Experimental Evaluation of Inductive Power Transfer System Using Multiple Concatenated Parallel-Line-Feeder Segments

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***Abstract* - It has been known that the dimensions of the primary coil of an inductive power transfer (IPT) system need to be smaller than approximately one-tenth of a wavelength to avoid impact of standing wave. Recently, an IPT system of concatenated parallel-line-feeder segments has been proposed to overcome this limitation. Numerical analysis in literatures has showed that the system is capable of providing a stable output profile regardless of the length of the primary coil. In this paper, the stability of output power of the system is verified via experiment systems at 13.56MHz.**

***Index Terms* — inductive power transfer, dynamic charging, HF, parallel line feeder, standing wave, resonance.**

1. Introduction

Inductive power transfer (IPT) is a promising technology for dynamic charging of future electric vehicles (EVs) [1]. Inductive coupling between a primary coil − buried under the roadway − and a secondary coil − mounted on the EV − allows wireless charging for the EV while it is on the move. The primary coil can be either a sequence of small circular coils as in [2] or one elongated coil as in [3]-[4]. In this paper, we focus on dynamic charging system using one elongated primary coil because of their simple structure.

Many dynamic charging systems, e.g., system in [2]-[4], limited the operating frequency, typically below or within the low frequency range. The purpose is to avoid the impact of the standing wave because it influences the system performance if the length of the primary coil is longer than approximately one-tenth of the wavelength. Recently, authors in [5] have proposed an elongated parallel line feeder (PLF) driven by an HF band (3-30MHz) power supply to exploit high resonance coupling for system simplification and misalignment tolerance. In order to avoid the impact of the standing wave, the length of primary coil of this system is, at most, 10 m, which is not sufficient for practical applications of dynamic charging.

Therefore, [6] has proposed using multiple short-length PLF segments. The segments are compensated by resonant capacitors and concatenated to each other to form an elongated primary coil. In [6], performance evaluation is carried out via computer simulation, meaning that experiments need to be conducted to rigorously confirm the effectiveness of the proposed scheme.

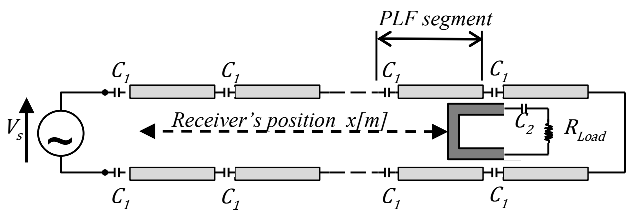

Fig. 1: Configuration of IPT using concatenated PLF segments.

In this paper, we carry out experiments to evaluate the output power of the dynamic charging system proposed in [6]. Our experimental results agree with the simulation results in verifying the stability of the output power of the system.

2. System model

Fig. 1 presents the dynamic charging using multiple concatenated PLF segments. A sinusoidal HF generator with voltage amplitude V_S, internal impedance R_S and operating frequency f is used as the power source. The feeder consists of multiple PLF segments of length l. The length l is chosen to be shorter than approximately one-tenth of a wavelength to avoid the impact of the standing wave within one PLF segment. Each segment is compensated by resonant capacitors C_1 and concatenated to each other. As the feeder is terminated in a short-circuit, the last segment becomes a short-circuit itself and acts as an inductor with inductance denoted L_1 and is series tuned with two capacitors C_1 following the condition below

$$C_1 = \frac{2}{2\pi f L_1}. \qquad (1)$$

Consequently, the two-wire line of the previous segment functions also an inductor with inductance denoted L_1, which is then compensated by two capacitances C_1 according to (1). Therefore, all PLF segments resonate at the operating frequency f. There is a phase shift in the magnetic field at the two ends of each segment. The resonant capacitors is determined to recover these phase shifts, thus the magnetic field generated by the whole primary coil is almost uniform.

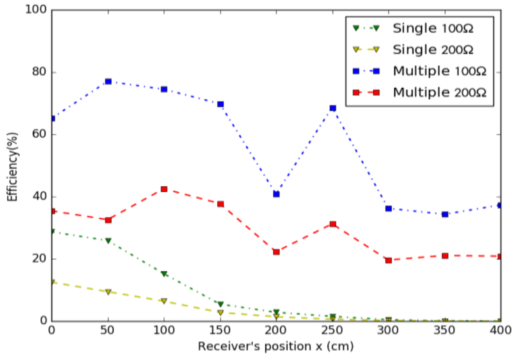

Fig. 2. Power transfer efficiency for single and multiple concatenated segments PLF system.

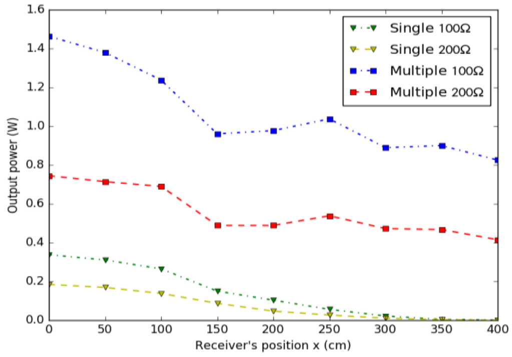

Fig. 3. Output power profile for single and multiple concatenated segments PLF system.

TABLE I
Experiment parameters

Operating frequency f	13.56 MHz
Load impedance R_{load}	100, 200 Ω
Feeding area length	λ/4 = 4 m
Air gap	2 mm
Tuning capacitor for C_2	1000 pF

Moving on top and along the longitudinal direction of the primary coil, a receiver with resistive load R_{load} uses a secondary coil to inductively gain power. The inductance of the secondary coil is denoted by L_2, which is series tuned with capacitance C_2 following the condition below

$$C_2 = \frac{1}{2\pi f L_2} \quad (2)$$

.

3. Experiments

(1) Configuration

Experiments have been conducted in order to compare the performances of single and multiple segments PLF systems on a quarter wavelength feeding line. The feeders were powered by HF sinusoidal generators at the frequency f of 13.56 MHz (ISM band), which has a wavelength in vacuum of 22.1 m. However, in the experimental system, a wavelength λ = 16 m was observed. Thus, the feeding area length is set to a quarter-wavelength, which is sufficiently long to evaluate the system performance under the impact of standing wave. The output power consumed by R_{load} is measured for every 50 cm of the feeding line and use to compute the power transfer efficiency (PTE) of the systems.

(2) Results

Fig. 2 and Fig. 3 show respectively the power transfer efficiency and the received power profile for different values of R_{load} in single and multiple segments PLF systems. As we can notice in Fig 2 and Fig. 3, in the case of single segment PLF system, the output power as well as the PTE drops drastically from a peak value (x=0m) to an extremely low (almost 0) value at the end of the line (x=4m). This is due to the standing wave appearing in the magnetic field. However, in the case of multiple segments, the output power and the PTE have much greater and a quite stable profile. That demonstrates the better performance of the multiple segments PLF for mitigating the impact of standing wave.

4. Conclusion

In this paper, we evaluated the performance of a dynamic charging system using multiple concatenated PLF segments to mitigate the impact of the standing wave. Experiments confirmed that the use of multiple adequately tuned concatenated PLF by creating a more evenly distributed magnetic field displays a stable output power as well as a higher power transfer efficiency along the feeding line and is therefore more suitable for dynamic charging applications.

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