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Downsizing Design of Powdered Iron Core Inductor Based on Variable-Frequency Modulation Targeted at Harmonics Suppression

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Content

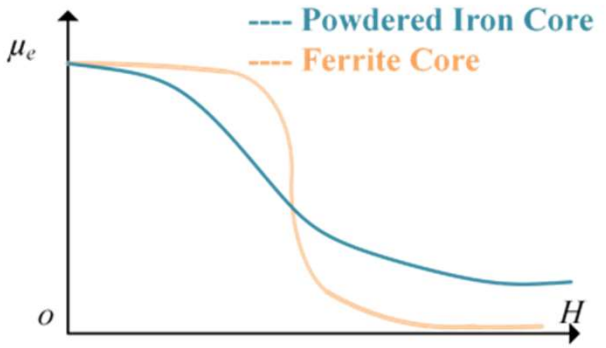
- Background
- Methodology
- Experiment Results
- Summary

Background

- Onboard Charger for EVs requires high power density
- Efforts to increase power density
  - Topology (Totem-Pole PFC rectifier)
  - Wide-Band-Gap device, such as GaN HEMTs and SiC MOSFETs
  - Magnetic components (Focus of this research)

Powdered Iron Core Inductor

- Powdered Iron Core (PIC) inductors
  - Higher magnetic flux density B_s
  - Comparison between PIC inductors and ferrite core inductors from the perspective of saturation process
  - Slow saturation
- Saturation of PIC inductor needs to be considered for normal working situation.
- Influence on current harmonics deserves attention.



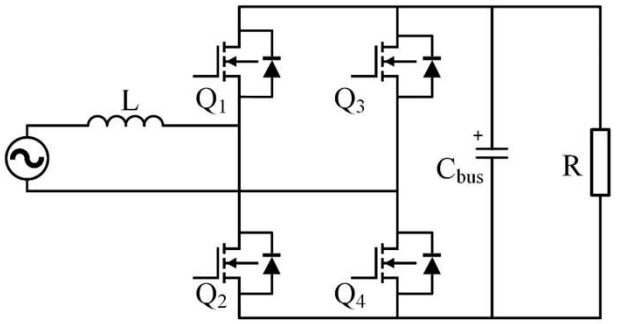
Frequency-Domain Analysis of Current Ripple

- Current ripple is main cause for harmonics.
- Difference equation of line current

$$\begin{cases} L\frac{di_L}{dt} = v_g, t \in (0, DT_s) \\ L\frac{di_L}{dt} = v_g - v_{bus}, t \in (DT_s, T_s) \end{cases}$$

- Expression of ripple peak-to-peak value

$$-I_{pp,ripple}(t) = \frac{V_g \sin(\omega t)}{L} DT_s$$

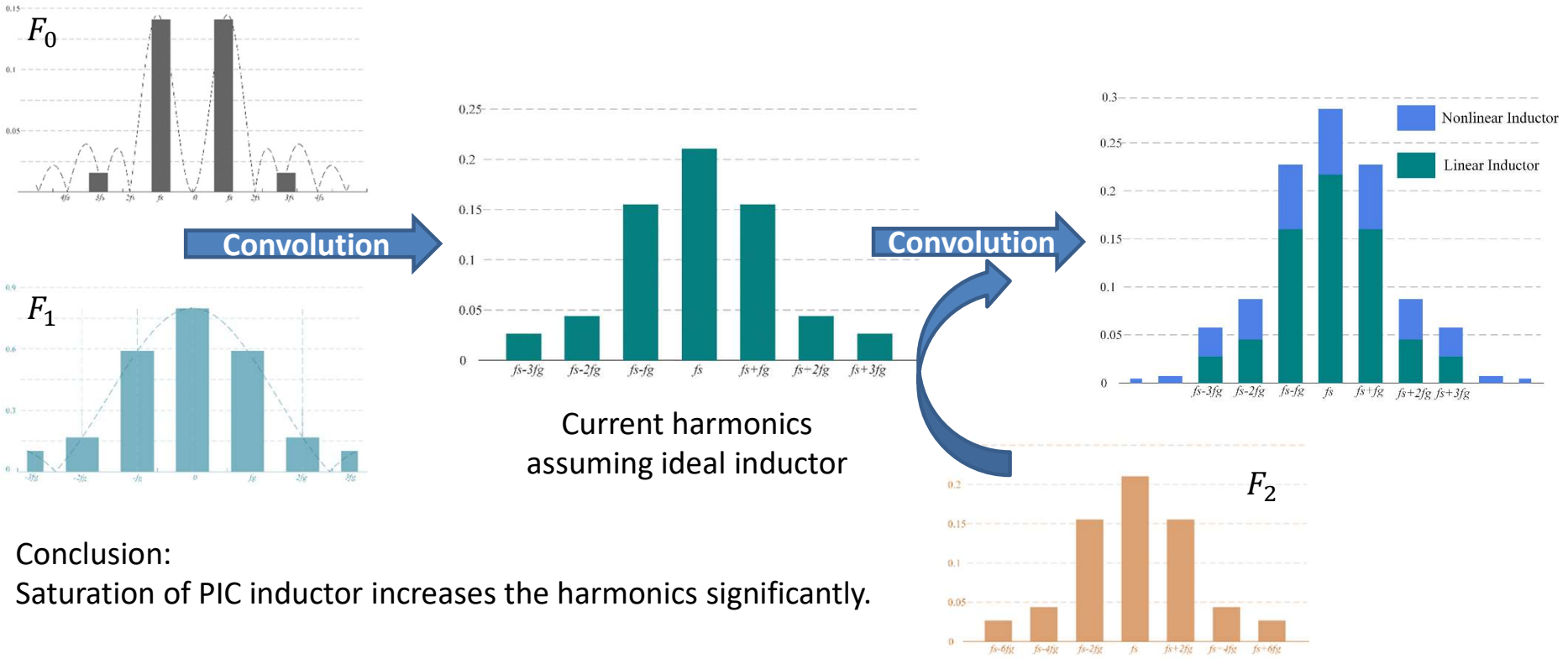


The Totem-Pole Converter

Frequency-Domain Analysis of Current Ripple

- Signal decomposition property of the current ripple
  - $I_{pp,ripple}(t) = f_0(t) f_1(t)\, f_2(t)$
  - Fourier Transform ↓
  - $I_{pp,ripple}(\mathrm{j}\omega) = F_0 * F_1 * F_2$
- Let
  - $f_0(t)$ be the periodic triangle waveform
  - $f_1(t)$ be function of the steadily moving duty ratio and input and output voltage
  - $f_2(t)$ be the inductance drop due to the saturation of PIC inductor
- Perform Fourier Transform to each sub-fuction, and convolute the results

Frequency-Domain Analysis of Current Ripple



Current harmonics assuming ideal inductor

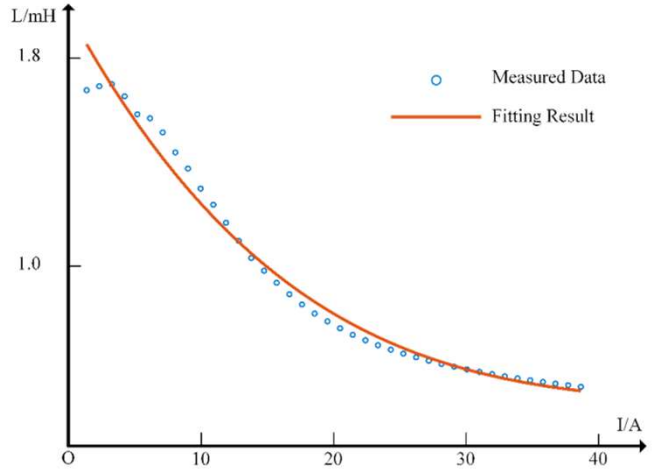
Conclusion:
Saturation of PIC inductor increases the harmonics significantly.

Variable Switching Frequency Scheme

- A variable switching frequency scheme to eliminate harmonics growth.

  $-I_{pp,ripple}(t) = \frac{V_g \sin(\omega t)}{L} DT_s$

- Keep $\frac{T_s}{L}$ constant
- Polynomial fitting is used to obtain the rational equation reflecting the saturation with current
- $f_2(t) = \frac{L_0}{L(i)} = a_0 + a_1 i + a_2 i^2 + a_3 i^3 + \cdots + a_n i^n$
- $\frac{f_{s,ref}}{f_{s,}} = \frac{\mathrm{T}_s}{\mathrm{T}_{s,ref}} = \frac{L_0}{L(i)} \rightarrow \frac{\mathrm{T}_s}{L} = const$

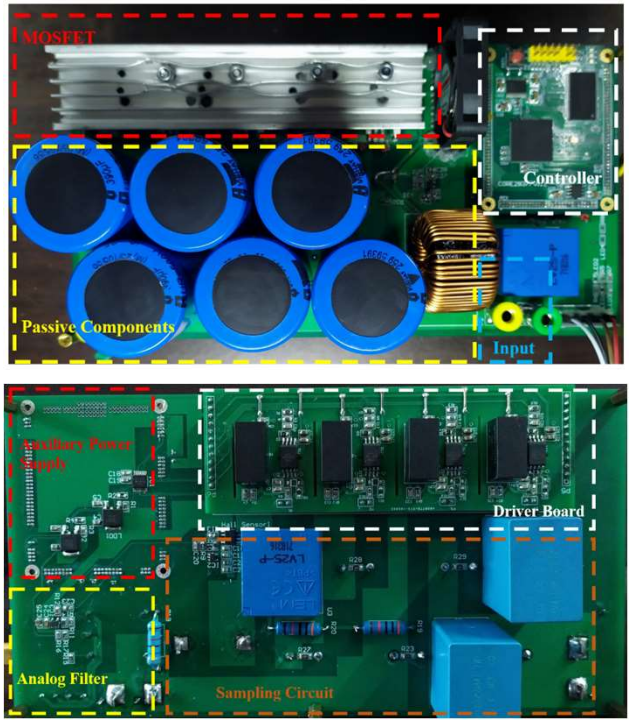


I-L curve: Measured data vs. fitting result

Experiment Results

- Introduction of the experiment platform

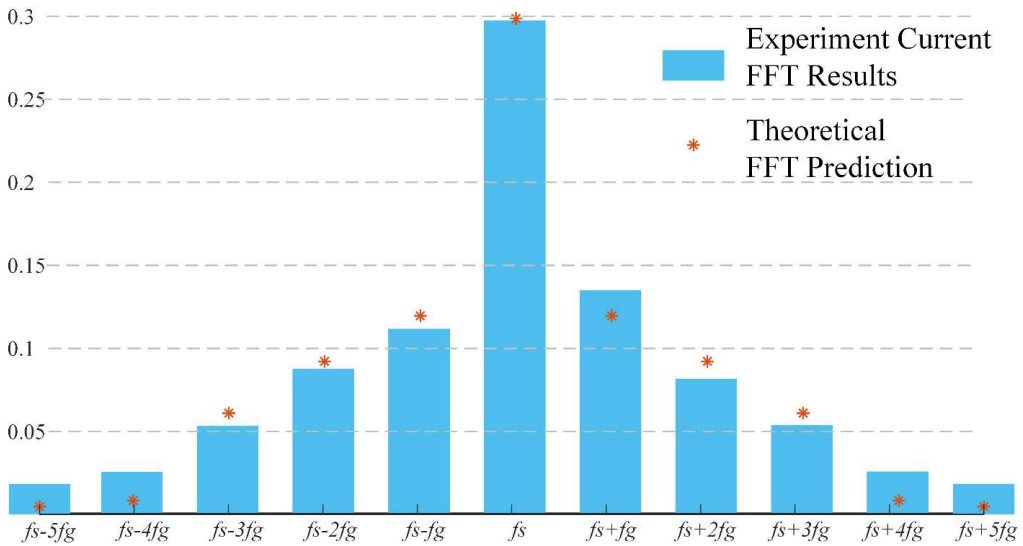
Experiment Parameters	
Item	**Value**
Power switches (SiC)	C3m0075120k
Magnetic Core	NPF184060C
Power Rating	3kW
Switching Frequency	40kHz
Grid Voltage	110V/220V
Bus Voltage	400V



The Totem-Pole Converter Prototype

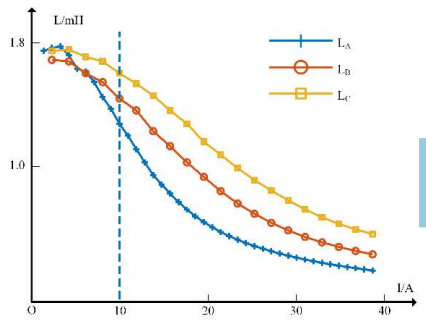
Experiment Results

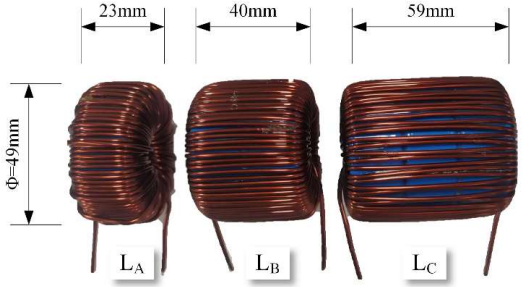
- Verification of the ripple analysis



Experiment Results

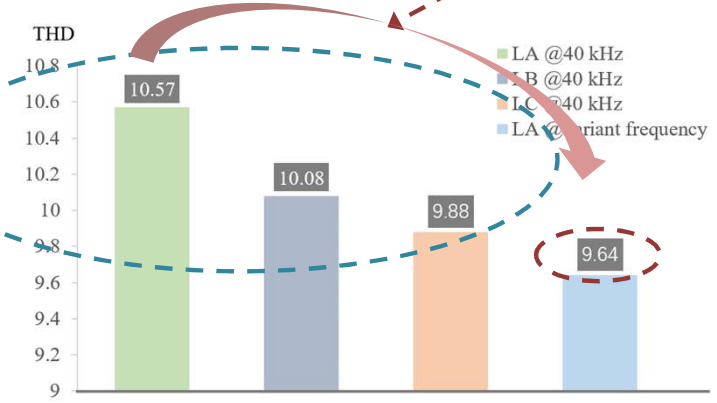
- Effectiveness of the variable switching frequency scheme





Influence of the different resistance to saturation

Variable switching frequency scheme



Summary

- Saturation of inductors causes the inductance drop and enlarge current ripple of the Totem-Pole PFC rectifier
- Signal decomposition property is used to analyze the current ripple and the influence of magnetic saturation
- Variable switching frequency scheme can eliminate the harmonics growth caused by the saturation of PIC inductors, so that smaller inductors can be used to replace the bigger ones with the same inductance