Saturable Inductors for Superior Reflexive Field Containment Capability in Dynamic Inductive Power Transfer Systems

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Overview

In dynamic Inductive Power Transfer (IPT) applications, it is required that the segmented transmitter coil transfer power to a moving receiver coil. One proposed method to achieve this is using the reflexive field containment approach [1].

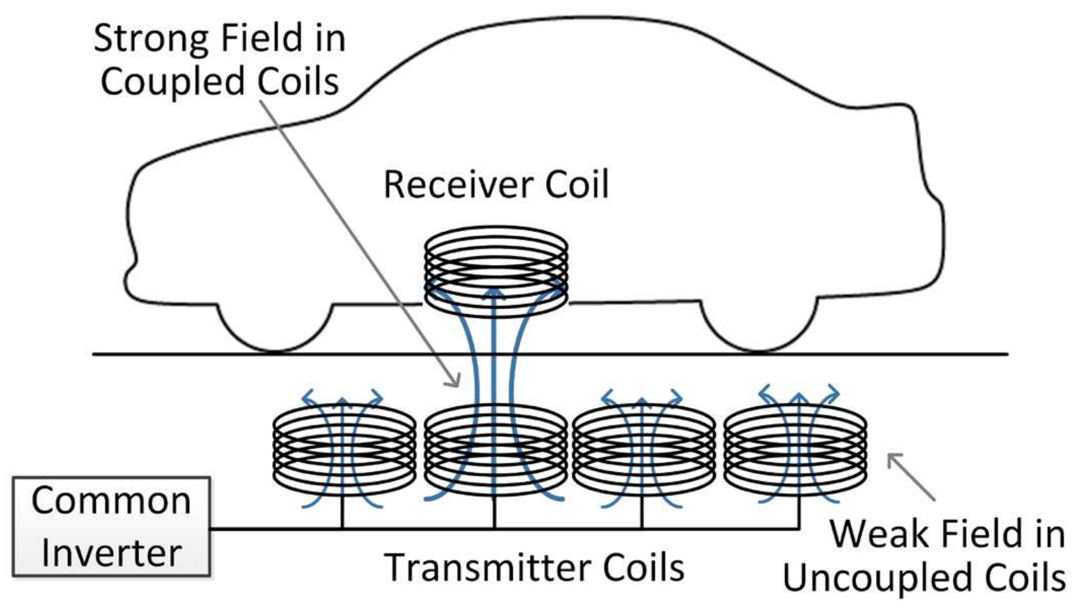


Figure 1: Reflexive field containment topology [1].

- In this approach, field containment performance is defined in terms of current gain G.

$$G = \frac{I_{t,coupled}}{I_{t,uncoupled}} = \frac{1}{Q \cdot n}$$

- Quality factor is denoted as Q, and n is the capacitor tapping coefficient:

$$n = 1 + \frac{C_2}{C_1} \qquad Q = \frac{R_{eq}}{\omega_0 L_2}$$

- Our new study introduces a saturable inductor L_{max} to maximize the difference between the coupled and uncoupled currents through the transmitter coil.

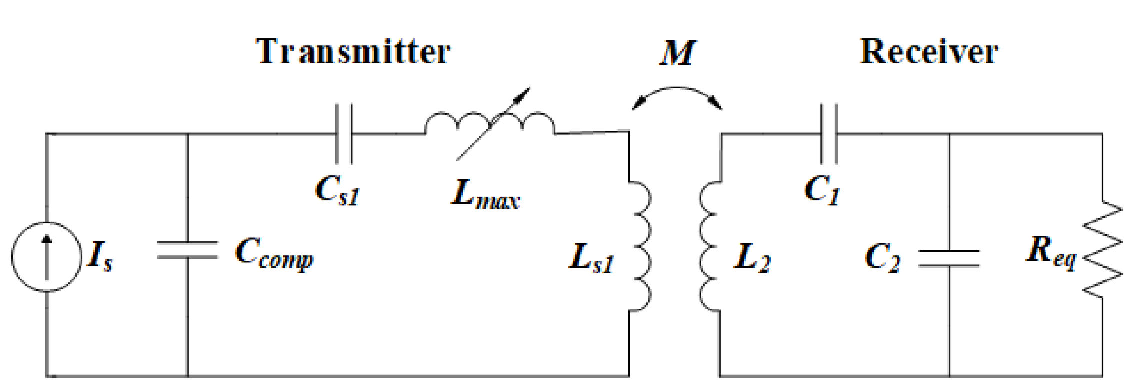


Figure 2: Single segment of proposed topology.

Method

- As the coils couple, the reflected impedance allows the current in the transmitter coil to increase and saturate $L_{max.}$ The inductance of the saturable inductor seen by the system is L_{eff} [2]:

$$L_{eff} = \frac{2L_{max}}{\pi}\left[\sin^{-1}\left(\frac{I_{sat}}{I_{peak}}\right) + \frac{I_{sat}}{I_{peak}}\sqrt{1-\left(\frac{I_{sat}}{I_{peak}}\right)^2}\right]$$

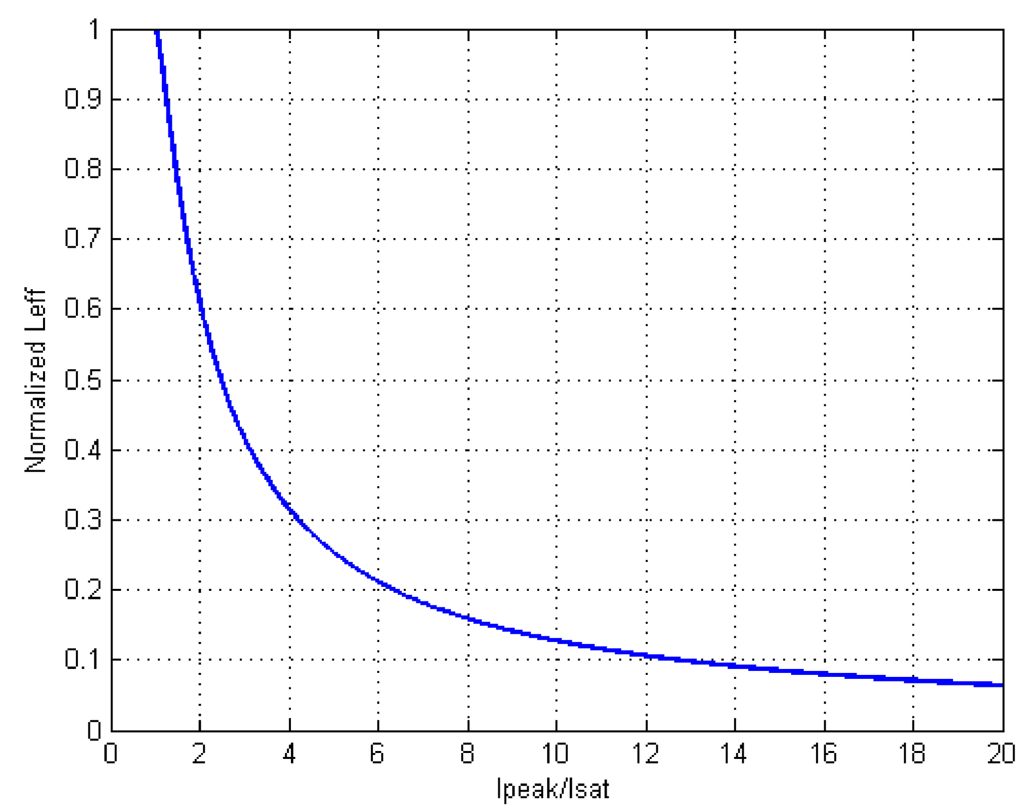


Figure 3: Normalized L_{eff} as a function of I_{peak} .

- With the inclusion of L_{max}, the new system current gain G_{total} is:

$$G_{Total} = G + G_{Sat} = \frac{I_{coupled}}{I_{uncoupled}} = \frac{1}{Q \cdot n} + \frac{\omega L_{max} - \omega L_{eff}}{\frac{\omega M^2}{L_2} Q \cdot n^2}$$

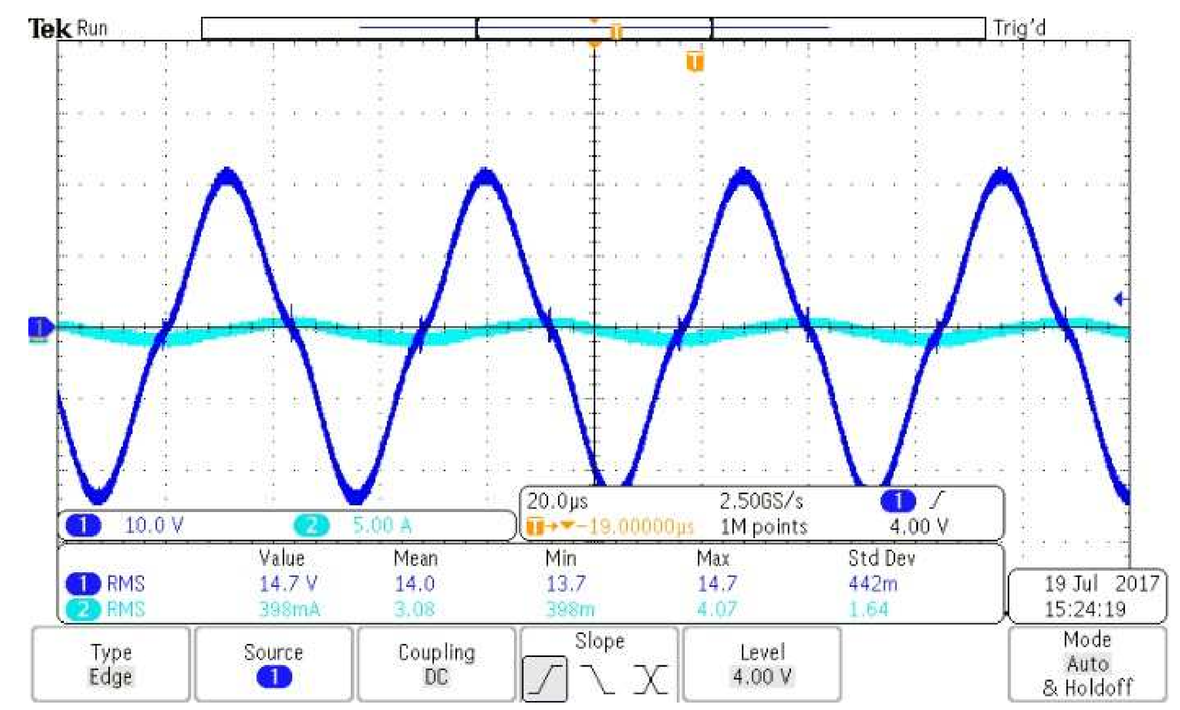
- G_{sat} may be designed for based on a chosen value of L_{max}:

$$G_{Sat} = \omega L_{max}\left(\frac{1 \pm \sqrt{1 - R_r \frac{16}{\pi \omega L_{max}}}}{2R_r}\right)$$

- At perfect coupling, the inductor is sufficiently saturated to minimize L_{eff}, allowing for power transfer at the designed system resonant frequency.

Results

- Experimental results demonstrated coupled and uncoupled currents of .398 A and 4.06 A respectively.
- The observed current gain G is thus approximately 10.2.



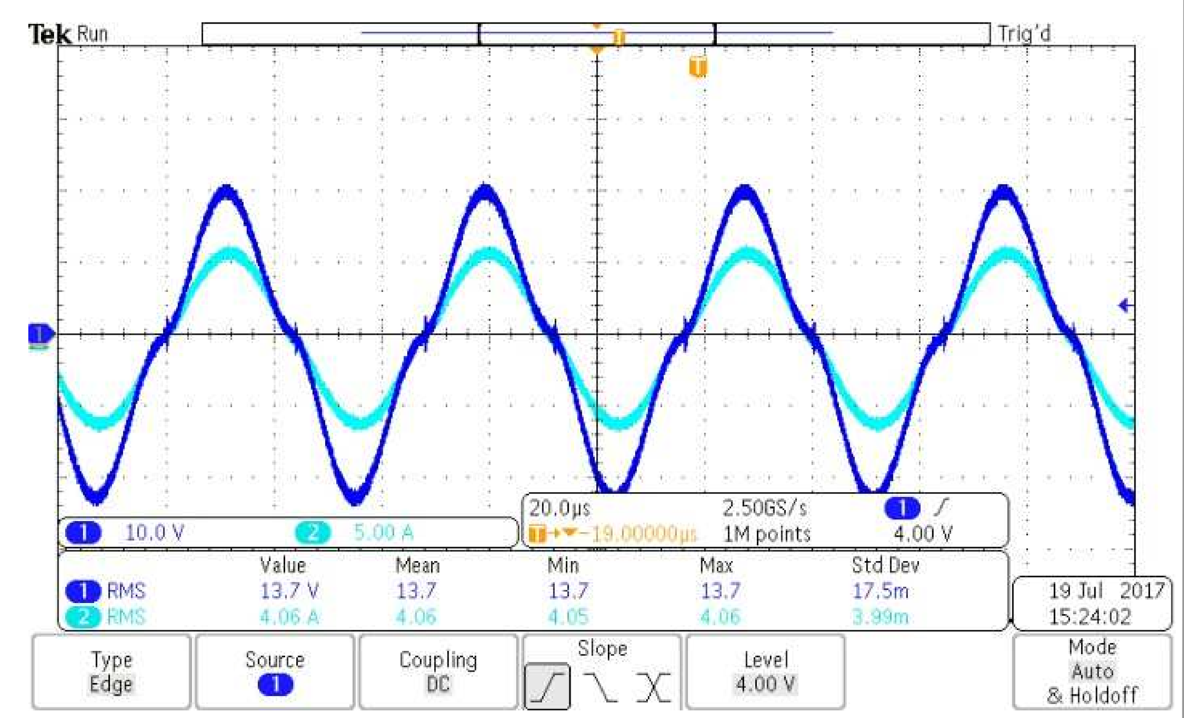


Figure 4: Uncoupled (top) and coupled (bottom) current through the transmitting coil and voltage across C_{comp}.

Segment	Component	Value
Transmitter System	L_s	191uH
	L_{sat} - L_{eff}	160uH - ~22uH
	C_{s1}	430nF
	C_{comp}	755nF
Receiver System	L_2	191uH
	C_1	330nF
	C_2	1616nF
	R_{Load}	1.1 Ω

Table I: Testbed system component values.

Testbed Details

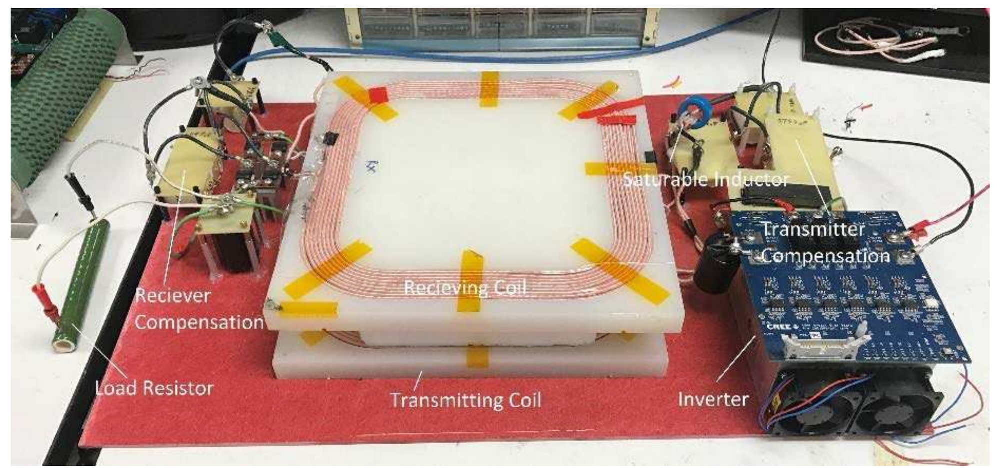


Figure 4: Testbed with SiC inverter and associated components.

- Using a full bridge SiC Inverter and bandpass filter, the topology shown in Fig. 2 was constructed.
- An EPOCS T38 core was used as the saturable inductor L_{max}.

Conclusion

- In comparison to the reference system [1], inclusion of $L_{max.}$ allows a high level of current gain and correspondingly reduces the induced electromagnetic field emissions.

References

[1] K. Lee, Z. Pantic and S. M. Lukic, "Reflexive Field Containment in Dynamic Inductive Power Transfer Systems," in IEEE Transactions on Power Electronics, vol. 29, no. 9, pp. 4592-4602, Sept. 2014.
[2] S. Chung, S. Huang, J. Huang, and E. Lee, "Applications of describing functions to estimate the performance of nonlinear inductance," IEE Proceedings-Science, Measurement and Technology, vol. 148, no. 3, pp. 108–114, 2001.

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