

# Power Efficiency Improvement of the Composite Resonant DC-DC Converter

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**Abstract**—This paper deals with the power efficiency improvement of the composite resonant DC-DC converter, which is developed to be applied to the power conditioner of the photovoltaic generation system. To improve the power efficiency, following three approaches are taken: 1) optimum design of the transformer 2) use of the voltage doubler rectifier. 3) reduction of the winding loss of the transformer. The maximum power efficiency of 98.0% can be realized.

**Keywords**-component; power efficiency improvement, composite resonant DC-DC converter, optimum design, voltage doubler rectifier, leakage flux

## I. INTRODUCTION

Of all the energy used all over the world, the fossil energy from such as oil, coal and natural gas is the largest in number, which emits the carbon dioxide that causes global warming.. As a result, abnormal weather, the rise of a sea surface and so forth are predicted. To solve this problem, great attention to the new energy resources such as the photovoltaic cell, fuel cell and wind force are are given.

This paper deals with the power efficiency improvement of the composite resonant DC-DC converter[1-4], which is developed to be applied to the power conditioner of the photovoltaic generation system. To improve the power efficiency, following three approaches are examined:

- (1) Optimum design of the transformer with reducing the size and weight of the transformer
- (2) Use of voltage doubler rectifier
- (3) Reduction of the winding loss caused by the leakage flux in the vicinity of the air gap of the transformer

## II. CIRCUIT CONFIGURATION

Fig.1 shows the proposed current resonant DC-DC converter with the voltage doubler rectifier, in which the current and voltage resonant circuits are employed. In this figure, TR1 and TR2 are main switches of MOSFETs. CTR1

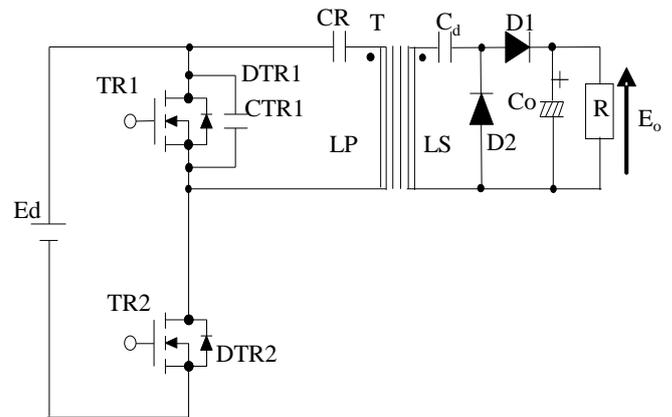


Fig. 1 Half-bridge current resonance DC- DC converter with the voltage doubler rectifier.

and CR are the voltage and current resonance capacitors, respectively. LP and LS are inductances of the primary and secondary windings of the transformer T. The voltage doubler rectifier is composed of the diodes D1 and D2, and capacitances Cd and Co. The MOSFET switches TR1 and TR2 are turned-on and turned-off alternatively. There exists the short dead time between the on-times of TR1 and TR2. The photovoltaic generation system has the output capacity of 2 kW. The DC-DC converter requirements are 80-450V input voltage, 396V output voltage and 2150W maximum input power.

## III. POWER EFFICIENCY IMPROVEMENT

### A. Optimum design for the transformer (Reducing the transformer's size and weight.)

To realize both of improvement of power efficiency and downsizing of the DC-DC converter, optimization of transformer is performed.

The comparison of specifications with conventional one is summarized in Table 1. In Table 2, the compared results for categorized power consumption of the optimized transformer and conventional one are summarized. From these results, the volume and weight of 57% of the optimized trans-former can be reduced, compared to the conventional one. By downsizing

Table 1 Specifications of DC-DC converter of the optimized transformer and conventional one.

	The optimized	Conventional
Transformer form	PQ50	PQ71
Air gap	1.2mm	1.5mm
Diameter and turn of Primary winding with litz wire	0.06mm / 1350 turn	0.12mm / 504 turn
Diameter and turn of Secondary winding with litz wire	0.06mm / 810turn	0.12mm / 252turn
Resonant Capacitor	1.16 $\mu$ F	0.88 $\mu$ F

Table 2 Power consumption and power efficiency comparison of the optimized transformer and conventional one.

	Optimized transformer (W)	Conventional transformer (W)
MOSFET (High + Low) conduction loss	11.0	10.0
MOSFET (High + Low) switching loss	1.2	0.8
Rectifier diode loss ( $D_1$ and $D_2$ )	12.0	11.2
Rectifier diode loss ( $D_1$ , and $D_2$ )	0.7	0.9
Winding copper loss (Primary)	4.5	2.3
Winding copper loss (Secondary)	6.5	2.2
The other winding losses	13.7	24.3
Loss of EMC filters	5.5	5.5
Other losses	3.0	3
Power efficiency (250V, 2150W)	97.3% (Total loss 58.1W)	97.2% (Total loss 60.2W)

of transformer, winding copper loss is increased, but otherwise the other winding losses, including iron loss and proximity effect loss, are become almost a half. As the result, downsizing of the transformer is realized with the increasing of 0.1% power efficiency. Precise descriptions are described in later.

**B. Employing the voltage doubler rectifier.**

To compare the recovery loss of voltage doubler rectifier and center tapped rectifier, the requirements are settled with 210V input voltage, 180V output voltage and 1kW output power. Figure 4 shows the conventional half bridge current

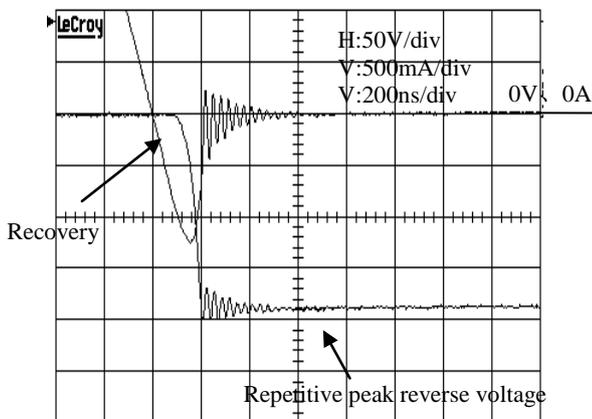


Fig. 2 Voltage doubler rectifier.

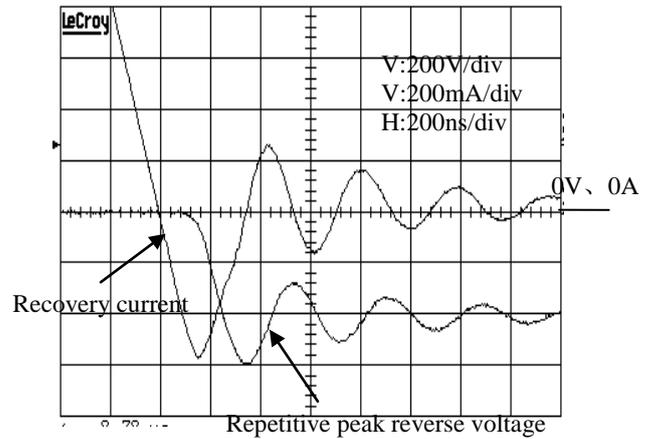


Fig. 3 Center tapped rectifier.

resonance DC-DC converter with the center tapped rectifier. In the experiment, FRD of the maximum reverse voltage 600V is used as a rectifier diode. The requirements are maximum requirements to avoid over avoid maximum reverse voltage of FRD.

In Figs. 2 and 3, the waveforms of voltage and current of the voltage doubler and the center-tapped rectifier are shown, respectively. Each of the recovery loss is 0.42W and 0.94W, respectively. The rectifier loss is reduced in half. The recovery loss of diodes is reduced by employing the voltage doubler rectifier in the secondary side as shown in Fig. 1. By the capacitor  $C_d$  in the voltage doubler, the reverse current loss is reduced.

Another advantage of the voltage doubler rectifier is it can be able to treat more power than the center tapped rectifier.

From the experimental result, the maximum output power was 2150W with 250V input voltage, 400V reverse voltage. Also, the recovery loss is almost 0.4W. The reverse voltage is clumped to regulated voltage between output voltage and secondary voltage of transformer. Therefore, the loss occurred by the oscillation is suppressed. Same result is realized with full bridge rectifier, but the number of diodes and heat sink are increased. The both of cost and difficulty of the circuit implementation are increasing.

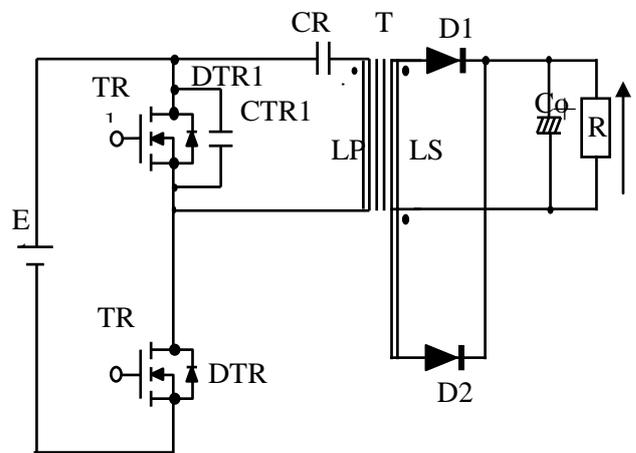


Fig. 4 The half bridge current resonance DC-DC converter with the Center tap rectifier.

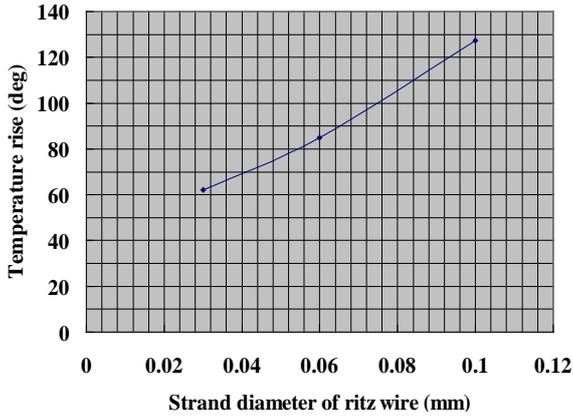


Fig. 5 Temperature rise vs. strand diameter of the litz wire

### C. Reduction of the winding loss by the leakage flux in the vicinity of the air gap of the transformer

The leakage flux in the vicinity of the air gap of the transformer intersects with the winding. Then eddy-current loss and loss due to proximity effect are caused. If the switching frequency increases with the rise of the input voltage, these losses increase. It is presumed as described above. In order to solve this problem, as shown in Fig. 5, temperature rise of winding is improved by making the strand diameter of the litz wire small. That is, the loss by winding is reduced and the power efficiency is improved. The magnetic analysis using simulation was performed. The simulation was performed to avoid the memory overflow with simplified settings that bundle litz wires are unified to 0.8mm wire.

Figure 6 shows simulation results. Each figure shows the magnetic field variation at  $\theta=0$  deg.,  $\theta=45$  deg. and  $\theta=90$  deg. The applied input alternative current is cosine waveform, that peak value is at 0 deg. ,

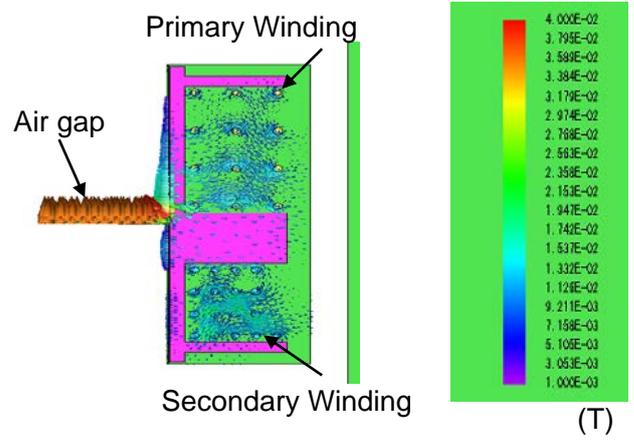
Typically, winding loss is simply categorized to skin depth loss, eddy current loss and proximity effect loss. The simulation results are analyzed with this categorization.

The diameter of litz wire using in experiments is 0.06mm. 0.06mm of the diameter size is decided as the minimum limit of mass productivity. The estimated skin depth is calculated 0.19mm with switching frequency 120 kHz. Therefore, the skin depth effect and loss can be ignored. Also, the test is performed with putting litz wire near to air gap. From the result, there was any generating heat in litz wire, that is, eddy current loss is able to be ignored.

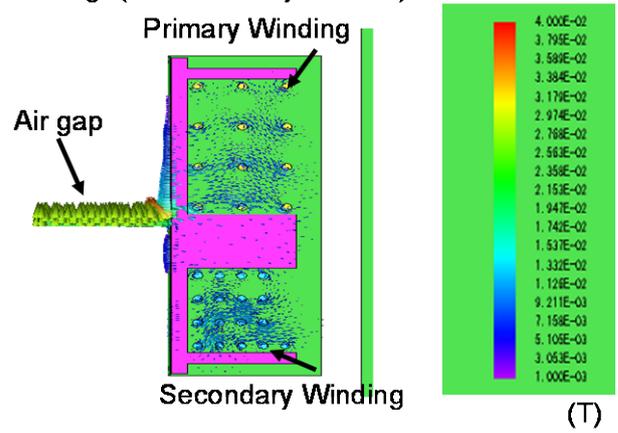
After all, it can be thought that the most of winding loss is occurred by proximity effect.

## IV. POWER EFFICIENCY

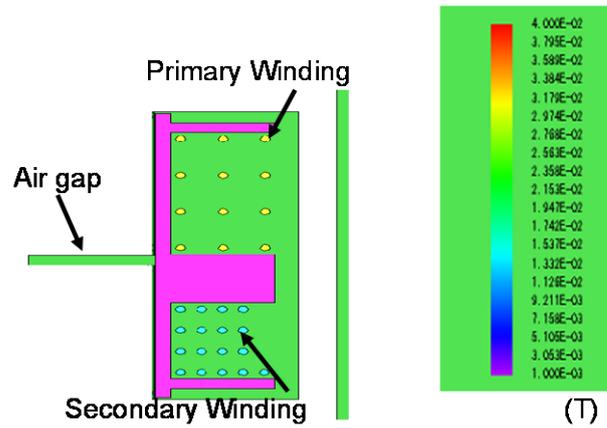
Fig. 7 shows the power efficiency characteristics of the composite resonant DC-DC converter. It is seen that the power



(a)  $\theta=0$ deg. (Peak Primary Current)



(b)  $\theta=45$ deg.



(c)  $\theta=90$ deg. (Zero Primary Current)

Fig. 6 The magnetic analysis results.

## REFERENCES

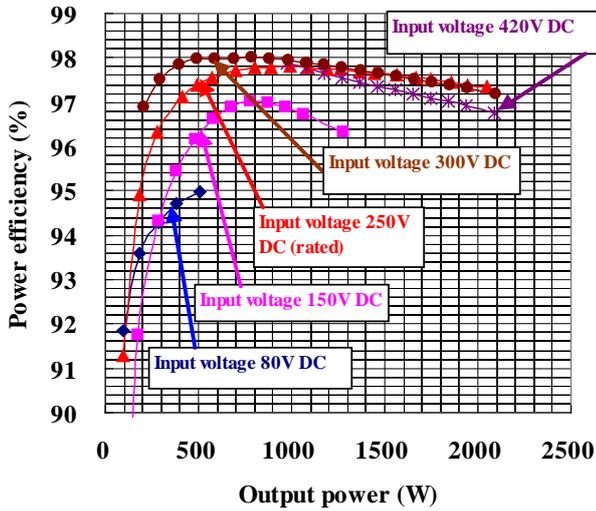


Fig. 7 Power efficiency of the proposed composite resonant DC-DC converter.

efficiency is very high and that the maximum power efficiency of 98.0% can be realized at 300V DC of the input voltage. Then the output voltage is 380 V DC. The high power efficiency over 97.0% can be realized from 150V DC to 420V DC of the input voltage and the high power efficiency over 97.0% can be realized at 250V DC (rated) of the input voltage and from 400W to 2150W of the input power.

## V. CONCLUSION

From the above discussion, the high power efficiency is obtained using the proposed half-bridge current resonance DC-DC converter. The maximum power efficiency is very high and 98% when the input voltage is 300 V DC. The power efficiency of 97% is realized at 250 V DC (rated) of the input voltage and from 400W to 2,150 W of the input power.

The improvement has been done with:

- (1) Optimum design of the transformer with reducing the size and weight of the transformer
- (2) Use of voltage doubler rectifier
- (3) Reduction of the winding loss caused by the leakage flux in the vicinity of the air gap of the transformer

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