Industry Day Theme#1 {Clean Energy for Sustainable Economy and Environment}

IIT DELHI INDUSTRY DAY 2019

Coil Design of Wireless Power Transfer for Electric Vehicle Charging

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Abstract

- The wireless power transfer(WPT) enables safe, efficient, and cordless charging of electric vehicles. However, the main limiting factor is the design of magnetically coupled coils (power pads), used for efficient power transfer.
- These power pads should be able to transfer the power in the order of 2-5kW with a large air gap of approximately 150mm and tolerance to misalignment. Durability, low weight, and cost efficiency also need to be considered.
- 3-D finite-element analysis modeling is used to design and optimize power pads. This technique is viable since measured and simulated results differ by 10% at most.
- This work focus on design consideration for power pads. Critical design parameters were investigated to determine their influence on coupling and mutual inductance for the distance between the coils and misalignment.
- Besides, some critical issues of practical design problems in the coil topologies are compared. Finally, human exposure issues are mentioned.

Introduction

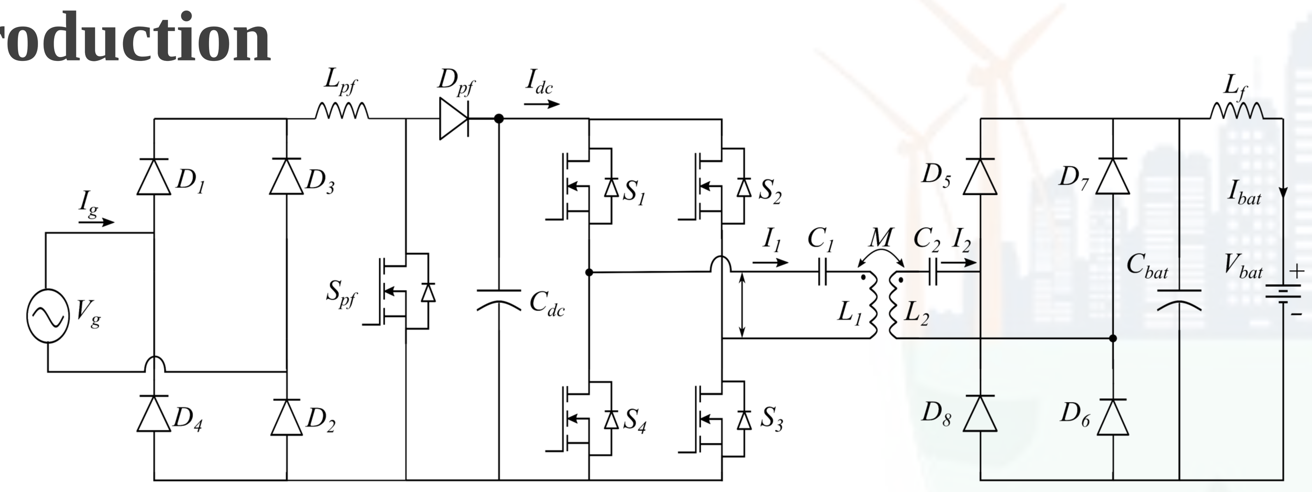


Fig.1 IPT circuit schematic for the experiments with full-bridge inverter and Boost PFC.

- The fundamental equations governing power transfer are given by

$$V_1 = j\omega M I_2 \quad \text{and} \quad V_2 = j\omega M I_1$$

- To boost power transfer capability, two types of compensation are used: Series compensation (voltage source characteristics), and Parallel compensation (current source characteristics).
- The level of the compensation is decided by the quality factor and it also decides the secondary inductance. Generally the secondary quality factor is in the range of 2 to 10.
- The primary and secondary resonance frequencies are given by

$$\omega_0 = \frac{1}{\sqrt{C_2 L_2}} = \frac{1}{\sqrt{C_2 L_2}}$$

- For equal number of primary and secondary turns $L_1 = L_2$.
- The primary capacitance is decided based on the type of compensation used. For series-series topology $C_1 = \frac{C_2 L_2}{L_1}$
- The reflected impedance from the secondary to primary can be found by

$$Z_r = \frac{\omega^2 M^2}{Z_2}$$ where Z_2 is the impedance of the secondary network.

- The power transferred from the primary to the secondary is given by

$$P = (Re\ Z_r) I_1^2$$

- At the resonance condition with unity power factor, the efficiency is

$$\eta = \left[\frac{(\omega_0 M)^2}{R_1[R_2 + R_{ac}] + (\omega_0 M)^2}\right]\left[\frac{R_{ac}}{R_2 + R_{ac}}\right]$$

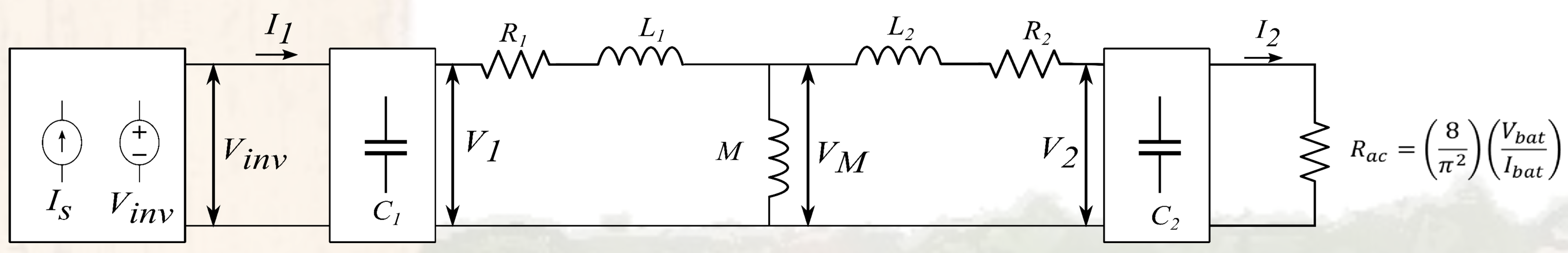
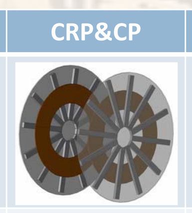
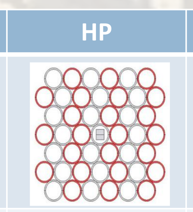
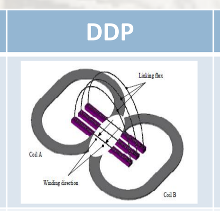
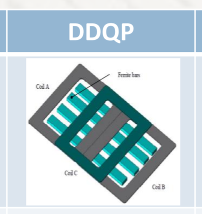
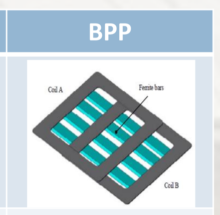
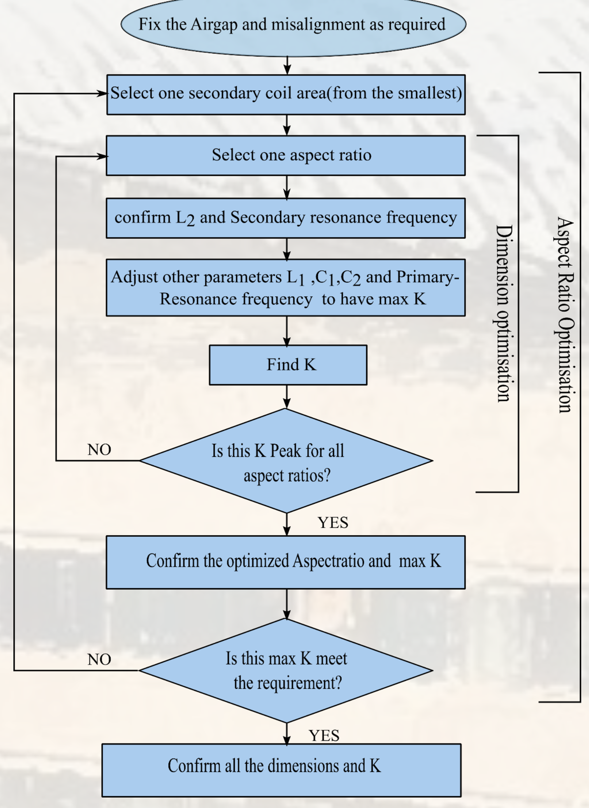


Fig.2 A general unified circuit diagram of an IPTS for all basic compensation schemes

Transmitter and Receiver Coil Design

	CRP&CP	HP	DDP	DDQP	BPP
					
Advantages	1. Low reluctance flux path. 2. Symmetric flux distribution around centre.	1. Average magnetic flux density 2. Increase Uniform flux distribution	1. Flux path narrow and taller 2. Transmitting distance extended with high efficiency	1. Generate both parallel and perpendicular magnetic fields	1. System complexity reduced 2. Cost reduced
Limitations	Flux Hight limited by pad size	High conduction loss and difficult to manufacture	Poor interoperability	Increased number of coils increase cost	-
Transferrable power	Medium	Low	High	High	High
Pad design size	Medium	Large	Small	Small	Small
Pad weight	Low	High	Low	Medium	Medium
System material cost	Low	High	Medium	High	Medium
Transmission distance	Low	Medium	Medium	High	High
Charging zone	Small	Large	Medium	Large	Large



Industrial Significance

- Roadways Electrical vehicle charging like buses, cars and e-scooters.. etc.
- Integrated wireless power for portable equipment like Phones, Laptops, and Hand tools

Technology Readiness Level:

FEM simulations for design of the transmitter and receiver coils are done and prototype development is in progress.

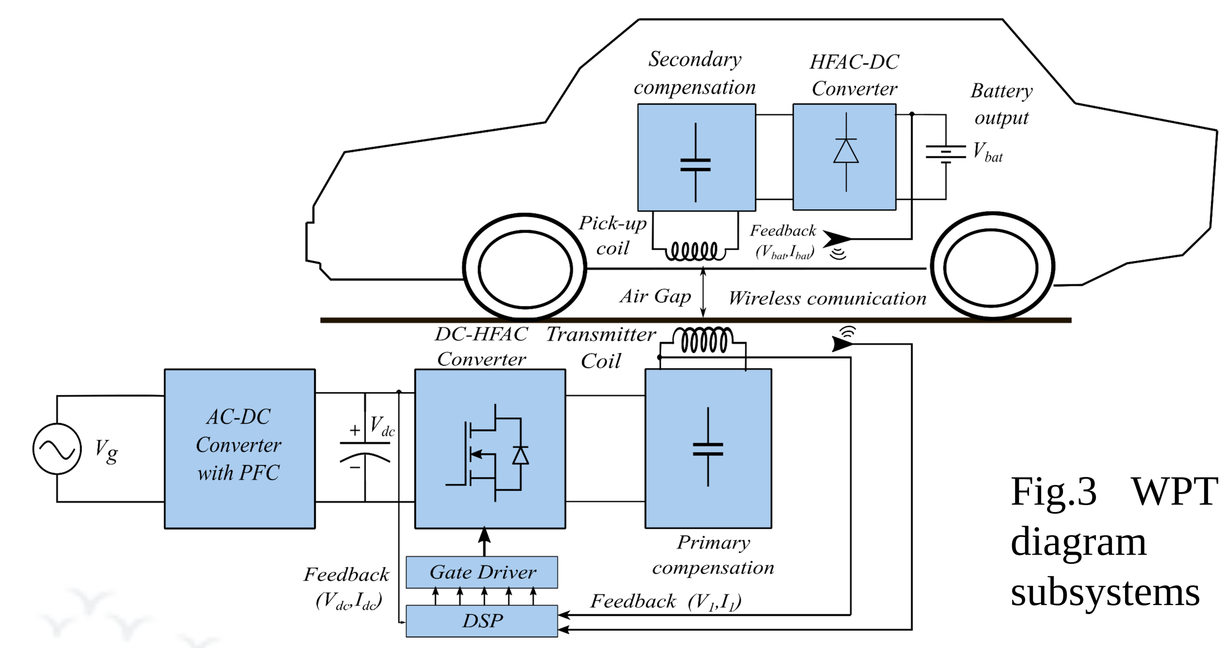


Fig.3 WPT System block diagram and major subsystems

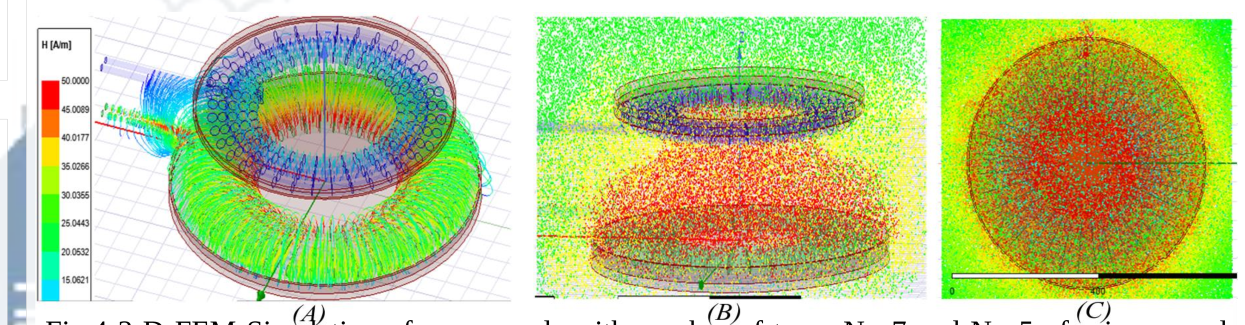


Fig.4 3-D FEM Simulation of power pads with number of turns N_1=7 and N_2=5 of primary and secondary respectively, and distance between pads 0f 150mm and with zero misalignment:(A) Stream line view of magnetic field strength in A/m (B) Lateral view of magnetic flux intensity (C)The crossectional view of the Transmitter power pad magnetic field strength.

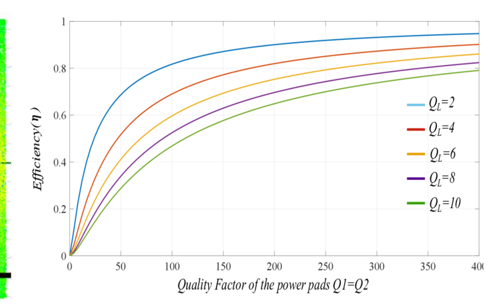


Fig.5 The power transfer efficiency of the power pads with respect to the Quality factors of the coils and the load.

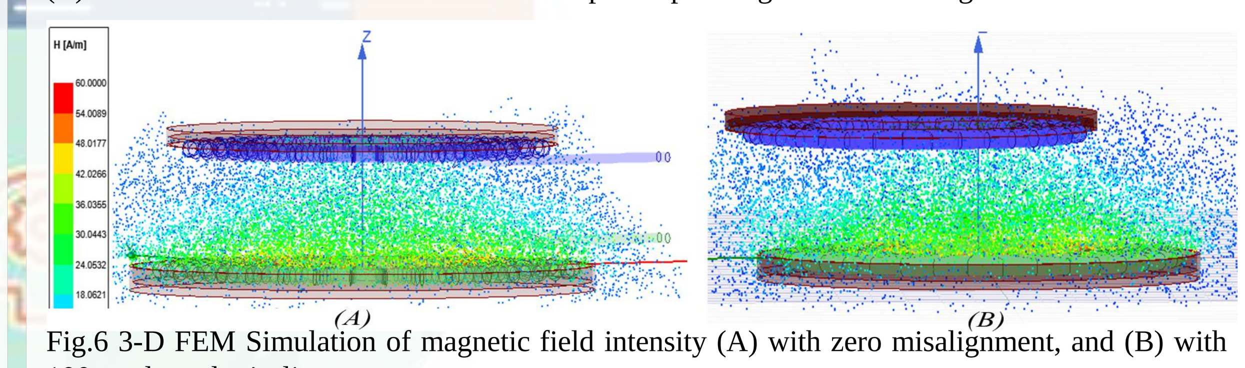


Fig.6 3-D FEM Simulation of magnetic field intensity (A) with zero misalignment, and (B) with 100mm lateral misalignment.

	L1 (μH)	L2 (μH)	M (μH)
Height=150mm, Zero misalignment	44.711	22.576	11.274
Height=150mm, misalignment= 100mm	44.608	22.407	8.8057

Challenges

- Switching frequency selection
- Coil design (coupling factor, size, tolerance, efficiency, EMF)
- Compensation circuit design (Gv, voltage/current ratings)
- Converter design (inverter, rectifier, regulator, ZVS, PF)
- Control of IPTS (short/open circuit, high voltage, protections)
- Communications between Tx and Rx
- Budgets (cost, mass, volume, power loss, reliability, etc.)

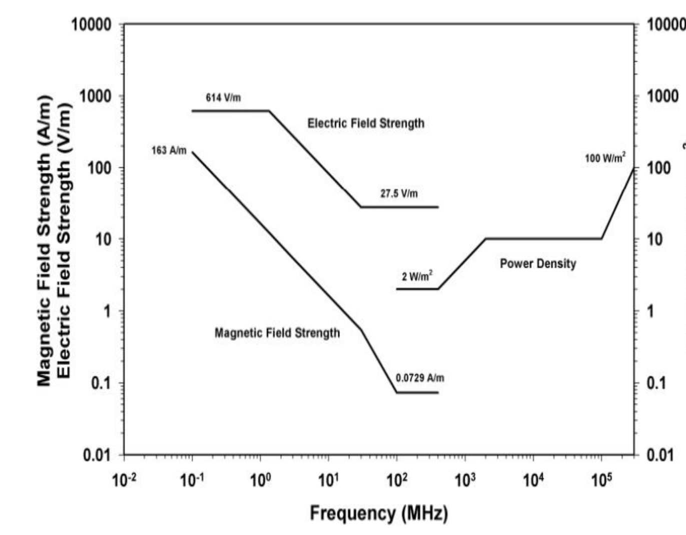


Fig. 7. IEEE reference levels for human exposure issues of EMF (Copyright IEEE) [9].

Conclusions

To make IPT systems are as efficient, cost-effective, and light as possible, the pad design should be optimized in such a way that there should utilize the minimum amount of ferrite to achieve the desired coupling between the power pads. In this work, A systematic power pad design procedure was discussed, and FEM simulation results were given for a particular power pad design with misalignment tolerance of 100mm and distance of 150mm between the pads. A generalized compensation network design was presented with relevant equations.

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