무접점 전력용 변환기의 다중공진형 토폴로지 비교

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Comparison of Higher-Order Resonant Topologies for Contact-less Power Converter Systems

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ABSTRACT

A higher-order power converter topology for an extremely low coupling (less than 0.15) transformer with high efficiency and wide air-gap (23 mm) is presented in this paper. Among the typical resonant converter topologies for contact-less power transferring systems, Series-Series Resonant Converter (SSRC) and Series-Parallel Resonant Converter (SPRC) are widely used in number of power electronic applications. However, when coupling coefficient of a transformer is seriously low (k<0.5), the series-series resonant converter will possibly operate at short circuited condition because of the small magnetizing impedance. To solve this problem, a modified and improved topology of seventh-order resonant converter for contact-less power converter system is proposed and the results are presented.

1. Introduction

Due to the simple and superior characteristics of the fifth-order resonant converters, they are largely employed in number of contactless power transfer applications. However, the fifth-order resonant converters fail to deliver energy efficiently and fail to regulate the output power especially under light load condition and at low magnetic coupled condition. The magnetically-coupled transformer windings suffer from the high circulating current and consecutively a high energy is dissipated on the transformer windings.

Among the fifth-order resonant converters, Series-Parallel Resonant Converter (SPRC) and Series-Series Resonant Converter (SSRC) are largely employed in number of power electronic applications in wide the frequency range. However, they cannot provide effective performance when the coupling factor is less than 0.5. Therefore, to overcome this problem, a seventh order resonant converter which can effectively block the circulating current under wide load condition with sufficient load regulation is designed. This paper discusses the effects of low coupling transformers on fifth-order resonant converters such as SSRC and SPRC. A 185W, 100V DC-DC contactless seventh-order resonant converter system was designed for 25mm gap application and its results are presented.

2. Lower-Order Resonance Converter

Losses on contactless transformer are classified as core-loss and winding loss. Furthermore, they are classified as:

1. Core-loss
   - Hysteresis Loss ($\propto f^2$)
   - Eddy Current Loss ($\propto$core reluctance)
2. Winding Loss
   - AC loss
      - a. skin effect
      - b. proximity effect
   - DC loss
      - a. I^2R winding loss

Each of the transformer losses varies based on the amount of power transferred and the operating frequency of the converter and the natural characteristics of the each device.

A SSRC topology is shown in Fig. 1, where the degree of its performance is proportional to its ratio between R_{ac} and the magnetizing impedance. If the magnetizing impedance is small, its impedance has to be increased by increasing the switching frequency of the converter [1]. However, when we increase the frequency, the ac loss of the converter also increases gradually.

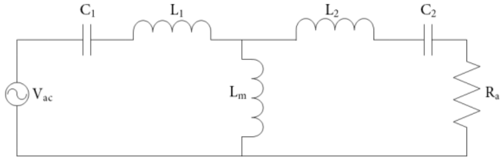


Fig. 1 Simplified series-series resonant converter topology

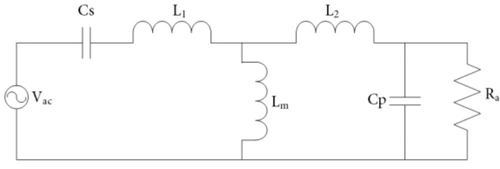


Fig. 2 Simplified series-parallel resonant converter topology

The series parallel resonant converter topology is shown in fig. 2. SPRC topology is effective only when the coupling coefficient is greater than 0.5, because Lm<<L2, $(L_2//L_m)$ =0. Therefore, at resonant frequency, the input voltage sees only the magnetizing impedance of the converter. However, at load side, the parallel resonance can effectively provide load regulation,

irrespective of the load variations. Whereas, the variations in the load resistance increase the conduction loss of the primary windings by increasing the amount of the self circulating current.

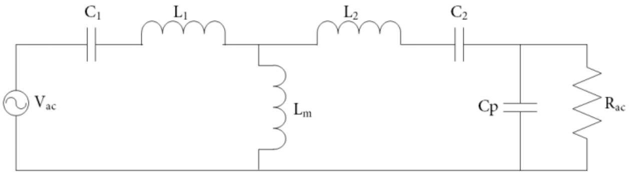


Fig. 3 Simplified sixth-order resonant converter topology

A sixth-order converter topology is shown in fig. 3. Comparatively, the converter reduces the circulating current by adding series-parallel compensation on the secondary side [2]. However, the additional capacitor on the secondary adds reactive power component to the converter and consequently increases the energy dissipation on the transformer windings.

3. Seventh-Order Resonant Converter

The seventh order converter system for wide gap leakage transformer is shown in Fig. 2. An optimized converter design can be achieved by choosing the parameters based on the following equations (1) and (2).

$$f_S=\frac{1}{2\pi\sqrt{C_1(L_1+L_m)}}=\frac{1}{2\pi\sqrt{C_2.L_2}}=\frac{1}{2\pi\sqrt{C_d.L_m}} \quad (1)$$

$$L_m=L_d \quad (2)$$

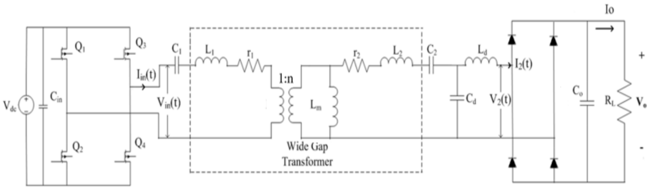


Fig. 4 Proposed seventh-order resonant converter topology

Table I. Key parameters of the hardware experimental set-up

MOSFET	IRFP4568
Rectifier	MBRB20200CT
L_1, L_2, L_m, L_d	8.77uH, 190uH, 27uH, 26uH
C_1, C_2, C_d	6315nF,3.33nF,23.42nF
Load Resistance	52Ω
Turns Ratio	1:4.6
Resonant Frequency	200khz
Air Gap Length	198khz
Coupling Factor	0.12
Vin, Po	23V, 185W

The input key waveforms of the inverter such as inverter voltage V_{in} (t), inverter current I_{in} (t) and instantaneous input power P_{in} (t) are shown in fig. 6. Fig. 7 shows the corresponding output key waveforms of the resonant tank. Table I gives the key parameter details of the hardware setup. The efficiency curve in fig. 5 shows the maximum coil to coil efficiency of 77%. The load voltage is fixed at 100 due to strong shunt impedance provided by the converter.

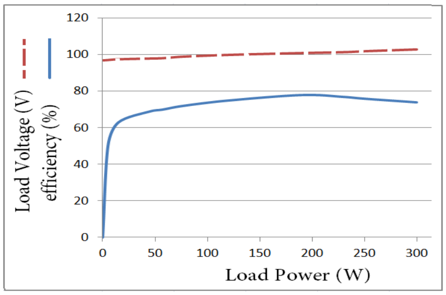
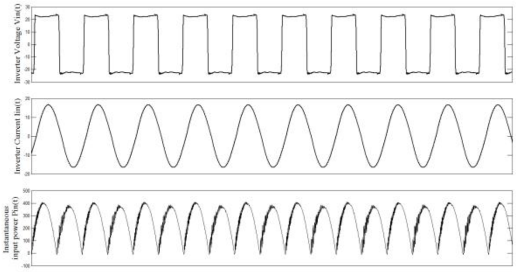
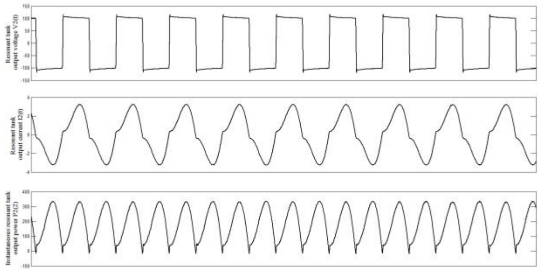


Fig. 5 coil to coil efficiency and load voltage variation



V_{in}_max(t)=23V, I_{in}_max(t)=16.5A, P_{in}-avg=245W, fs=197kHz

Fig. 6 Key waveforms of the Inverter



V_2_max(t)=100V, I_2_max(t)=3.3A, P_2-avg=188W, fs=197kHz

Fig. 7 Key waveforms of the resonant tank output

3. Conclusion

When the coupling coefficient of a converter is less than 0.5, it severely affects due to circulating current and its consequences are seen at load voltage variations. The issues regarding the conventional resonant topologies were discussed and the seventh order resonant converter topology is proposed. Its experimental result also has been presented. The maximum coil to coil efficiency of 77 % is measured.

참 고 문 헌

[1] Daniel.T Thayalan, Park Joung Hu "A novel series-series parallel resonant converter topology with loosely coupled transformers," IEEE International. Conf. Indus. Electronics., Busan, 2014.

[2] kibok Lee, Zeljko Pantic, "Reflective field containment in dynamic inductive power transfer," IEEE Trans. Power Electron., vol. 29, no. 9, pp. 4592-4602., Sep. 2014.