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A NOVEL TOPOLOGY FOR RIPPLE-FREE INPUTTING CURRENT TECHNIQUES*

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Abstract: A novel topology for ripple-free input current circuit is put forward in the paper. Compared to traditional EMI(electromagnetic interference) filter consisting of choke and capacitor, the ripple-free topology can reduce the converter's ripple current with the use of smaller component. The new ripple-free topology proposed in this paper does not need elaborate adjustment of the coupling coefficient as required by conventional ripple-free techniques, and is ripple voltage cancellation or isolation mode, which can attenuate the ripple further if the line impedance is considered. The theoretical prediction is confirmed by experimental results.

Key words: EMI, input current, ripple free converter(TN86)
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INTRODUCTION

To meet the requirements of EMI standard, switching mode converters should limit its switching ripple of input current to a low level. One of the typical traditional methods is to place a costly and bulky EMI filter at the input circuit of the converter. For AC/DC converters the input filter size is limited by power factor requirement, and the ripple reduction condition may not be satisfactory. Several ripple-free topologies developed recently (Cheng, 1998; Hamill, 1999; Miwa, 1992; Wang, 1996), are based on ripple current cancellation and usually need elaborate adjustment of their parameters.

The novel topology for ripple-free technique put forward in this paper is also based on ripple voltage cancellation or isolation, and does not need elaborate adjustment of the coupling coefficient as required by conventional ripple-free techniques. Moreover, it can attenuate the ripples further if the line impedance is considered. The theoretical prediction is confirmed by experimental results.

PRINCIPLE OF RIPPLE-FREE TOPOLOGIES AND EXISTING PROBLEM

A conventional ripple-free topology is shown in Fig.1 (Cheng, 1998; Hamill, 1999;). By magnetic coupling, the ripple current in primary winding L_p is absorbed by a capacitor C via secondary winding L_s.

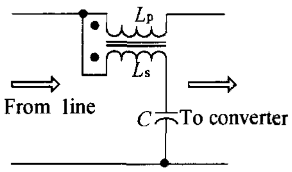

Fig.1 Conventional ripple-free topology

For DC/DC application the capacitance in Fig.1 should theoretically be infinite and ideal ripple-free effect can be expected if the transformer's coupling coefficient $k = \sqrt{L_p/L_s}$. However, a large capacitance will lower the AC/DC converter's power factor in practice. With finite capacitance the circuit cannot eliminate the ripple generally but has a notch frequency

$$\omega_n = 1\sqrt{(1 - k\sqrt{L_p/L_s})L_sC} \qquad (1)$$

When ω_n equals the switching frequency of the converter, the fundamental component of the ripple will be cancelled. Above this notch frequen-

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cy the attenuation factor of ripple approximates to $1 - k\sqrt{L_p/L_s}$ (Cheng, 1998).

A coupling coefficient $k\sqrt{L_p/L_s}$ close to unity is necessary for attenuating the ripple components above ω_n. Eq. 1 shows that the notch frequency will be very sensitive to the parameters when $k\sqrt{L_p/L_s}$ is close to unity. In fact, it is difficulty to ensure the accuracy of the coupling coefficient in loosely coupled inductors at different current levels. Hence, the coupling coefficient is not easy to be controlled in mass production if it is not close to unity (Lu, 2000).

PROPOSED RIPPLE-FREE TOPOLOGY

The conventional ripple-free topology is based on current cancellation mode. The proposed novel ripple-free topologyis shown in Fig. 2.

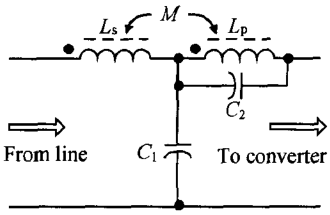

Fig. 2 Proposed ripple-free topology

Unlike current ripple cancellation mode, the two windings of the transformer in the new topology both carry DC or line frequency current. The primary winding connects to the converter' s noisy input port and the secondary winding connects to line. The converter's whole original ripple current flows into C_1, and result in a ripple voltage. If the transformer' s magnetizing inductance L_m is infinite, ripple voltage across C_1 and C_2 will be identical. And if the transformer' s two windings have the same number of turns, the transformer' s secondary winding will induce an identical ripple voltage, which will cancel the ripple voltage across C_1. Hence, only ripple-free current flows in the secondary winding.

In practical situation, L_m is finite. The capacitance C_2 should be a little bigger than that of C_1. The extra capacitance is used to block up the fundamental component of switching ripple. The switching frequency is chosen as the parallel resonant frequency $\omega_n \approx \sqrt{L_m(C_2 - C_1)}$. Above this frequency, the ripple components are still significantly attenuated.

The transformer turn ratio is designed to be unity, so double wires winding method can be used to ensure near unity coupling coefficient. Moreover, the parallel resonant frequency is less sensitive compared to the current cancellation mode mentioned above. The capacitance of C_1 in Fig. 2 needs not necessarily to be as large as that in the current cancellation mode.

The conventional topology mentioned above cannot benefit from the fact that in practical situation input impedance exists in an inputting circuit or a line cable. The proposed topology works in voltage cancellation mode. Its circuit input impedance becomes lower above tuning frequency ω_n, so increasing the line impedance enhances ripple reduction. This implies that the new topology can even get better results by adding an extra small input inductor.

PARAMETER DESIGNING FOR NEW RIPPLE-FREE TOPOLOGY

The equivalent circuit of the proposed topology is shown in Fig. 3, where

$Z_r = -jk\omega L$, $Z_a = Z_b = j(1+k)\omega L$,
$Z_{C_a} = 1/(j\omega C_a)$, $Z_{C_b} = 1/(j\omega C_b)$,
$Z_{C_1} = 1/(j\omega C_1)$, $L = L_p = L_s$.

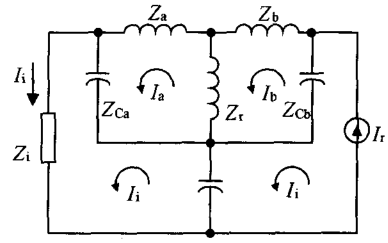

Fig. 3 Equivalent circuit of proposed topology

Kirchoff's Voltage Law was applied to the circuit to derive the following equations:

$$\begin{cases} I_i(Z_i + Z_{C_a} + Z_{C_1} - I_r Z_{C_1} - I_a Z_{C_a} = 0 \\ I_a(Z_{C_a} + Z_a + Z_r) - I_i Z_{C_a} - I_b Z_r = 0 \\ I_b(Z_{C_b} + Z_b + Z_r) - I_r Z_{C_b} - I_a Z_r = 0 \end{cases} \quad (2)$$

Provided $I_i = 0$, the following condition is required:

$$Z_{C_1}[(Z_{C_a}+Z_a+Z_r)(Z_{C_b}+Z_b+Z_r)-Z_r^2]+ Z_{C_a}Z_{C_b}Z_r = 0 \qquad (3)$$

When $Z_{C_a} = \infty$, Eq.3 becomes

$$Z_r(Z_{C_b}+Z_{C_1})+Z_{C_1}(Z_{C_b}+Z_b) = 0 \qquad (4)$$

The solution of Eq.4 is

$$C_b - kC_1 = 1/\omega^2 L \qquad (5)$$

Under this condition, the fundamental component of the switching ripple voltage can be cancelled or isolated. The topology was proved to have symmetrical characteristics in both directions. Namely, when output current (by substituting I_o for I_r in Fig.3) $I_o = 0$ and $Z_{C_b} = \infty$, the solution becomes

$$C_a - kC_1 = 1/\omega^2 L \qquad (6)$$

SIMULATION AND EXPERIMENT ON RIPPLE CANCELLATION IN BOOST CONVERTER

One of the simulation and experimental circuits is shown in Fig.4. The ripple-free boost converter was simulated and tested under conditions of $60V_{DC}$ input and $200V_{DC}$ output. The switching frequency was 50 kHz. For comparison, the magnetic energy stored in the ripple cancellation filter in Fig.4 is the same as that in Fig.1. The capacitor C_2 shown in Fig.4 is the same as C_b in Eq.5.

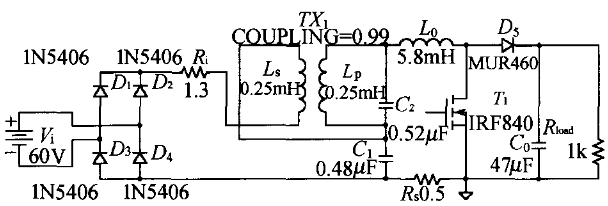

Fig.4 Simulation and experiment circuit for new design

For ripple free topology, the values C_1, C_2, L_p and L_s must be designed properly. The upper bound of the capacitance of C_1 is limited by the requirement of unity power factor if AC/DC converter is concerned, and can be expressed as $C_1 \propto P/(V_{ac}^2 f)$. For a 100W converter with $220V_{AC}/50$ Hz line input, C_1 is about 0.1 μF. The lower bound of C_1 is constrained by the cancellation effect of the ripple voltage then. For compactness and lower cost, the size of the ripple free transformer is often smaller than that of the boost inductor. On the other hand, L_p and L_s must be bigger enough to have good cancellation effect and smaller size of C_2.

The simulation results (Fig.5) of the conventional topology and the new design show that the amplitudes of the residual ripples in new design and conventional circuits are similar. The residual ripples in the new design have a higher ripple frequency, which is easier to dealt with.

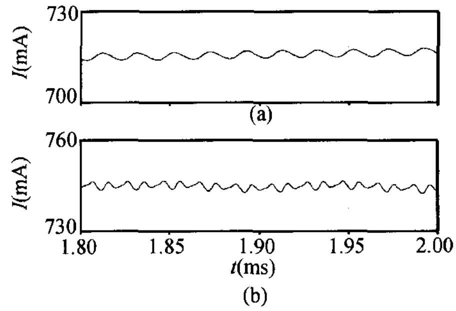

Fig.5 Simulation results of residue ripples in two circuits
(a) residual ripples in conventional ripple-free circuit;
(b) residual ripples in new design circuit

Fig.6 shows the experiment results, for comparison of residue ripples from converter with or without ripple-free topology. It is impressive that the conventional ripple-free topology can reduce the inputting switching ripples dramatically. The capacitance has been adjusted elaborately however.

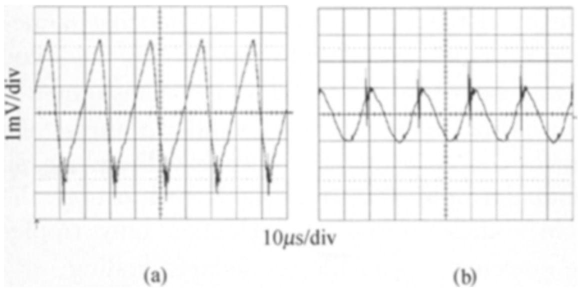

Fig.6 Comparison of residue ripples with or without ripple-free topology
(a) original converter;
(b) conventional ripple-free topology, $k = 0.99$, $L_p = L_s = 1$ mH

The experimental results of residue ripples in the new designed circuit are shown in Fig. 7. Compared to conventional ripple-free topology, the proposed circuit can reduce inputting ripples further. Fig. 7b also shows that the residue ripples can be attenuated further more by adding an extra 1mH inductor on the input port, and is placed in series with R_{s2} in Fig. 4.

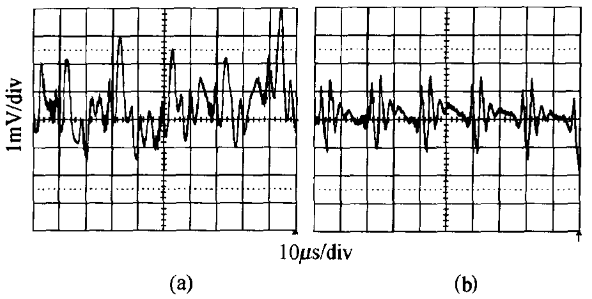

Fig. 7 Comparison of residue ripples with or without an extra input inductor
(a) proposed circuit;
(b) proposed circuit with an extra inductor

Simulation and experiments led to the following findings:

1. The new circuit's ripple cancellation result is equal to or better than that of conventional ripple-free topology.

2. The residual ripple component in the new circuit is mainly above the switching frequency, and so is easy to be cleaned by extra filter.

3. The extra inserted 1mH inductor can further attenuate ripples by a factor almost of 30 in simulation.

The experimental results are not as perfect as the simulation results. The testing results were affected apparently by common mode interference, as the residual of differential mode ripple current was not dominant.

CONCLUSIONS

The new proposed topology can reduce input current ripple dramatically without elaborate adjustment of the coupling coefficient of the ripple-free circuit's transformer. Different from the conventional ripple-free methods, the new topology is based on ripple-free voltage mode. Because the basic proposed circuit has lower input impedance, the ripple cancellation quality can be further improved by inserting a small extra input inductor. It was also confirmed that the method is insensitive to the parameters. The new topology can realize perfect ripple-free characteristic for both DC/DC and AC/DC converters. Its excellent ripple cancellation quality is especially suitable for unity-power-factor converter. Due to its symmetrical characteristics in both directions, the new topology is also suitable for application to DC/AC inverter for output ripple current cancellation.

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