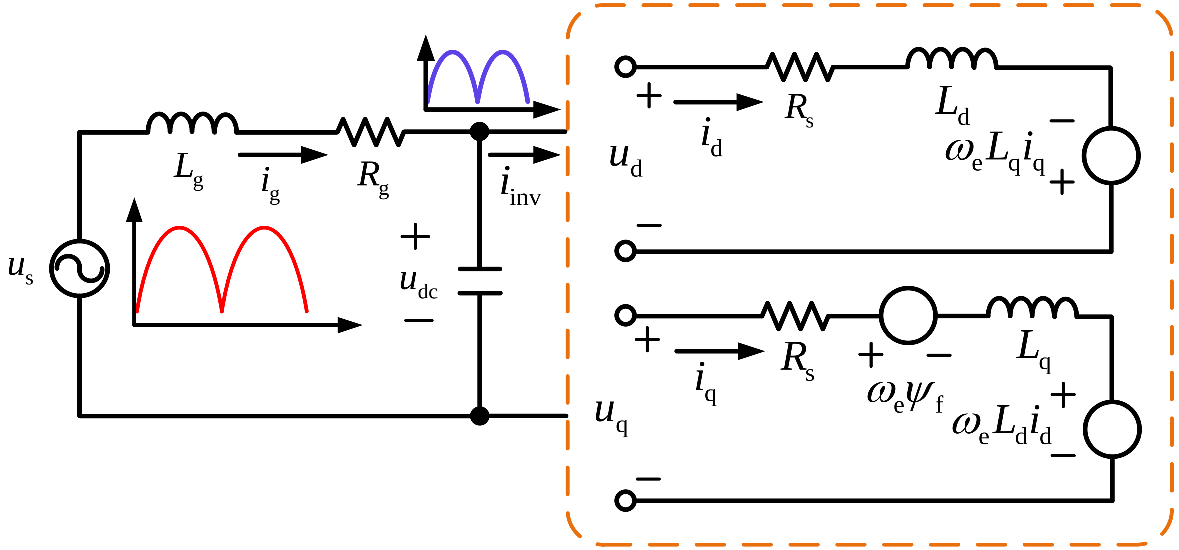
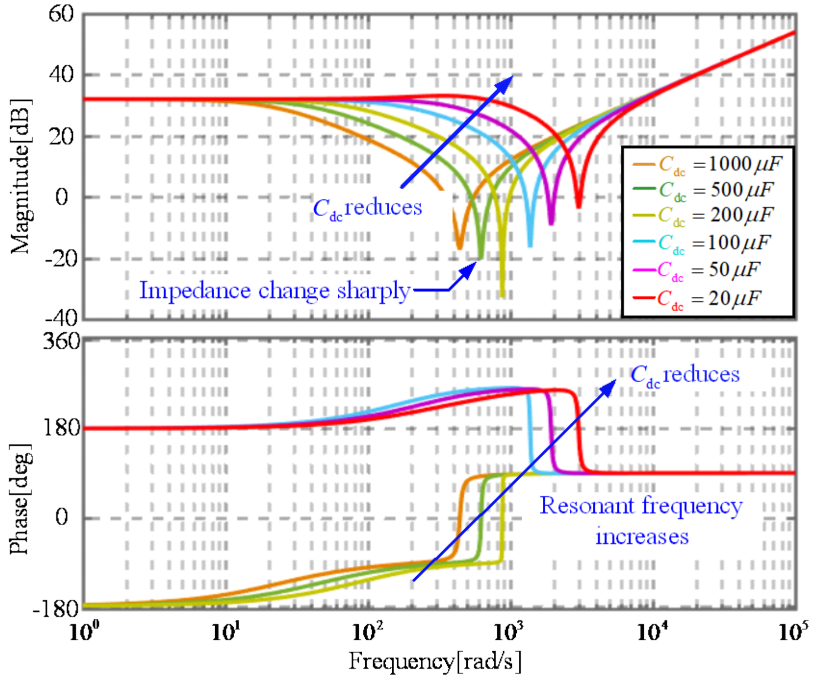
Drive system impedance model

Drive system characteristic analysis



Drive system model



Grid input impedance with different DC-link capacitance

- **Grid input impedance:**

$$Z_g(s) = L_g s + R_g + \frac{Z_m(s)}{1 + Z_m(s) \cdot C_{dc} s}$$

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Drive system performance evaluation

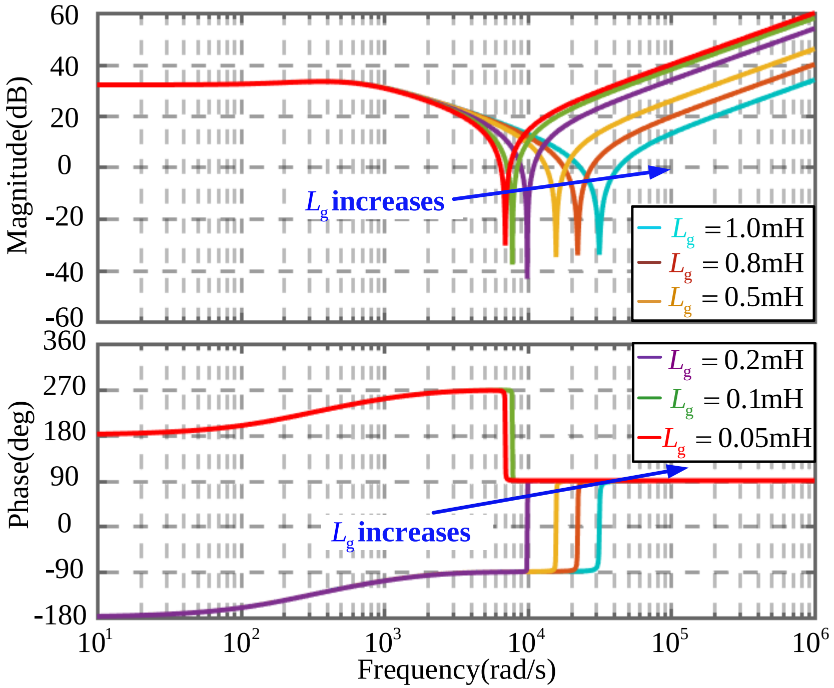
□ Resonant DC-link voltage estimation:

$$u_{dcr} = \frac{2K_g \xi \omega_{BPF} i_g s^2}{s^2 + 2\xi \omega_{BPF} s + \omega_{BPF}^2}$$

where K_g and ω_{BPF} are the feedback gain and the bandwidth of the band-pass filter

□ Apply u_{dcr} to q-axis voltage:

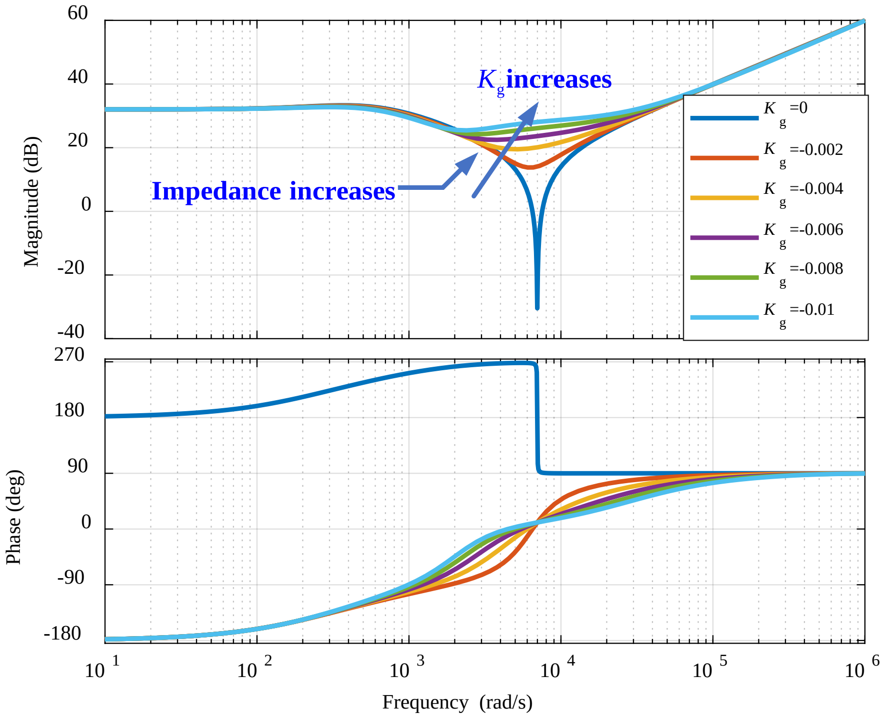
$$Z_{mad}^{-1}(s) = \frac{\left(Z_m^{-1}(s) + \frac{3}{2}\frac{sC_{dc}u_{dcr}}{u_{dc,0}i_g}\frac{u_{q,0} - \omega_e L_q i_{d,0} + L_q i_{q,0} s + i_{q,0} R_s}{R_s + L_q s + G_q(s)} \right)}{1 - \frac{3}{2}\frac{u_{dcr}}{u_{dc,0}i_g}\frac{u_{q,0} - \omega_e L_q i_{d,0} + L_q i_{q,0} s + i_{q,0} R_s}{R_s + L_q s + G_q(s)}}$$



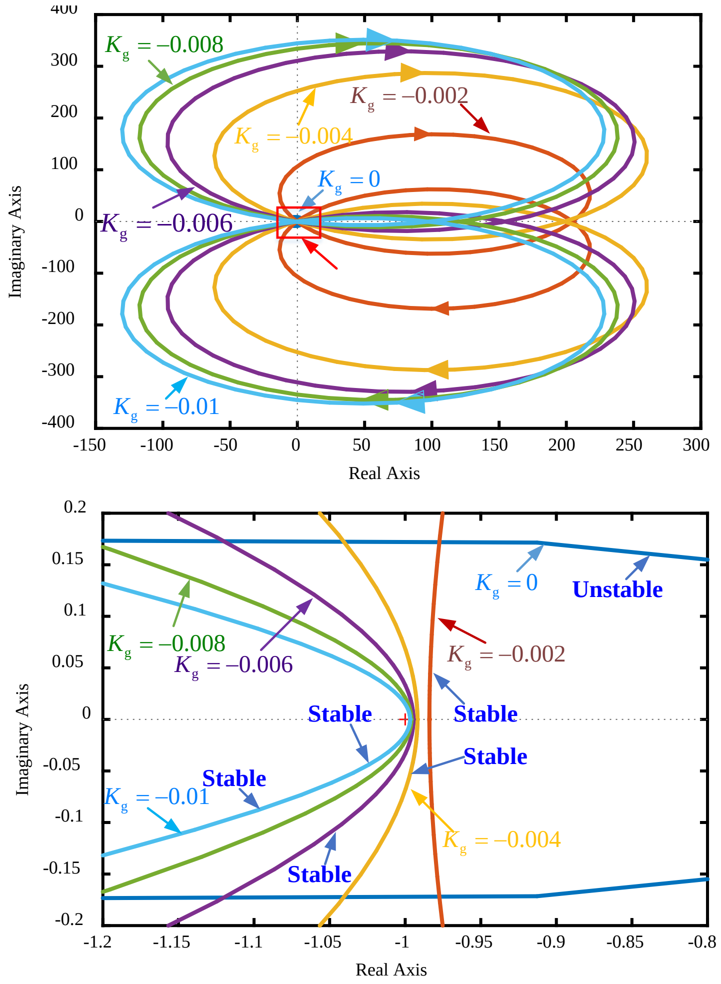
Grid input impedance before applying the proposed control method

Drive system performance evaluation

Drive system performance evaluation



Grid input impedance after applying proposed method



Nyquist plots after applying proposed method

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Experimental results

Experimental platform

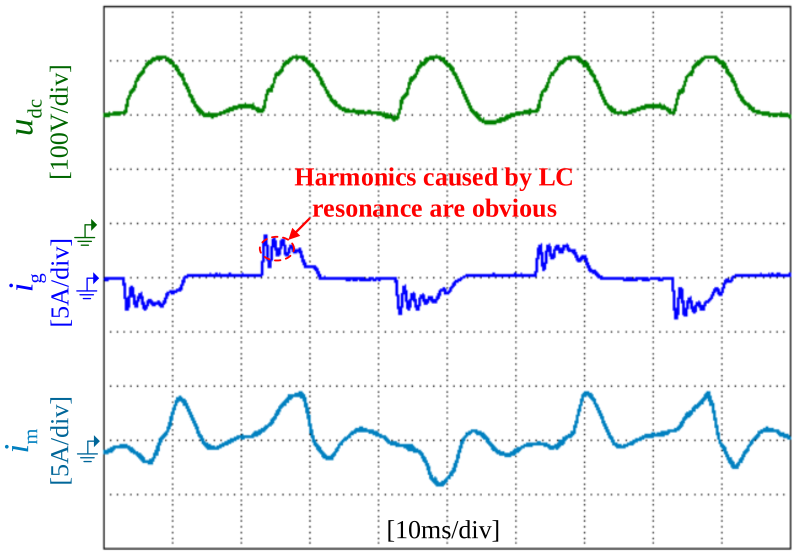
Grid input impedance after applying proposed method

Table I Parameters of the experimental platform

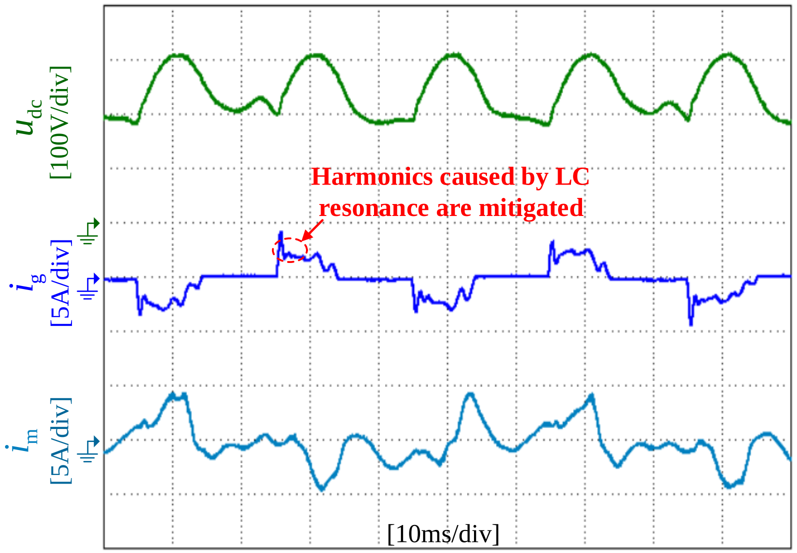
Parameters	value
Grid voltage	220 Vrms
Grid frequency	50 Hz
d-axis inductance	7.9 mH
q-axis inductance	11.7 mH
Flux linkage of rotor	0.11 Wb
Number of pole pairs	3
Rated power	1.0 kW
Rated speed	3000 r/min
Stator resistance	2.75 Ω

Experimental results

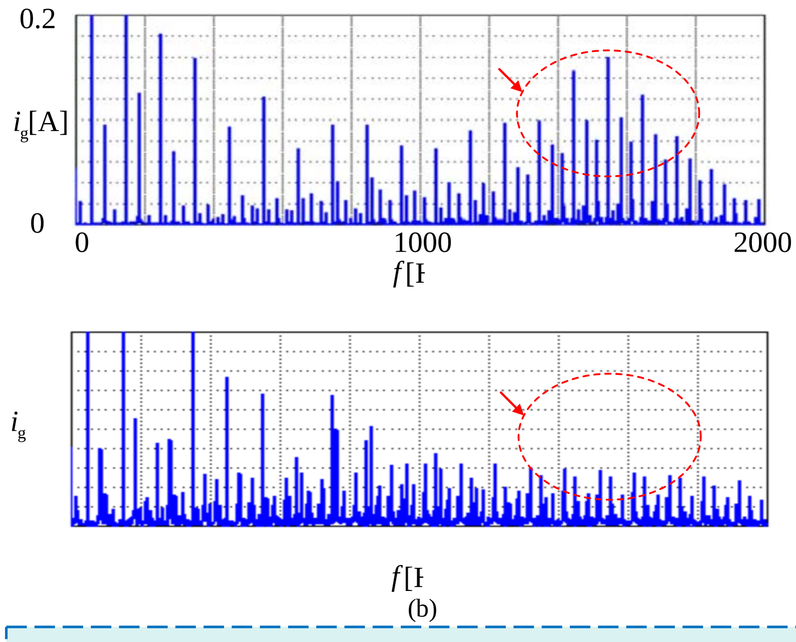
Drive system performance results



Without proposed method



With proposed method



Fourier analysis of grid current

Thank you for your attention!