東京大学 工学系研究科 電気系工学専攻 古関研究室

非接触給電システムの電力伝送特性可視化と対称コイルを用いた異物検知

博士３年 武田 広大,修士２年 Han Xu ,教授 古関 隆章

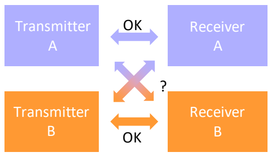
Visualizing power transmission characteristics of WPT

Interoperability of WPT for practical uses

SAE J2954: International standard of WPT for EV

・Ground and vehicle system might be different especially in public parking space

・The number of combination is large



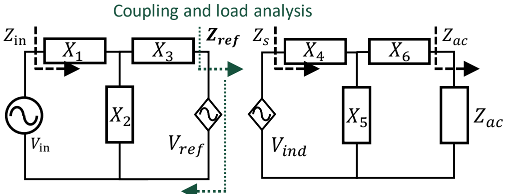
Constraints

Inverter voltage, Inverter current, Transmitter coil current, Phase between current and voltage of the inverter

Suitable analysis method is necessary

Divided analysis

Coupling and load analysis



Power analysis

Power analysis

Constraints consideration

Inverter voltage limit	Inverter current limit	Coil current limit	Phase
$P^V_{trans} = \frac{R_{in}}{R_{in}^2 + X_{in}^2}\lvert V_{in}\rvert^2$	$P^I_{trans} = R_{in}\lvert I_{in}\rvert^2$	$P^{limit}_{trans} = R_{ref}\lvert I_{L1_{max}}\rvert^2$	$\theta_1 = \tan\frac{X_{in}}{R_{in}}$

$$P^{max}_{trans} = \begin{cases} \min(P^V_{trans}, P^I_{trans}, P^{limit}_{trans}) & (\theta_l < \theta_1 < \theta_h) \\ 0 & (otherwise) \end{cases}$$

Coupling and load analysis

$$R_{dc} = \frac{V_b^2}{P_{out}} \Rightarrow Z_{ac} = Rect(R_{dc}) \Rightarrow Z_s = g(Z_{ac}) \Rightarrow Z_{ref} = \frac{(\omega L_m)^2}{Z_s}$$

Visualized power transmission characteristics

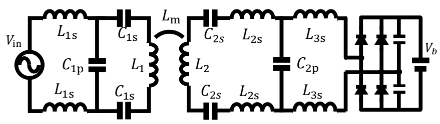
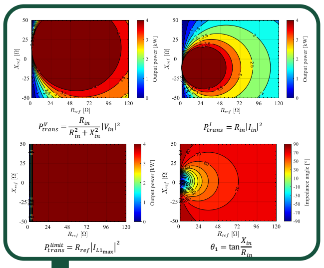


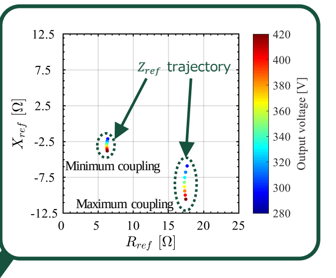
Table: Circuit parameters and constraints

V_{dc}	450 V	V_{max}	405 Vrms
I_{max}	30 Arms	$I_{L1_{max}}$	30 Arms
θ_l	0°	θ_h	90°
k_{min}	0.111	k_{max}	0.193
L_1	223.6 uH	L_2	233.8 uH
V_b	280 - 420 V	P_{out}	3 kW
f	81 - 90 kHz		

Power map



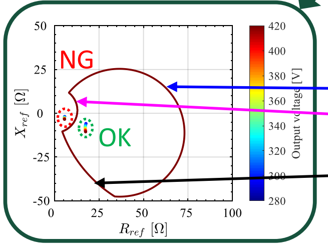
Reflected impedance trajectory

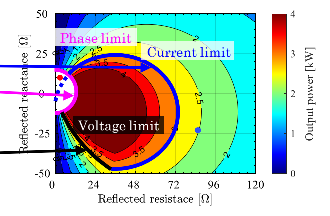


$P^{max}_{trans} = \begin{cases} \min(P^V_{trans}, P^I_{trans}, P^{limit}_{trans}) & (\theta_l < \theta_1 < \theta_h) \\ 0 & (otherwise) \end{cases}$

Extract 3kW contour line

Overlaid on the power map





Feasibility of power transmission under constraints can be guaranteed if the Z_{ref} trajectory is in the contour line, otherwise some of the constraints are violated.

Power transmission can be intuitively evaluated

Metal Object Detection in WPT

Metal Object Problem

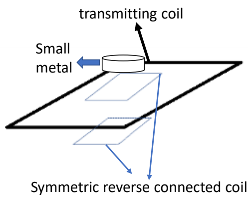
- Fire hazards caused by metal overheating
- Unnecessary energy loss

Previous Detection Method

- Active Detection Method : Camera radar, detection signal
  - ○ High Precision
  - ○ No Dead Zone
  - ○ Not affected by Coil Position
  - ✖ Expensive
- Passive Detection Method : Search Coil, Circuit Parameter
  - Search Coil:
    - ○ High Precision
    - ○ Cheap
    - ✖ Dead Zone
    - ✖ Affected by Coil Position
  - Circuit Parameter:
    - ○ No Dead Zone
    - ○ Cheap
    - ✖ Low Precision
    - ✖ Affected by Coil Position

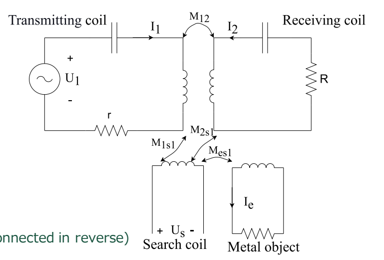
Proposal Method

- Symmetric coil with phase detection



- Advantage
  - ○ No Dead Zone
  - ○ Cheap
  - ○ High Precision
  - ○ Not affected by Coil Position

- Circuit Model



Voltage of search coil Ⅰ and search coil Ⅱ

$$U_{s1} = I_1\omega^2\frac{M_{12}M_{2s1}}{r+R} + j(I_e\omega M_{es1} + I_1\omega M_{1s1})$$

$$U_{s2} = I_1\omega^2\frac{M_{12}M_{2s2}}{r+R} + j(I_e\omega M_{es2} + I_1\omega M_{1s2})$$

Total Voltage function of search coil, and search coil Ⅱ (connected in reverse)

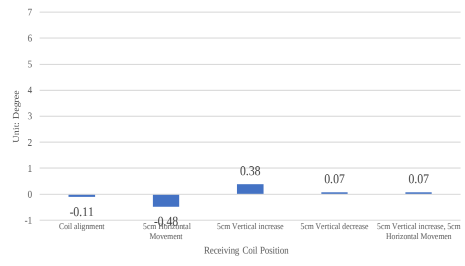
$$\Delta U_s = U_{s1} - U_{s2} = I_1\omega^2\frac{M_{12}}{r+R}(M_{2s1} - M_{2s2}) + jI_e\omega(M_{es1} - M_{es2})$$

Real part is only affected by the receiving coil.

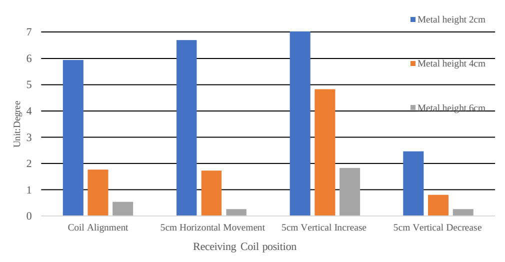
Imaginary part is only affected by the metal.

The phase of ΔU_s is only affected by the metal exists and will not be affected by the position of receiving coil

- Simulation



Without Metal



With Metal

The phase of symmetrical coil total voltage is not easily affected by coil position, but can be affected by metal exists or not. Until now, this method can detect coin size metal in WPT system.