Optimum Inductance for Isolated DC to Three-phase AC Converter using Indirect Matrix Converter

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This paper proposes a Zero Voltage Switching (ZVS) method for an isolated DC to three-phase AC converter using an indirect matrix converter at the secondary side converter. The secondary side inverter employs the pulse density modulation in order to achieve ZVS on all switches at the secondary side. On the other hand, ZVS at the inverter side at the primary side is achieved by the leakage inductance of the transformer. However, there is a trade-off relationship between the switching loss and the sum of the snubber loss at the secondary side and the copper loss of an additional inductor connected to the transformer in series for ZVS. In this paper, the efficiency characteristic in terms of the leakage inductance is evaluated. From the experimental results, the validity of the proposed circuit is confirmed by a 3-kW prototype.

Keywords Indirect matrix converter, Zero voltage switching, DC-AC converter

1. Introduction

Energy storage systems require a DC-AC converter for connecting the grid and batteries. Such converters necessary to be isolated by a transformer in order to protect from failures and noises. However, the transformer for commercial frequency is bulky and heavy. Therefore the high frequency AC link converter has been researched for down-sizing the transformer [1]-[2].

The authors have proposed the isolated DC-AC converter which adopts the indirect matrix converter using the pulse density modulation in order to improve the efficiency [3]. This proposed circuit achieves ZVS by using the pulse density modulation.

The leakage inductance of the transformer is required to achieve ZVS at primary inverter. However, the effect of varying the leakage inductance for ZVS range has not evaluated. In this paper, the efficiency characteristic in terms of the leakage inductance is evaluated.

2. Relationship between leakage inductance and ZVS

Fig. 1 shows the circuit configuration of the DC-AC converter with the indirect matrix converter. This circuit is divided into the full bridge inverter which adopts the phase shift control at the primary side of the transformer and the indirect matrix converter at the secondary side.

PDM used in the conventional circuit is applied to the indirect matrix converter in order to achieve ZVS at the secondary side. As a result, the proposed system achieves high efficiency because both the primary and the secondary inverters of the proposed system achieves ZVS. Ignoring the effects of the transformer magnetizing inductance L_m and the load inductance L for simplicity, the condition of the transformer current I_{inv_lim} which achieves ZVS in each arm of the inverter at the primary side is given by (1).

$$I_{inv\_\lim} \geq V_{dc}\sqrt{\frac{2C_{ds}}{L_t}} \qquad (1)$$

where, V_{dc} is the input DC voltage, C_{ds} is the drain-source capacitance of MOSFET in the inverter at the primary side, and L_t is the sum of the leakage inductance in the transformer and the inductance of an air-coil inductor connected to the primary side of the transformer in series.

From (1), it is understood that ZVS range is extended by increasing the leakage inductance. On the other hand, the increase of the snubber loss is small even though the total inductance value L_t is changed. From calculations results, the difference of the snubber loss between the total inductance of 0.8 μH and 2.4 μH is only 1.2 W at the rated output power. Therefore, the efficiency in the heavy load region is not affected by the leakage inductance.

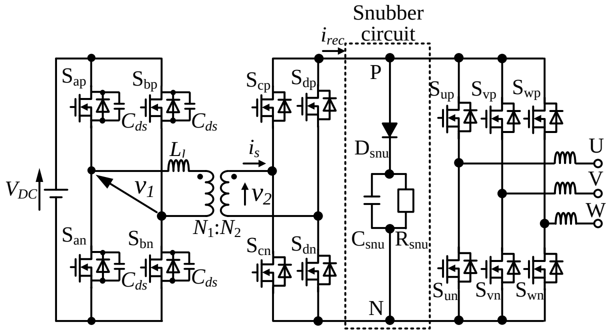

Fig.1. DC-AC converter with indirect matrix converter.

Table 1. Experimental conditions.

Element	Symbol	Value
Input DC voltage	V_{dc}	200 V
Output line voltage	V_{rms}	200 V
Carrier frequency of inverter	f_{c_inv}	50 kHz
Carrier frequency of indirect matrix converter	f_{c_imc}	5 kHz
Output frequency	f_{out}	50 Hz
Turn ratio	N_1:N_2	1:2
Duty of primary voltage	D	0.9 p.u.
Load resistance	R	12.9 Ω
Load inductance	L	3 mH
Rated power		3 kW
Drain to source capacitance of MOSFET	C_{ds}	2.94 nF
Winding resistance	R_l	39.0 mΩ
Leakage inductance	L_l	0.40 μH
Magnetizing inductance	L_m	4.58 mH
Dead time of primary inverter	t_{dead1}	125 ns
Dead time of secondary converter	t_{dead2}	100 ns

3. Experimental Results

Table 1 shows the experimental conditions. The experiments with a prototype circuit are conducted in order to confirm the ZVS. By inserting an air-coil inductor, total inductance which corresponds to the leakage inductance is changed. The inductance of air-coil inductor is 0.4 μH and 2.0 μH while the original leakage inductance is 0.4 μH.

Fig. 2 (a), (b), (c) and (d) show the gate-source voltage and the drain-source voltage of S_{ap} and S_{bn} when the total inductance which corresponds the leakage inductance is 0.8 μH and 2.4 μH, respectively. When the total inductance is 2.4 μH, the minimum current which achieves ZVS is smaller than that of when the total inductance is 0.8 μH. From Fig. 2(a) and (b), the extension of area witch achieves ZVS is confirmed.

Fig. 3 shows the efficiency characteristic with two different total leakage inductances. In order to minimize the effect of copper loss in the air-coil inductor, the length of the air-coil inductor is same.

Fig. 4 shows the efficiency characteristic at rated output power of 3 kW. The iron loss of transformer is changed due to the voltage drop on the additional inductor of the transformer. Therefore, the efficiency is different between two conditions. However, the maximum difference of the efficiency is only 0.3%. As a conclusion, the efficiency characteristic is not changed by the total inductance which corresponds to the leakage inductance.

Fig. 5 shows the snubber loss at the secondary side of the transformer. From the results, the snubber loss increases with the increasing the total inductance. However, the increase of the snubber loss is small against the variation of the output power. Hence, the change of the snubber loss does not affect the efficiency of prototype circuit.

4. Conclusion

This paper experimentally verified the effect on the efficiency characteristic by total inductance which corresponds to the leakage inductance of the transformer. The minimum value of the inverter output current which achieves ZVS in primary side inverter is extended by increasing the total inductance. From the experimental results, it is confirmed that ZVS is achieved at the output power of 2.1 kW when the air-coil inductor of 2.0 μH is inserted. The switching loss at the primary side is decreased by ZVS. The efficiency the rated output power is not affected even though the total inductance is changed because the change of the snubber loss is very small compared to the output power.

In the future work, the ZVS range at the primary side of the proposed circuit in terms of the output power will be derived.

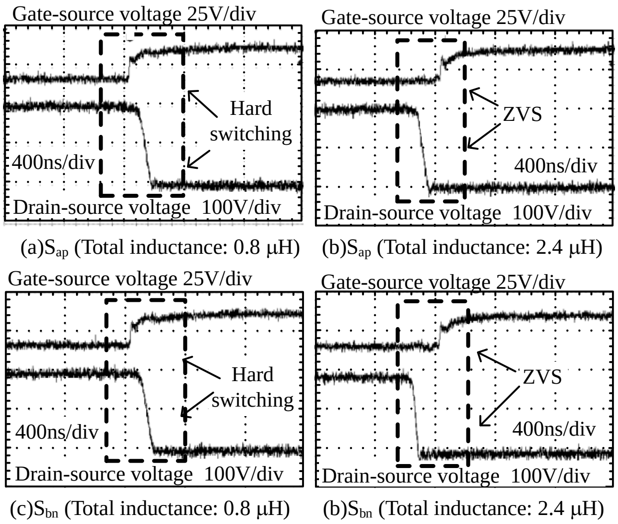

Fig.2. Gate-source voltage and drain-source voltage of S_{ap} and S_{bn} of inverter in primary side at 2.1 kW.

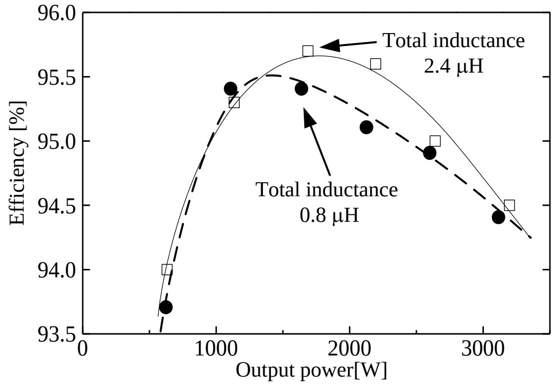

Fig.3. Efficiency characteristics.

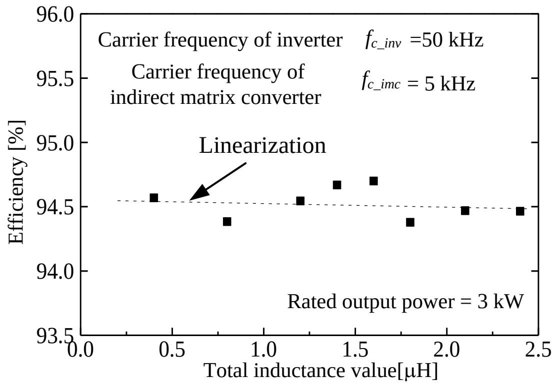

Fig.4. Comparison of efficiency at rated power.

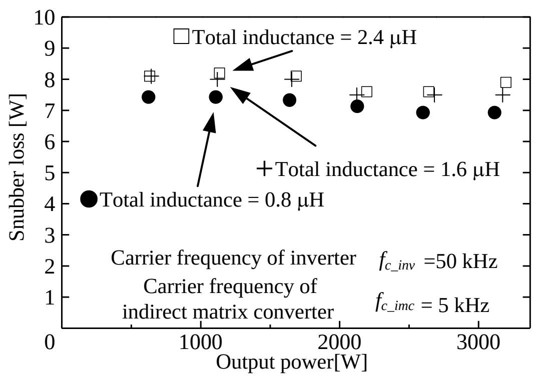

Fig.5. Comparison of snubber loss

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