Wireless Power Transfer System for Utility Frequency Output with Non-Linear Load Compatibility

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This paper proposes a wireless power transfer (WPT) system suitable for utility-frequency output. Conventional a WPT systems with AC-DC-AC conversion have required large electrolytic capacitors for DC conversion. Since DC conversion is unnecessary in the proposed system, smaller film capacitors can substitute for the large DC-link capacitors. Therefore, the proposed system holds the potential for reducing circuit volume and extending its lifetime. Additionally, to address the issue of non-linear loads generating unacceptable harmonic currents in the system, an active power filter is applied. This enables harmonic current suppression, and the total harmonic distortion on the output current is improved from 16.9% to 5.28%.

Keywords Wireless power transfer system, High-frequency injection, Single-phase active power filter

1. Introduction

The use of mobile devices with built-in batteries, such as smartphones and laptops, has been on the rise. In recent years, there has been an increasing interest in WPT, and research as one of the charging methods for these batteries [1-3]. However, previously reported systems have been individually designed based on the battery voltage requirements of specific applications, and they all produced DC output [4-5]. Consequently, applying the WPT system to existing systems with AC input was not possible. In order to apply WPT to existing systems, utility frequency output is necessary [6-7].

In this paper, a WPT system optimized for utility frequency output is proposed. In the proposed system, the large-capacity electrolytic capacitor used in converting low-frequency AC to high-frequency AC can be replaced with a small-capacity film capacitor. As a result, the entire circuit can be downsized and an extension of operational lifetime. Additionally, a compensating circuit is applied to mitigate the introduction of unacceptable current harmonics into the system when high crest factor loads are connected. Finally, through simulation, the feasibility of the proposed system for power transmission and the ability to generate sine waves at utility frequency are verified, and its practical implementation is considered.

2. Proposed a WPT system

Fig. 1 illustrates the system configuration of the proposed WPT topology. In a conventional a WPT system with AC-AC conversion, it is necessary to convert low-frequency AC to DC in order to transform high-frequency AC. Large electrolytic capacitors are employed for DC smoothing, leading to the potential for overall circuit enlargement and reduced lifetime. In the proposed system, the full-wave rectified sinusoidal waveform generated by the primary-side diode rectifier is supplied to the primary-side inverter. This allows the DC link capacitor to be replaced with a small film capacitor. High high-frequency components are injected by switching the inverter at the resonant frequency of the transmission coil and the resonant capacitor of the power transmission unit. A diode rectifier and LC filter are used to regenerate the full-wave rectified sinusoidal waveform on the secondary side. Here, DC smoothing is also not performed, making it possible to replace the DC link capacitor with a small capacitor, similar to the primary side. Finally, the secondary-side inverter operates as an unfolder to restore the system output to a utility frequency sine wave.

Additionally, a compensation circuit is connected to prevent unacceptable harmonics from flowing into the system when a non-linear load with a high crest factor is connected to the proposed system. In this paper, an active power filter (APF) is utilized as the compensating circuit to suppress current harmonics.

Fig. 2 presents a block diagram for the generation of the control signals for the APF [8]. To establish the single-phase load current in the $\alpha\beta$ coordinate system, shift the phase by $\pi/2$ as follow

$$\begin{bmatrix} i_{l\alpha} \\ i_{l\beta} \end{bmatrix} = \begin{bmatrix} i_l(\omega t + \phi) \\ i_l(\omega t + \phi + \pi/2) \end{bmatrix}. \quad (1)$$

Using a transformation matrix, the dq coordinate system of the single-phase load current can be determined as follows

$$\begin{bmatrix} i_{ld} \\ i_{lq} \end{bmatrix} = \begin{bmatrix} \sin(\omega t) & -\cos(\omega t) \\ \cos(\omega t) & \sin(\omega t) \end{bmatrix} \cdot \begin{bmatrix} i_{l\alpha} \\ i_{l\beta} \end{bmatrix} = \begin{bmatrix} i_{l\alpha}\sin(\omega t) - i_{l\beta}\cos(\omega t) \\ i_{l\alpha}\cos(\omega t) + i_{l\beta}\sin(\omega t) \end{bmatrix}. \quad (2)$$

The calculated d-axis current combined both fundamental and harmonic components. To extract only the fundamental component

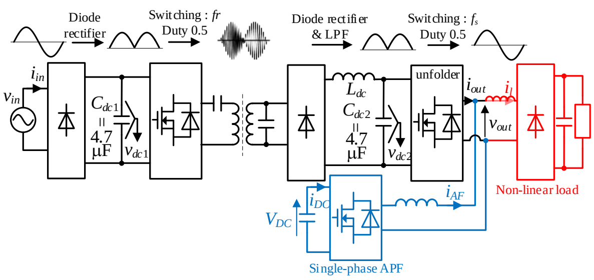

Fig. 1. Proposed system configuration with APF applied as a circuit for compensation.

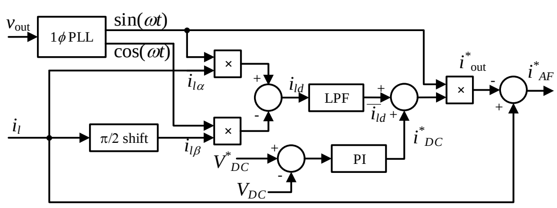

Fig. 2. Generation of reference current for APF.

using a LPF and add the current command i_{DC} to maintain the direct bus voltage of the APF. The calculated signal is then inverse dq-transformed, and the compensation current command is generated by calculating the difference with the load current as follows

$$i_{AF}^{*} = i_l - (i_{ld-DC} - i_{DC})\sin(\omega t) \ , \tag{3}$$

where $i_{ld\text{-}dc}$ is the fundamental component of the load current.

Note that PR controllers are employed to compensate for the AC current distortion.

3. Simulation results

Fig. 3(a) illustrates the voltage across the capacitors on the primary and secondary sides of the system, as well as the input and output current of the system when non-linear loading is connected. Fig. 3(a) illustrates the transmission voltages on the primary and secondary sides. For the load in this system, a capacitor-input diode rectifier with a crest factor of 1.97 is connected. At this point, the compensation circuit is not in operation.

From these results, it is confirmed that power transmission can be achieve using the high-frequency injection method even when non-linear loading is connected. Furthermore, the total harmonic distortion (THD) of the output current at this time is 16.9%.

Fig. 4(a) illustrates the voltage and current waveforms when the compensation circuit is activated, while (b) shows the transmission voltage. From these results, it is observed that the presence of harmonics on the output current is significantly reduced compared to Fig. 3. Consequently, it is confirmed that the compensator effectively mitigates the harmonic currents, which are generated when non-linear loads are connected, resulting in a system output current resembling a utility frequency sine wave.

Fig. 5 illustrates the THD analysis results for system input current. These results indicate that the 3rd harmonic, which is at 16.6% before compensation, has been reduced to 4.72% by the APF. As a result, THD has been reduced from 16.9% to 5.28%.

4. Conclusion

In this paper, a WPT system suitable for integration into existing systems is proposed. This system conducts power transfer by injecting high-frequency without the need for DC smoothing. As a result, the feasibility of power transmission was confirmed by replacing the required large-capacity electrolytic capacitors for DC smoothing with small film capacitors. Additionally, the operation of the system when the APF is used as a compensating circuit was investigated. This confirmed a reduction of 11.6% in harmonic content within the grid current.

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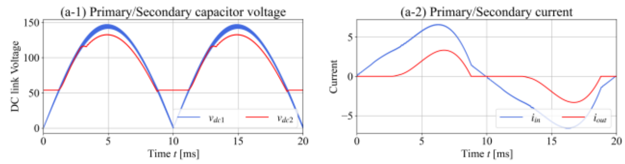
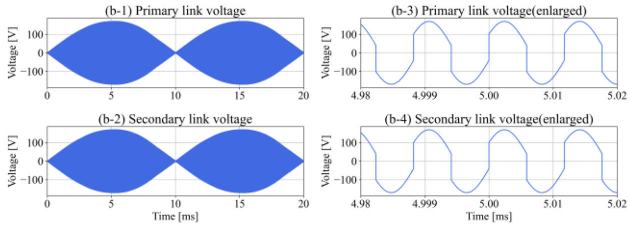
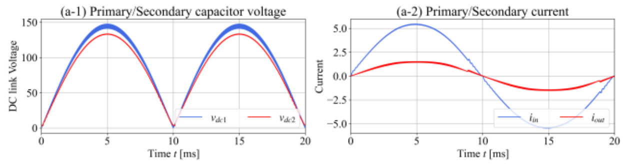


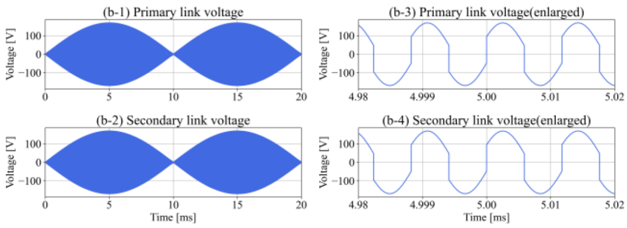
(a) Operating waveform with non-linear loads.



(b) Primary and secondary transmit voltages.



(a) Operating waveform with non-linear loads.



(b) Primary and secondary transmit voltages.

Fig. 4. Proposed system applying APF as a compensation circuit.

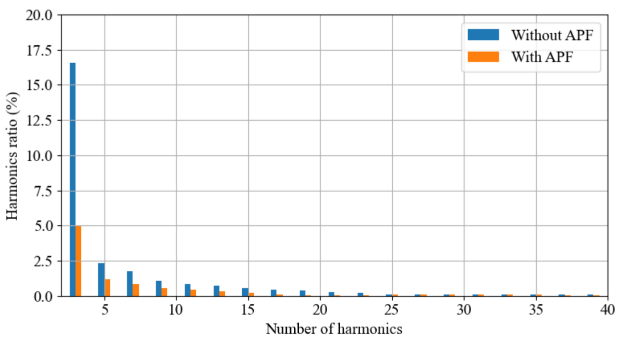


Fig. 5. Harmonics distortion ratio.

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