Constant Power Control on the Primary Side with Robustness Against Coupling and Load Fluctuations for Wireless Power Transfer of AGVs

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Abstract – AGVs (Automated Guided Vehicles) require frequent charging for continuous operation. Wireless power transfer (WPT) is gaining attention to fully automate this process. However, variation in coupling coefficients due to AGV positional errors and load fluctuations caused by battery voltage changes hinder a stable power supply in a WPT system without wireless communication between the primary and the secondary side. This study aims to investigate a system that is robust against these variations and enables a constant power supply to the AGV through control solely on the primary side. The simulation results confirmed that constant power transmission is achievable with a maximum power transmission error of 7.2%.

Keywords power control, disturbance observer, coupling coefficient, load fluctuation

I. Introduction

In recent years, the use of automated guided vehicles (AGVs) has been growing. A frequent battery charging of AGVs is required for the continuous operation of AGVs. Wireless Power Transfer (WPT) is gaining attention as a way to automate this charging process. However, fluctuations in the coupling coefficient caused by misalignment between the transmitting and receiving coils, as well as load variations due to changes in battery voltage, hinder a stable power supply.

In conventional WPT for AGVs, wireless communication between the AGV and the transmitting side controller was necessary for charging power control. This presented problems such as an increase in the number of components and system complexity. Since the simplification of the power receiving equipment is required for AGVs, a power control method that operates solely from the transmitter side without wireless communication is desired.

Furthermore, “Transmitting-side current envelope control using the disturbance observer” has been proposed as a power transfer control method with robustness against coupling coefficient variations [1]. In this technique, the voltage error caused by the time variation of the coupling coefficient is treated as a disturbance, which is then estimated and compensated for using a disturbance observer (DOB). However, this method cannot achieve the constant power transfer required by the AGV, nor does it take into account load variations.

Therefore, this study presents a power regulation strategy exhibiting robustness to variation in both the coupling coefficient and load conditions. The proposed approach extends conventional current control at the transmission side by integrating a power management mechanism. Simulation results substantiate that the approach maintains consistent power transfer despite concurrent fluctuations in load and coupling parameters.

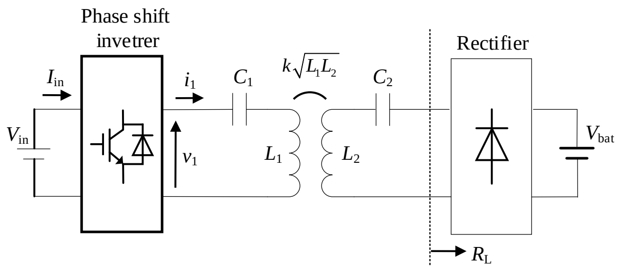

Fig. 1. Circuit configuration of an AGV-oriented WPT system.

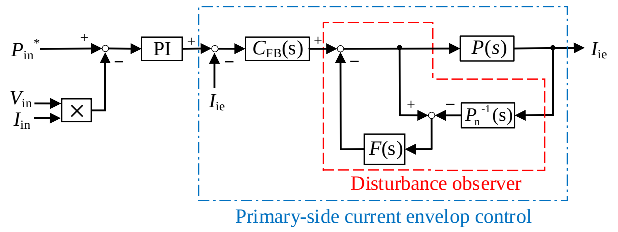

Fig. 2. Control block diagram of the proposed system.

II. Proposed control system

Fig. 1 shows the circuit configuration of an AGV-oriented WPT system employing an S-S resonant compensation circuit. The self-inductances and resonant capacitors of the respective coils are L_1, L_2 and C_1, C_2, respectively. The equivalent resistance after the rectifier is R_L, the coupling coefficient is k, and the resonant frequency is ω_o. Under these conditions, the envelope transfer function $P(s)$ from the transmitting-side voltage v_1 to the transmitting-side current i_1 is expressed by Equation (1).

$$P(s) = \frac{2L_2 s + R_L}{4L_1L_2 s^2 + 2L_1R_L s + L_1L_2\omega_o^2 k^2} \quad \cdots\cdots (1)$$

In this model, two parameters fluctuate in the AGV used for dynamic WPT: the load resistance R_L and the coupling coefficient k.

Fig. 2 shows the control block diagram for the proposed transmitting-side power control, where $P_n^{-1}(s)$ is the nominal inverse model of the plant, $F(s)$ is the first-order low-pass filter, and $C_{FB}(s)$ is the controller for the current control system. The configuration involves transmitter-side current envelope control using a DOB, with the addition of a power control mechanism.

The power at the input stage of the inverter is detected, and a PI controller is used to generate the reference value for the peak current on the transmitting side.

III. Simulation Results

A simulation was performed under conditions where both the coupling coefficient and the load were varied. Table 1 shows the simulation parameters. For simplification, the Equivalent Series Resistance (ESR) of the coils was ignored. To focus primarily on compensation through DOB, the observer's operating frequency was set to be the fastest within the control system. The controller for the current control system was designed using the pole placement method, and the controller for the power control system was designed to be sufficiently slower than the bandwidth of the current control system.

Fig. 3 shows the changes in the coupling coefficient and load applied during the simulation. Both parameters are varied continuously over time, with a maximum fluctuation of 50% from their nominal values. The coupling coefficient is varied in a Gaussian-distribution to simulate an AGV passing over the coil at a constant velocity.

Fig. 4 shows the response of the Reference value P_{in}^* and the average secondary power. The blue line represents the power response when both the coupling coefficient and the load are varied simultaneously. The red line represents the power response when only the coupling coefficient is varied. The green line represents the power response when only the load is varied.

The simulation outcomes corroborate that the secondary power system effectively tracks the specified command signal across a load resistance variation range of ±50% relative to its nominal value, thereby maintaining stable power delivery. Conversely, the received power remains relatively constant when the coupling coefficient is held at a fixed deviation from its nominal value; however, considerable temporal fluctuations in the coupling coefficient can induce a power transmission error reaching up to 7.2%.

Therefore, it is confirmed that the proposed control method enables constant power transfer under both load and coupling coefficient variations, except in cases where the coupling coefficient experiences large, transient fluctuations.

Table 1. Specifications of the proposed system.

Parameter	***Symbol***	***Value***
Input Voltage	V_{in}	200V
Resonant frecuency	f_o	85kHz
Self Inductance	L_1, L_2	189.7μH
Resonance Compensation Capacitor	C_1, C_2	18.5nF
Nominal value of coupling coefficient	k_n	0.16
Nominal value of road	R_{Ln}	16.2 Ω
LPF cutoff frecuency		10000rad/s

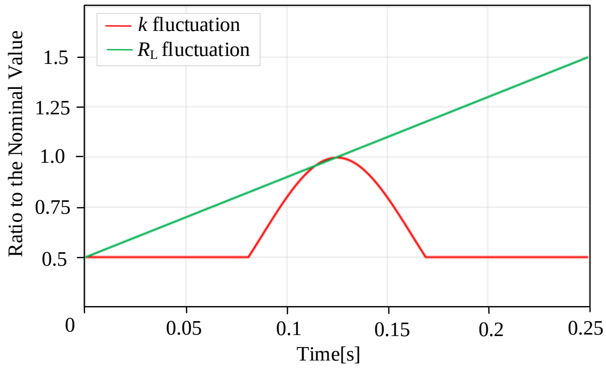

Fig. 3. Coupling and load variation.

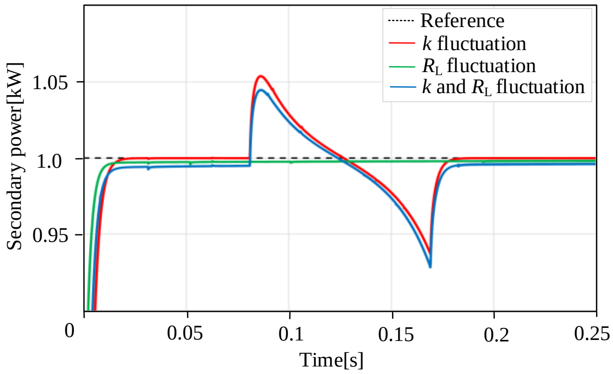

Fig. 4. Secondary average power response.

V. Conclusion

In this study, a constant power control strategy robust to coupling and load fluctuations was proposed and simulated for AGV-oriented WPT. The simulation results confirmed that constant power transfer is achievable with a maximum power transmission error of 7.2%. For future work, we will focus on independently estimating both coupling and load fluctuations and developing a method to reduce the power transmission error observed during coupling variations.

References

[1] Yuki Ochiai, Keisuke Kusaka : “Wireless power transfer while driving with a disturbance observer using a current envelop model robust to coupling coefficients”, Joint Technical Meeting on “Semiconductor Power Converter” and “Motor Drive”, IEE Japan, Vol.2, NO.SPC-25-020, pp7-11, Jan 2025