ANALYSIS AND DESIGN OPTIMIZATION OF PARALLELED CLASS-Φ_2 CONVERTERS FOR HIGH-FREQUENCY AND HIGH-POWER APPLICATIONS

01

STUDENTS: MANAS PALMAL

Motivations

- Delivering High-frequency and High-power for applications like Plasma generations, magnetic resonance imaging (MRI), and etc.

Trade-offs of Existing Technology

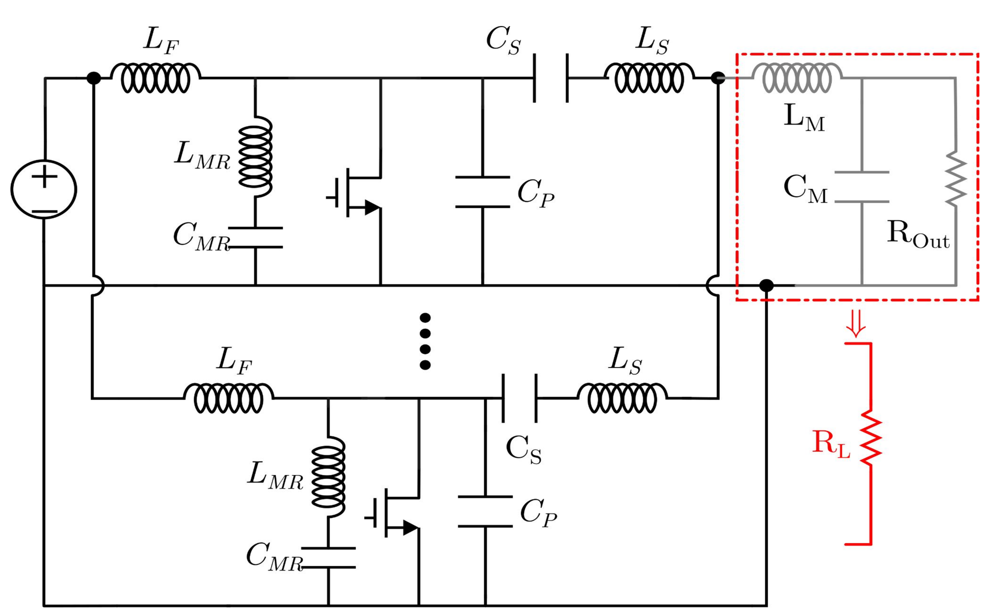
- Multiple highly inefficient radio-frequency (RF) power-amplifiers are used along with power-combiner network.
- Though power combiner network combines the output power to improve the overall output power ratings, it increases the overall size of the converter.

Objectives of the Proposed Design Method

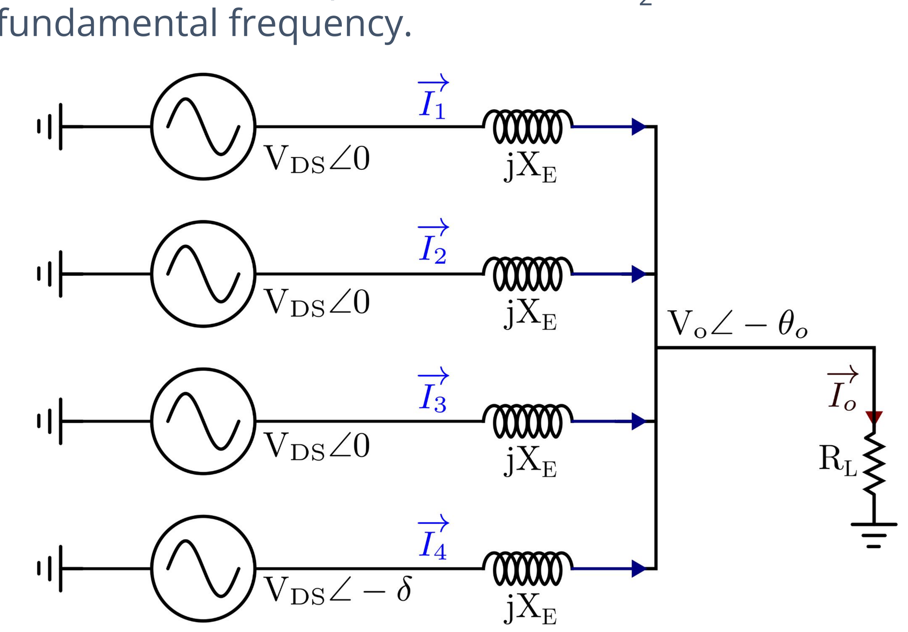
- Paralleling class-Φ_2 converter, a resonant RF converter, with soft-switching operations, ensures very high-efficiency (≥ 90%) of the overall system.
- Elimination of power combiner network improves the energy density of the overall converter.

Paralleled Class-Φ_2 Converters

- Proposed paralleled class-Φ_2 converters topology



- Simplified circuit model of paralleled class-Φ_2 converters connected to the load at fundamental frequency.



Design of Paralleled Class-Φ_2 Converters

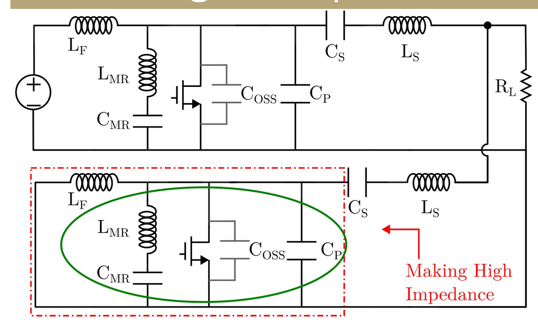
Output power equations of paralleled class-Φ_2 converters:

$$P_o = \frac{8V_i^2}{\pi^2} \cdot \frac{R_L}{m^2R_L^2 + X_s^2} \cdot \left[1 + (m-1)^2 + 2(m-1)\cos\delta\right]$$

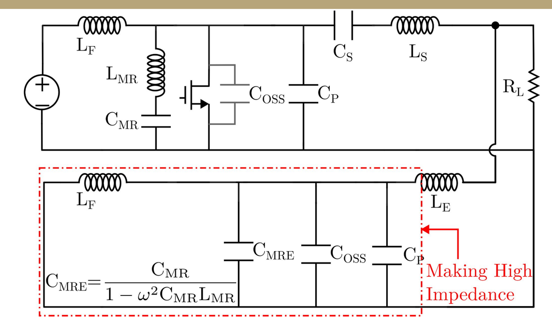
where, V_i is the input DC voltage, R_L is the load resistance.

- The output power variation is possible either by turning on multiple converters or by changing the phase-shift.

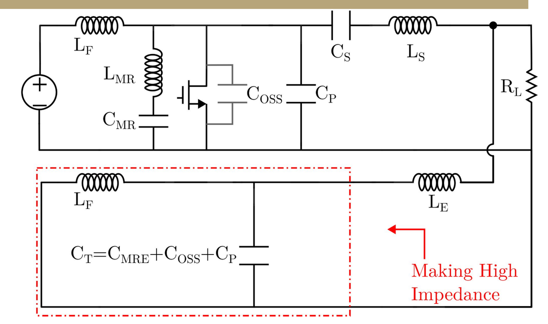
Minimizing the Impact of OFF-mode Converters:



OFF-mode converters are connected in parallel with the ON-mode converter



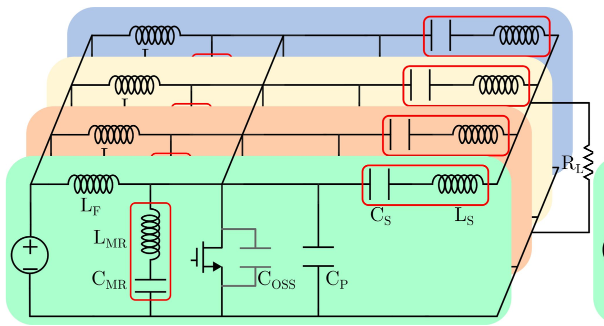
Equivalent circuit model of the OFF-mode converter



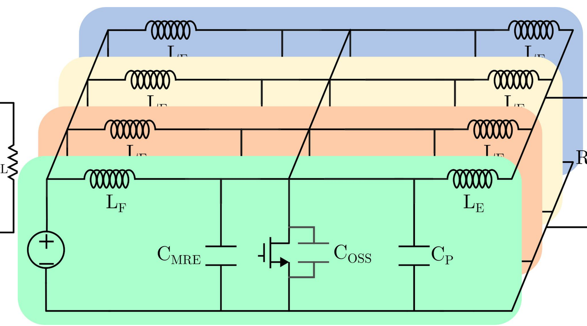
Simplified circuit model at the fundamental frequency

- L_F and C_T are in resonance. So, OFF-mode converters have no impact on ON-mode converters.

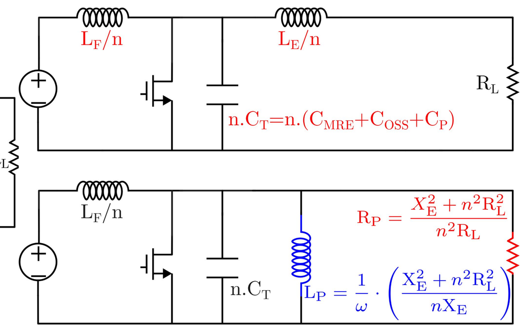
Soft-switching Analysis of ON-mode Class-Φ_2 Converters:



Original circuit diagram



Equivalent circuit model at fundamental frequency



Simplified circuit diagram and circuit transformation

- Condition for soft-switching operation:

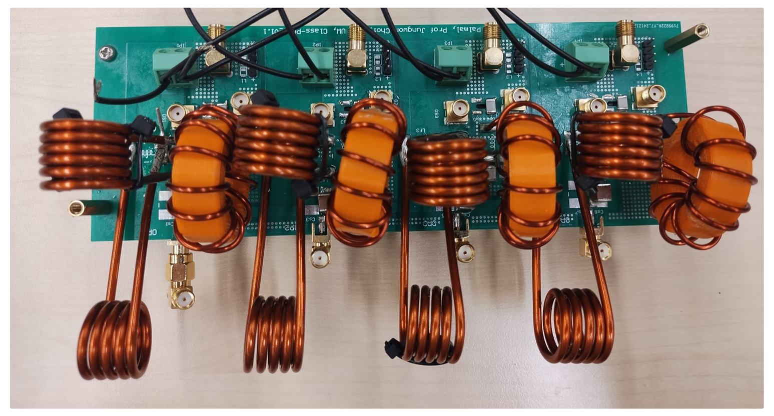
$$\frac{X_E}{nR_L}\left[1 + \left(\frac{1-\omega^2 C_T L_F}{\omega L_F}\right) \cdot \left(\frac{X_E^2 + n^2R_L^2}{X_E}\right)\right] \triangleq \gamma$$

- When LF and CT are in resonance, soft-switching operations depend on the ratio of the output inductance and load resistance, and the number of ON-mode converters.

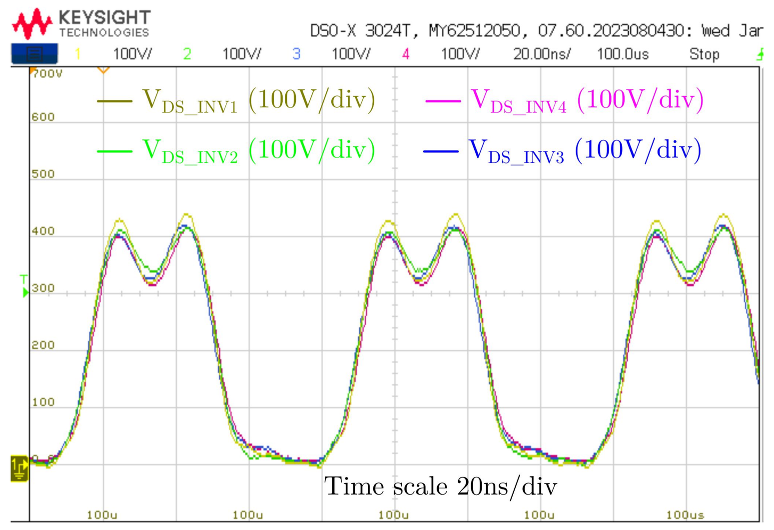
Design Circuit Parameter

Parameter	Values	Parameter	Values
L_S	$1.76\,\mu$H	C_{MR}	100pF
C_S	105pF	C_{OSS}	110pF
R_L	15Ω	C_P	100pF
L_{MR}	342nH	L_F	350nH

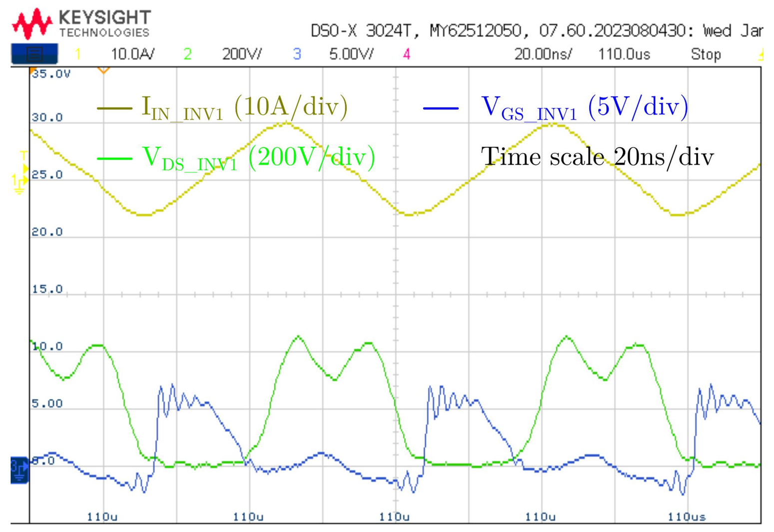
Experimental Results



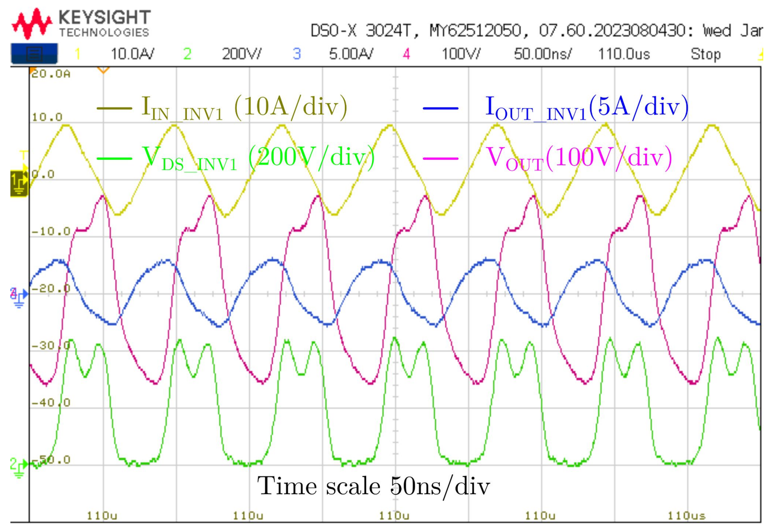
Hardware prototype developed in lab.



Drain-source voltage waveforms of the four class-Φ_2 converters connected in parallel



Gate-source and drain-source voltage waveforms during turn-on transitions indicate soft-switching operation.



Input and output current of a single class-Φ_2 converter along with output voltage.

Future Work

- High quality factor design.
- Incorporating of variable load operation.
- Closed-loop control.

References

[1] J. M. Rivas, Y. Han, O. Leitermann, A. D. Sagneri, and D. J. Perreault, "A high-frequency resonant inverter topology with low-voltage stress," IEEE Transactions on Power Electronics, vol. 23, no. 4, pp. 1759–1771, 2008.
[2] L. Roslaniec, A. S. Jurkov et al., "Design of single-switch inverters for variable resistance/load modulation operation," IEEE Transactions on Power Electronics, vol. 30, no. 6, pp. 3200–3214, 2015.
[3] Y. Zhou and J. Choi, "Design of high-frequency, paralleled resonant inverter to control output power for plasma generation," in 2022 IEEE 23rd Workshop on Control and Modeling for Power Electronics (COMPEL), 2022, pp. 1–7.

ELECTRICAL & COMPUTER ENGINEERING
UNIVERSITY of WASHINGTON

ADVISORS: Prof. Jungwon Choi