Evaluation of an isolated DC-DC converter for a micro inverter

Naoki Koike[1], Shinichiro Nagai[1]
[1]Pony Electric co., ltd. 2-8-4 Kitasaiwai Yokohama Nishi-ku, Kanagawa 220-0004 Japan

Abstract

Although it is necessary to increase the frequency of the microinverter, it is difficult to improve efficiency at high frequency. In this paper, consideration and efficiency evaluation were made on reduction of loss occurred at high frequencies in current mode resonant DCDC converter for micro inverters. In the following, the operation analysis including the parasitic component in the current mode resonant DCDC converter was performed and the switching loss was reduced by Zero Voltage Switching(ZVS). In order to reduce the eddy current loss which causes the loss of the high frequency transformer, we used an extremely fine litz wire to quantitatively show the influence due to the difference in strand diameter and realized a highly efficient DCDC converter.

1. Introduction

Solar power generation has attracted attention for a long time as a very useful energy source for Japan with little resource such as petroleum, but it was difficult to disseminate due to high equipment cost. However, in recent years, the expectation for solar power generation has increased due to the momentum of environmental conservation and renewable energy, and the dissemination policy including the subsidy system has been proactively promoted, and the purchase system in 2012 Many energy trading companies have entered into the market as a result of being started, and in recent years the number of installations of solar power generation system facilities has been rapidly increasing [1]. As a result, expensive facility costs, which had been hindered by the spread of solar power generation systems, have also been improved [2], and the penetration rate of solar power generation in Japan has dramatically increased in recent years. However, facilities and maintenance costs of photovoltaic power generation systems for general households are still expensive, so we think that cost reduction is the most important factor in order to further spread.

In the long term, it is possible to cover these costs in the profit obtained by the sale of electricity of the electric power generated by the solar power generation. We intend to reduce the costs in solar power generation systems from two points of improvement of power generation efficiency and reduction of maintenance cost by improving product life and proceed with the development of long-life microinverter

In solar power generation systems, there are many systems in which a plurality of solar cell strings are connected in parallel and input to a power conditioner. In this method, the generated power of the whole solar light string decreases due to the solar panel that does not generate electricity due to shadows and the like, so there is a problem that the generated power drops extremely. However, in the micro inverter system connected in parallel to solar panels, since there is no strings, even if panels that do not generate electricity exist, the influence can be minimized, and improvement in power generation efficiency of the system can be expected.

We have proposed an electrolytic capacitor-less microinverter as a long-life microinverter system. However, in order to extend the lifetime of the microinverter, not only the electrolytic capacitor but also the loss must be reduced in order to reduce the load on the element. However, in a small device such as a microinverter, it is necessary to set the switching frequency high, so it is difficult to achieve high efficiency. We evaluated the efficiency of the high frequency DCDC converter for the microinverter, and considered it.

2. Circuit configuration of microinverter

The circuit configuration of the microinverter is shown in Figure 1. It consists of a Current Mode

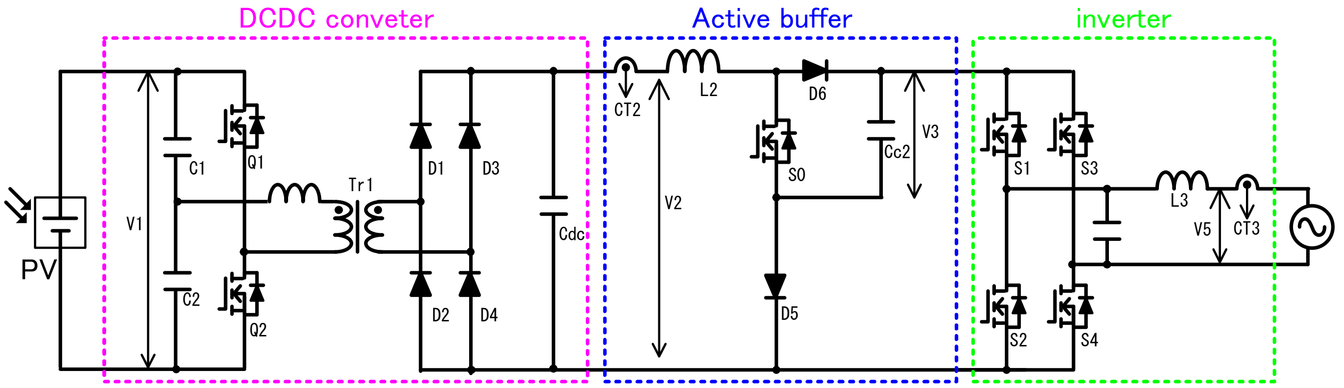


Figure 1 Circuit configuration of microinverter

Resonant isolated DCDC Converter, an active buffer, and a current type inverter.

Normally, most of the electrolytic capacitors have a lifetime of 15 years at the maximum, but in order to achieve a long life, the electrolytic capacitors are not used in this method, and the circuit is composed only of the ceramic capacitors. Since a large capacity can not be obtained with a ceramic capacitor, an active buffer system is adopted. In the active buffer system, it is possible to reduce the capacity by controlling the charging / discharging amount of the capacitor of the DC link voltage (Figure 1,Cc 2) according to the ripple of the instantaneous power generated by the grid interconnection.[3][4]

3. Circuit configuration of DCDC converter

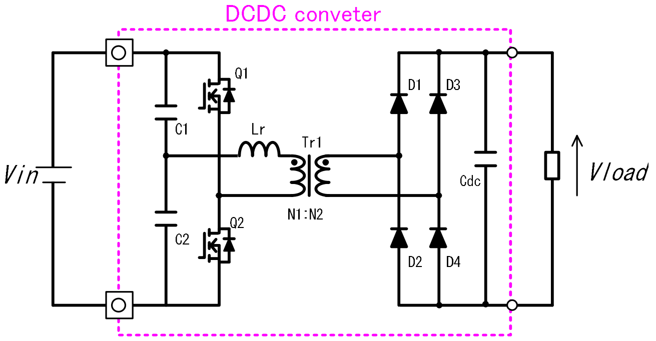
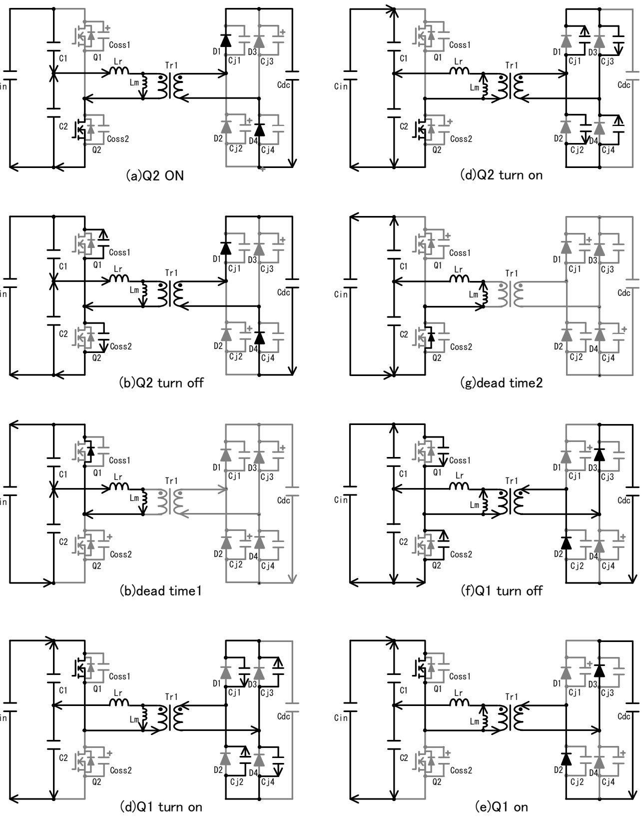


Figure 2 Circuit configuration of DCDC converter

The circuit configuration of the evaluated DCDC converter is shown in Figure 2. The switching frequency of the DCDC converter was 200 kHz, and the input DC voltage was 40 V assuming the maximum output voltage of the PV panel. In order to make the output voltage twice the input DC voltage, the winding ratio of the transformer was 1: 4. In this DCDC converter, the output voltage is not controlled, and the voltage is controlled by the active buffer and the inverter. The duty ratio was fixed at 50% and the switching frequency was fixed to the resonance frequency of Lr, C1, C2, and it was always operated with ZVS.

4. Operation mode analysis including parasitic components

In the DCDC converter of Figure 2, soft switching of current resonance is performed. As the switching frequency increases, the parasitic component of the switching element greatly affects the resonance. In Figure 2 ,C1, C2 and Lr resonate and



(a)Q2 ON (d)Q2 turn on

(b)Q2 turn off (g)dead time2

(b)dead time1 (f)Q1 turn off

(d)Q1 turn on (e)Q1 on

Figure 3 Operation mode analysis including parasitic components

Q1 and Q2 become zero current switching (ZCS). However, since the parasitic capacitance is charged and discharged at the moment when Q1 and Q2 turn on, switching loss occurs. As the switching frequency increases, this loss also increases.

Figure 3 shows an operating mode analysis including parasitic components affecting soft switching operation. The parasitic component considered is the output capacitance (Coss) of Q1 and Q2, and the junction capacitance (Cj) of D1 to D4. Each operation mode will be described below.

<a>Q2 ON

Q 2 are in the ON state. Current resonance occurs at the load currents C1, C2 and Lr to the secondary side diode, and reactive current flows through the excitation inductance Lm. The reactive current depends on the input voltage and does not depend on the load power. Consequently, on the primary side, a conduction loss due to a certain amount of reactive power occurs regardless of the load.

<b>Q2 turn off

When Q 2 turns off from the state of Figure 3(a), it shifts to the mode of Figure 3(b). In this mode, the load current is interrupted as Q2 turns off, the exciting current flows due to the back electromotive force of the exciting inductance of the transformer, the output capacity Coss of Q1 and Q2 is charged and discharged, and when charge and discharge are completed, Q1 The body diode turns ON.

<c>dead time1

Figure 3(c) shows the state in which the body diode of Q1 is turned on. In this state, since a voltage is applied to the exciting inductance Lm in the opposite direction, the exciting current flowing through Lm rapidly decreases and the body diode turns OFF.

<d>Q1 turn on

When Q1 is turned on just before the body diode turns OFF in Figure 3(c), it goes to the mode of Figure 3(d). When the transistor Q 1 is turned on, the polarity of the transformer is switched and the junction capacitances C j 1 to C j 4 of the secondary side rectifier diodes D 1 to D 4 are instantaneously charged and discharged.

At this time, when Q1 turns on before deadtime is small and charge / discharge of Coss is completed, Q1 generates not only its own parasitic capacitance Coss but also turn-on loss corresponding to the sum of the junction capacitances of Q2 and D1 ~ D4, so deadtime Is very important for the timing adjustment.

Table 1 circuit constants

Item	symbol	value	unit
input voltage	Vin	40	V
output voltage	Vout	80	V
duty cycle	D	0.5	
switching frequency	fsw	200k	Hz
magnetizing inductance	Lm	25u	H
resonant inductor	Lr	400n	H
resonant capasitor	C1,C2	750n	F
DCcapacitor	Cdc	15u	F
junction capasitance	Cj	500p	F
output capacitance	Coss	1500p	F

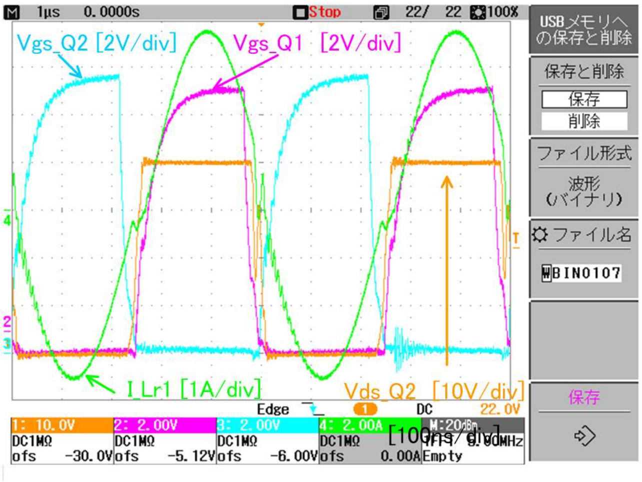


Figure 4 current resonant waveform

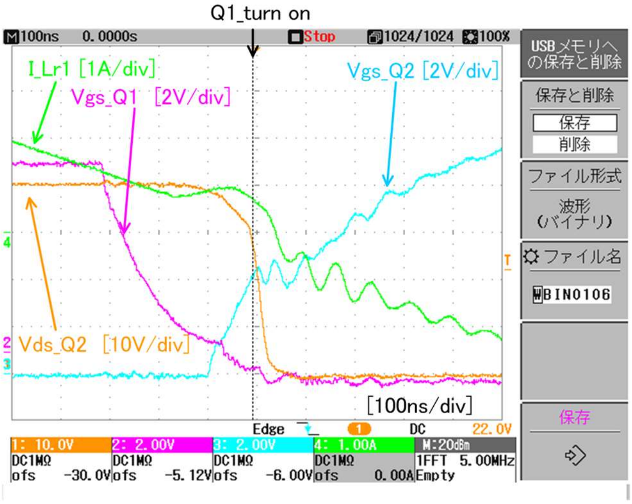


Figure 5 waveform @turn on (ZCS)

5. evaluation of DCDC conveter

5.1. Analysis of switching waveform

The evaluation results of the DCDC converter are shown below. The circuit constants are shown in Table 1. Figure 4 shows the waveform of current resonance. A sin wave due to the resonance of Lr and Cr can be confirmed. Figure 5、Figure 6 is the enlarged waveform of the switching at the moment Q2 turns on.

Figure 5 shows the waveform when the dead time is 200 ns. Q 2 of Vgs is turned ON before the output capacity of Q 2 is discharged after the gate of Q 1 is turned OFF. In this case, since ZVS has not been achieved, a loss due to a short circuit of the output capacity occurs. Figure 6 shows the waveform when the dead time is extended by about 100 ns from Figure 5. In this case, since the gate of Q1 falls and the output capacity of Q2 is fully discharged, ZVS is achieved and switching loss does not occur.

Figure 7 shows the waveform of the same dead time as in Figure 5 at light load. The triangular wave current of 200 kHz is the exciting current flowing through the transformer. It can be seen that a large peak current flows at the instant of switching. This current flows by charging / discharging the junction capacitance of the diode on the secondary side via Q1 as in the mode in Figure 3 (d). Figure 8 shows the waveform in the case of light load in Figure 6. Compared to Figure 7, it can be seen that the peak current flowing at the instant of switching decreases. This shows that switching loss can be reduced by ZVS.

Figure 9 compares the efficiency evaluation results with and without ZVS. Efficiency difference of up to 1% occurred at 100 W operation. In addition, it can be seen that the efficiency difference decreases as the load increases, since the switching loss generated in the MOSFET is caused by the short circuit of the output capacitance, it is not dependent on the load and is almost constant .

5.2. The study of the high frequency transformer

We studied for transformer high frequency. isolated DCDC converter increases loss in transformer as frequency increases. One of the causes is the eddy current loss due to the leakage of the transformer (Figure 11)。 Therefore, we used the litz wire for the transformer of the high-frequency insulated DCDC converter and measured how the difference in the wire diameter influences the efficiency. In the following, we examined the change in efficiency at high frequencies, the dependence of strand diameter and frequency on changing the wire diameter of Litz wire to φ0.1 and φ0.05.

Table 2and Figure 10 show the characteristics and outline of the isolated transformer Tr1. In order to reduce the eddy current loss due to leakage, the core gap was eliminated, the litz wire was used for the winding and the ferrite was used for the core material because of the high frequency.

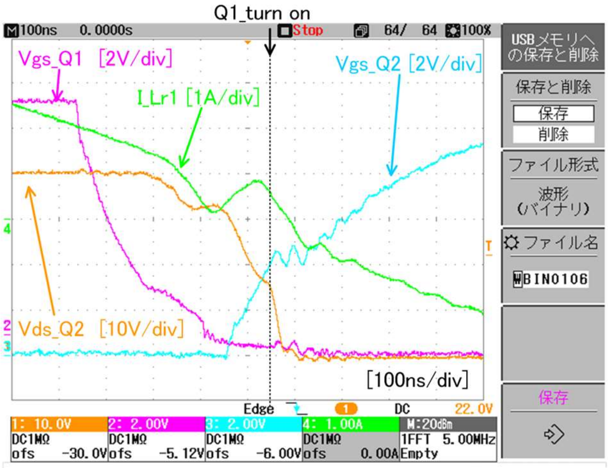


Figure 6 waveform @turn on (ZCS&ZVS)

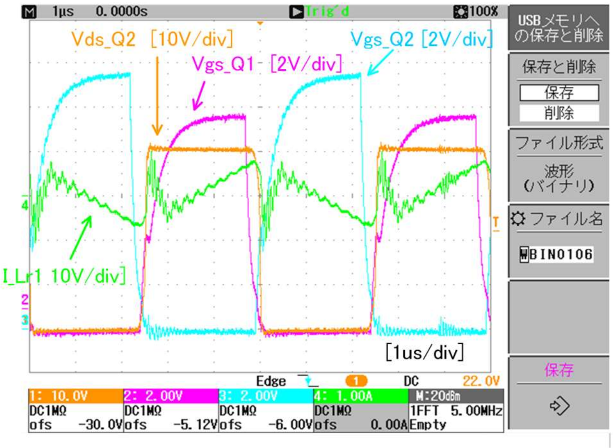


Figure 7 waveform (ZCS) (@light load)

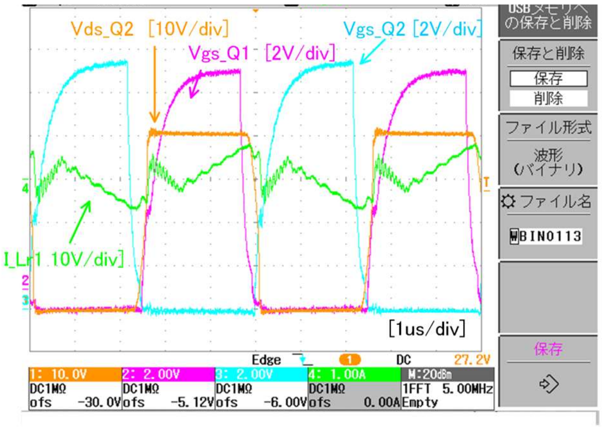


Figure 8 waveform (ZCS&ZVS) (@light load)

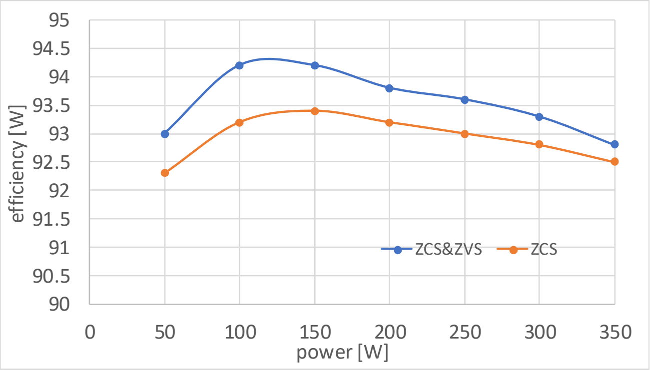


Figure 9 power vs frequency @ ZCS ,ZCS&ZVS

5.2. Evaluation of high frequency transformer

The transformer of Table 2 was connected to the DCDC converter and evaluated.

Figure 13 shows the conversion efficiency when the load power of the converter is changed from 50 W to 350 W at the switching frequency of 200 kHz. We compare the case where the wire diameter of the Litz wire of the transformer is φ0.05 and φ 0.1. At this time, transformers with current density, core material and core size under the same conditions were used.

In this case, the efficiency of the converter using the transformer with the wire diameter φ 0.05 was improved by about 0.5% at the maximum.

Figure 12 compares the conversion efficiency of the converter when the switching frequency is varied from 100 kHz to 200 kHz.

At a high frequency of 200 kHz, efficiency of φ 0.05 is about 0.8% better. However, the difference became smaller as the frequency became lower. At 100 kHz or less the difference between the two was reduced to 0.2%. Figure 14 shows the analysis results of the loss at the switching frequency of 200 kHz. In this regard, it was found that transformer loss can be reduced by 1.5 W by changing the Litz wire. Since the operating conditions of the converter are the same, the loss of 1.5 W is considered to be an eddy current loss due to leakage.

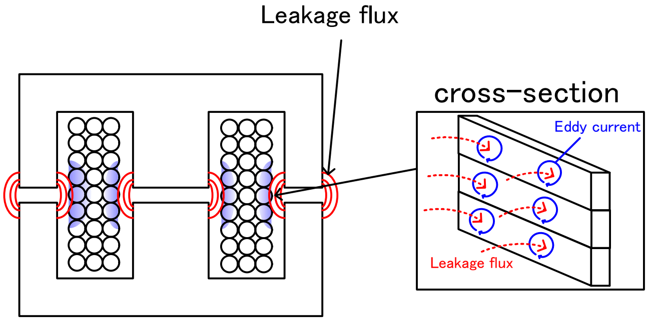


Figure 11 Eddy current loss of winding

Table 2 specifications of transformer

		trans former ①	trans former ②
number of turns[T]	primary	2	
	secondary	8	
ritz wire	primary	150/Φ0.1×4p	600/Φ0.05×4p
	secondary	150/Φ0.1	600/Φ0.05
current density[A/mm^2]		4.24	
core material		ferrite(PQ)	
gap [mm]		0	
magnetizing inductance [uH]		21.3	21.5

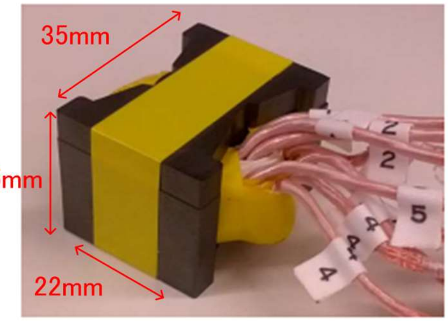


Figure 10 High frequency transformer

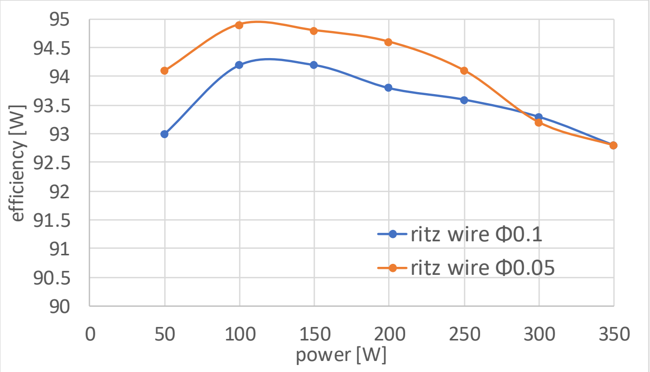


Figure 13 power vs efficiency

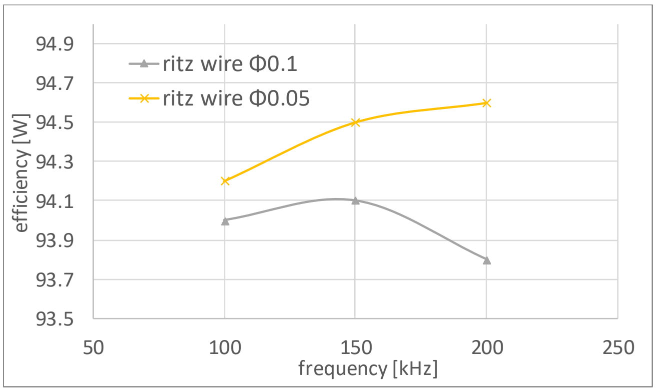


Figure 12 switching frequency vs efficiency(@200W)

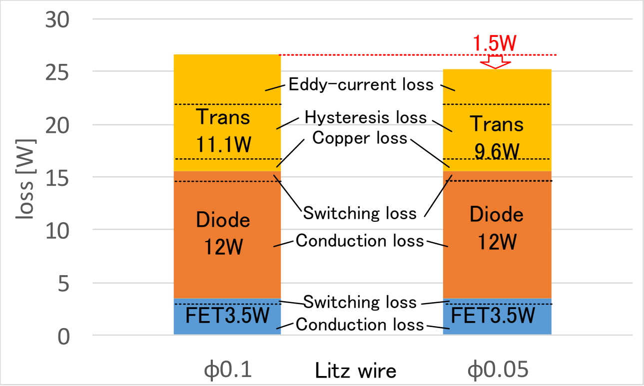


Figure 14 loss analysis (@200kHz,300W)

6. Conclusion

We investigated and evaluated the loss reduction which becomes noticeable at high frequencies in the current resonant DCDC converter for micro inverters. We performed operating analysis considering the parasitic component and achieved ZVS by experiment. A loss of 0.3% to 1% was improved compared with ZCS. In addition, the usefulness of a transformer using a litz wire with a small wire diameter at high frequencies was quantitatively shown using an insulated DCDC converter. Miniaturization of the microinverter is required. For miniaturization, it is necessary to increase the frequency. We believe that this evaluation is a very useful result for miniaturization. In the experiment, when the wire diameter of the Litz wire was changed from φ0.1 to φ0.05, the conversion efficiency of the converter improved by about 0.8% at the maximum at 200 kHz. Moreover, it was found that the loss in the case of the Litz wire strand diameter φ 0.05 is reduced in the region of 100 kHz or more. In the future, we will study the influence of transformer leakage on the Litz wire and the method of supplementing the resonance inductance with the leakage of the transformer on a real machine basis and we will strengthen the guidelines for transformer design in the high frequency range.

Acknowledgement

This study was supported by New Energy and Industrial Technology Development Organization (NEDO) of Japan.

References

[1] Ministry of Economy, Trade and Industr,y
Fiscal year 2012 Survey on promotion of introduction of new energy etc.
Survey on diffusion trend of photovoltaic power generation system etc

[2] Association, Japan Photovoltaic Energy,
Residential photovoltaic power generation subsidy applications received.pdf

[3] J. Y.Ohnuma,
A Single-phase Current Source PV Inverter with Power Decoupling Capability using an Active Buffer, IEEJ Journal of Industry Applications ,pp169-172 , 2012.

[4] K. J. I. Y. S. H.Watanabe,
Miniaturization of the Boost-up type Active Buffer Circuit in a Single-phase Inverter, The 2014 International Power Electronics Conference, No. 19,P1-4, pp. 84-91 , 2014.