2차원 무선전력전송 시스템의 상호 인덕턴스 각 추정

곽천치, 설원규, 정세교
경상대학교

Estimation of Mutual Inductance Angle for 2-D Wireless Power Transfer System

Tianqi Guo, Won Kyu Seol, Se Kyo Chung
Gyeongsang National University

ABSTRACT

In a two dimensional wireless power transfer system, the mutual inductance angle is the most important parameter for determining the power transmission efficiency. This paper presents a technique to estimate the mutual inductance angle from the voltage and current information of the transmitting (Tx) coils. The equation to estimate the mutual inductance angle is derived, and the validity of the proposed method is verified through simulation and experiment.

1. Introduction

An inductive coupled wireless power transfer (WPT) system has been used for charging mobile devices. Existing WPT systems have a disadvantage that power transmission efficiency drops depending on the face angle, distance, and alignment of the transmitting (Tx) and receiving (Rx) coils. In order to overcome this disadvantage, various researches on multi dimensional WPT system have been made [1] [2]. In the previous works, it is known that the mutual inductance angle is the most important parameter to achieve the maximum power transmission efficiency. This paper describes the structure of the two dimensional (2 D) WPT system, and the estimation of the mutual inductance angle is proposed. The simulation and experimental results are provided to show the feasibility of the proposed method

2. 2-D WPT System

2.1 Modeling of 2-D WPT system

Fig. 1 shows the structure of the 2 D WPT system considered in this paper. The system consists of two orthogonal circular Tx coils and one Rx coil. The physical, mutual inductance angles and current vector can be defined as shown in Fig.2.

Fig. 3 shows the equivalent circuit of the 2 D WPT system. The voltage and current equations of this equivalent circuit can be represented as

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \begin{bmatrix} R+jX & 0 \\ 0 & R+jX \end{bmatrix} \begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} + j\omega \begin{bmatrix} M_{\alpha r} \\ M_{\beta r} \end{bmatrix} I_r \qquad (1)$$

where the parameters of the Tx circuits are the same and the reactance X can be defined as $X=\omega L-1/\omega C$. The mutual inductances between the Tx and Rx coils are given as $M_{\alpha r}$ and $M_{\beta r}$. The mutual inductance $M_{\alpha\beta}=0$ because two Tx coils are orthogonal.

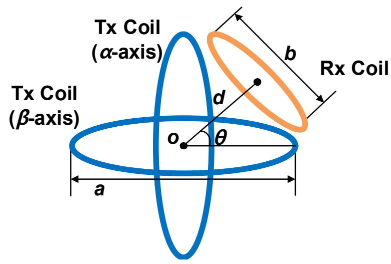

Fig. 1 Structure of Tx and Rx coils

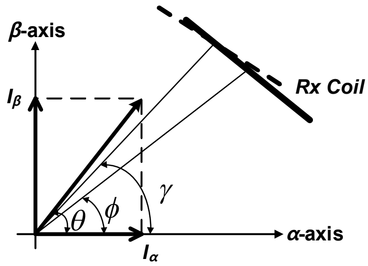

Fig. 2 Definitions of the angles θ, ϕ and γ.

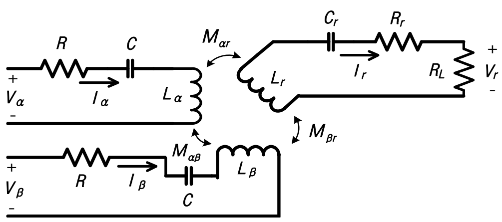

Fig. 3 Equivalent circuit of Tx and Rx coils

If the input currents are given as $I_\alpha = I\cos\theta\cos\omega t$ and $I_\beta = I\sin\theta\cos\omega t$, the power transmission efficiency can be calculated as [1]

$$\eta=\frac{P_{out}}{P_\alpha+P_\beta+P_r+P_{out}}=\frac{1}{1+\frac{R_r}{R_L}+\frac{R}{R_L}\frac{1}{kcos^2(\theta-\gamma)}} \quad (2)$$

where $k=\frac{\omega^2(M_{\alpha r}^2+M_{\beta r}^2)}{(R_r+R_L)^2+X_r^2}$, $\gamma=\tan^{-1}\left(\frac{M_{\beta r}}{M_{\alpha r}}\right)$

It is noted in (2) that the efficiency is maximum at $\theta=\gamma$ and depends on the mutual inductance angle γ between the Tx and Rx coils.

2.2 Estimation of mutual inductance angle

The ratio of the mutual inductances in the α and β axes can be represented using (1) as

$$\frac{M_{\beta r}}{M_{\alpha r}}=\frac{V_\beta-I_\beta(R+jX)}{V_\alpha-I_\alpha(R+jX)} \quad (3)$$

Since $X=0$ at the frequency $\omega=\omega_r=1/\sqrt{LC}$, the angle γ can be estimated at this frequency as

$$\gamma=\tan^{-1}\left(\frac{M_{\beta r}}{M_{\alpha r}}\right)=\tan^{-1}\left(\frac{V_\beta-I_\beta R}{V_\alpha-I_\alpha R}\right) \text{ for } \omega=\omega_r \quad (4)$$

Thus, the angle γ can be obtained from the voltages and currents of Tx coils.

3. Simulation and Experiment

The simulation is performed to verify a method for estimating mutual inductance angle γ. Table 1 shows the parameters of simulation and experimental 2 D WPT system. Table 2 shows the mutual inductance values ($M_{\alpha r}$) between the Tx (α axis) and Rx coils and the calculated mutual inductance angles for the different angles and distances. The mutual inductances of the Tx (β axis) and the Rx coils are assumed in reverse order.

Table 1 Parameters of experimental system

R [Ω]	0.1005	R_r [Ω]	0.035
C [nF]	10	C_r [nF]	31
L [μH]	9.341	L_r [μH]	2.98
R_L [Ω]	10	f [kHz]	520

Table 2 Measured mutual inductance and its angle

ϕ[°]	$M_{\alpha r}$[μH]		γ[°]	
	d=0cm	d=2cm	d=0cm	d=2cm
0	1.4426	1.1805	2.1	2.09
15	1.3230	1.1011	16.19	22.37
30	1.2140	1.0364	31.6	33.58
45	1.0454	0.9199	45	45
60	0.7473	0.6817	58.38	56.41
75	0.3841	0.4533	73.8	67.62
90	0.0529	0.0432	87.89	87.9

Figs. 4 and 5 show the simulation results for the mutual inductance estimator. The current of the Tx coils, demodulated currents, and estimated and real γ are shown, respectively, from the top. It is known that the estimator is well operated.

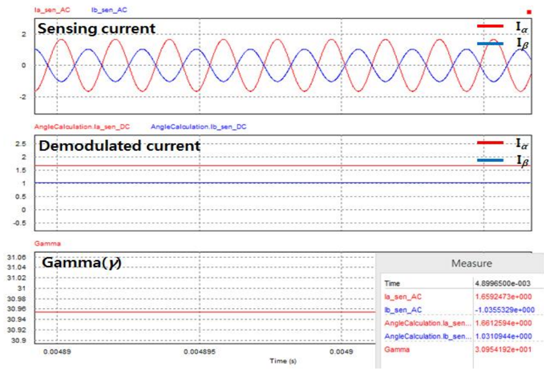

Fig. 4 Simulation results ($\gamma=30.95$°, d = 0cm)

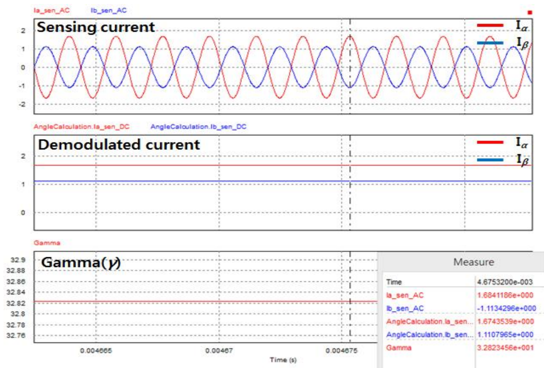

Fig. 5 Simulation results ($\gamma=32.82$°, d = 2cm)

4. Conclusion

The estimation of the mutual inductance angle of the 2 D WPT system was presented. A method using the current and voltages of the TX coils is proposed for maximum power transfer efficiency. The simulation and experimental and experimental results were provided to verify the proposed method.

이 논문은 교육부와 한국연구재단의 기초연구과제 (NRF 2015R1D1A1A01059616) 지원으로 연구되었슴

References

[1] Wai Man Ng, Cheng Zhang, Deyan Lin, S. Y. Ron Hui.: 'Two and Three Dimensional Omnidirectional Wireless Power Transfer', IEEE Transactions on Power Electronics vol. 29, pp. 4470 4474, 2014.

[2] Pengpeng Sun, Yunwei Dong, Hong Ye, Hongbin Zhao.: 'A Wireless Power Transfer CPS Based on 2D omni directional Rotating Magnetic Field', 2016 IEEE International conference on Software Quality, Reliability and Security Companion(QRS C), pp. 252 258, 2016