QUASI-RESONANT CONVERTER WITH DIVIDED RESONANT CAPACITOR ON PRIMARY AND SECONDARY SIDE

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Abstract — This paper presents a quasi-resonant converter with divided resonant capacitor on primary and secondary side of the isolation transformer. A conventional quasi-resonant converter using flyback topology can realize soft switching with simple circuit. However, relatively large surge voltage is generated in the switching device. To suppress such surge voltage, resonant capacitor is divided on primary side and secondary side in the proposed converter. In case of prototype 95W converter, the voltage applied to switching device of proposed converter has been 26% lower than that of conventional converter. In addition, efficiency of proposed converter has been 1% higher than that of conventional converter.

I. INTRODUCTION

Smaller size, lower weight, higher efficiency and low noise have been required for switching power supplies. Many types of the power supply with zero voltage switching (ZVS) have been presented to realize the requirement. As to most of the power supply with ZVS, there is the weak point that control circuit is complicated and auxiliary switching devices have to be added. On the other hand, power supplies with simpler circuit are also required, especially in home electric appliances.

For such a demand, a quasi-resonant converter with flyback topology is employed. However, large surge voltage is applied to switching device in such conventional quasi-resonant converter. Therefore, a switching device with high withstand voltage is used and it causes decrease of efficiency because a switching device with high withstand voltage has relatively high on voltage. Such surge voltage of the conventional converter is analyzed and the optimum design is proposed. [1], [2]

On the other hand, to decrease the surge voltage applied to the switching device more effectively, we proposed a novel quasi-resonant converter of which resonant capacitor is divided and placed in both primary and secondary side as shown in Fig.1.[3]

In this paper, the characteristics are verified under some conditions in order to fined optimum condition by simulation and experiment.

II. OPERATION PRINCIPLES

Fig.1 shows the circuit configuration of the proposed quasi-resonant converter. The circuit consists of transformer T_1, switching device Q_1, diode D_1, output capacitor C_o, resonant capacitor C_{rp} and C_{rs}. Resonant capacitor is divided into C_{rp} and C_{rs} and placed in primary and secondary side. The secondary resonant capacitor C_{rs} is not employed in the conventional quasi-resonant converter.

The circuit is converted to equivalent circuit as shown in Fig.2 in order to explain the operation simply. Transformer T_1 is replaced with primary inductance L_m, leakage inductance L_L and winding resistance R_p and R'_s. The secondary resonant capacitor C_{rs} is replaced with C'_{rs} by following equation:

$$C'_{rs} = \left(\frac{N_S}{N_P}\right)^2 C_{rs} \qquad (1)$$

Where N_p is number of turns of primary winding and N_s is number of turns of secondary winding. C_o is also replaced with C'_o by the same way. Replaced output voltage V'_o is represented by following expression (2).

$$V'_o = \left(\frac{N_P}{N_S}\right) V_o \qquad (2)$$

The operation is explained by 6 states. Fig.3 shows voltage and current waveform. Fig.4 shows current flow in each state.

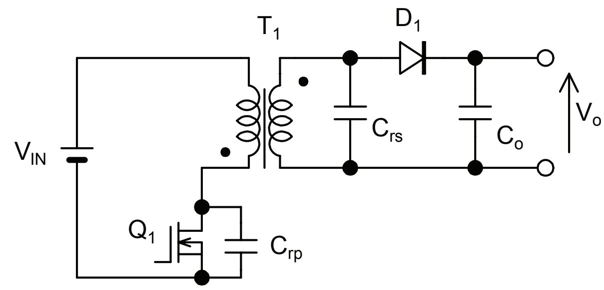

Fig.1 Circuit configuration of proposed converter

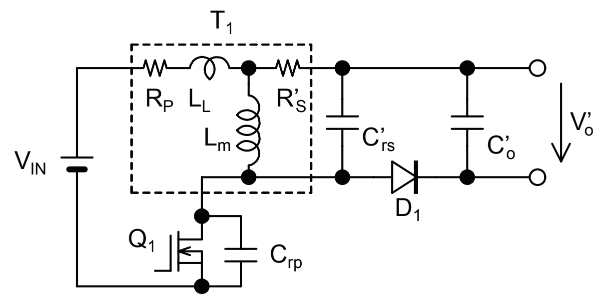

Fig.2 Equivalent circuit for analysis of operation

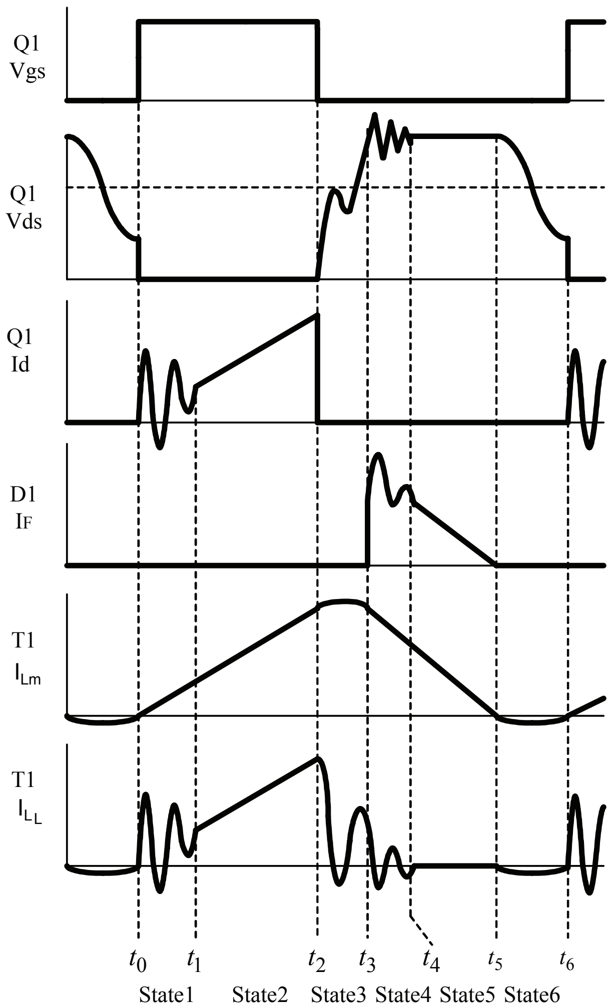

Fig.3 Voltage and current waveform

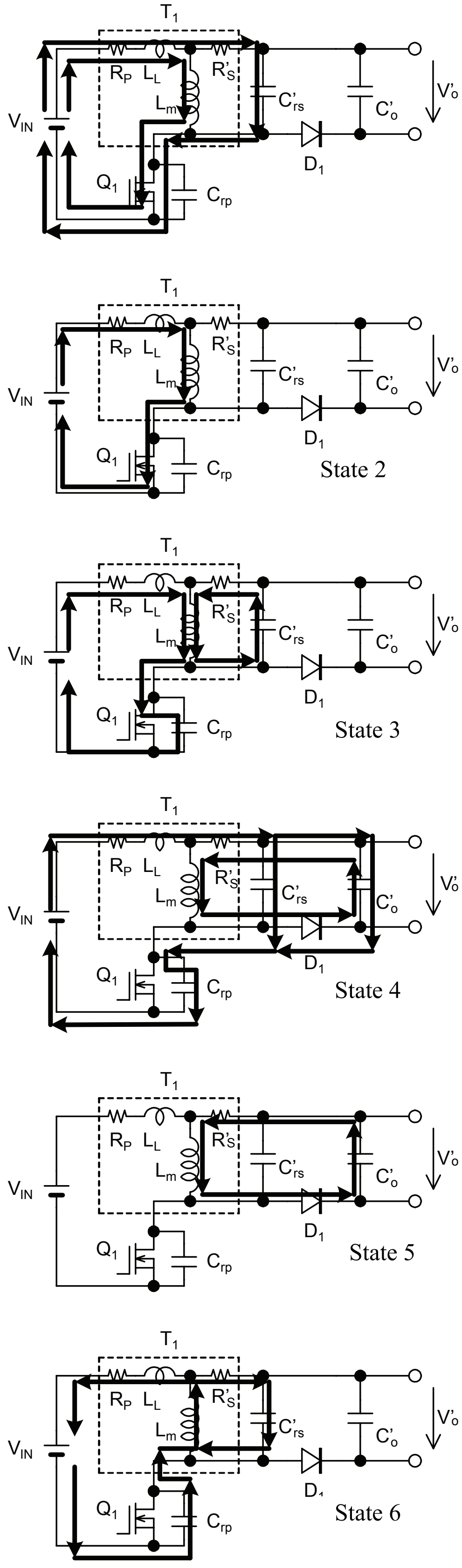

Fig.4 Operating state of proposed converter

Each state is explained as follows:

(i) State 1 ($t_0 - t_1$)

Q_1 turns on and the current of primary inductance L_m rises from zero. At the same time, a current flows to secondary resonant capacitor C_{rs} through leakage inductance L_L. The resonant frequency of the capacitor C_{rs} and inductance L_L is higher than switching frequency. Therefore, oscillation current is observed on the L_L current and Q_1 current. Then, the resonant current flowing to C_{rs} is attenuated and becomes almost zero because of R_P and R_S.

(ii) State 2 ($t_1 - t_2$)

The primary inductance current I_{Lm} increases linearly and the electrical energy is stored in the transformer T_1.

At time t_2 Q_1 is turned off.

(iii) State3 ($t_2 - t_3$)

The primary inductance current I_{Lm} flows through the resonant capacitor C_{rp} and C'_{rs}. The current I_{Lm} separate in proportion to capacitance of C_{rp} and C'_{rs}. On the other hand, the same current to I_{Lm} flows to leakage inductance L_L in state

2, therefore the current I_{LL} becomes smaller as I_{Lm} is separate. However, I_{LL} decreases with oscillating because of the current loop consist of V_{IN}, L_L, C_{rp} and C'_{rs}.

(iv) State 4 ($t_3 - t_4$)

The C'_{rs} voltage reaches V'_o and the diode D_1 turns on at time t_3. The energy stored in primary inductance L_m is output to secondary side. The leakage inductance L_L also stored energy in state 3 and the energy is charged to resonant capacitor C_{rp} in state 4. It causes surge voltage on the Q_1 Vds.

(v) State 5 ($t_4 - t_5$)

L_m current I_{Lm} gradually decrease as the stored energy is output.

(vi) State 6 ($t_5 - t_6$)

When the all energy stored in inductance L_m has been output and current I_{Lm} and I_F becomes zero, Q_1 voltage Vds drops with sinusoidal waveform because of resonance of L_m, C_{rp} and C_{rs}. Q_1 turns on at the bottom of resonance.

As described above, the current flows leakage inductance L_L decreases in state 3. Decrease of the current of leakage inductance is effective to reduce surge voltage applied to switching device Q_1 in state 4. On the other hand, conventional quasi-resonant converter does not have the secondary resonant capacitor C_{rs}. Therefore, the current of leakage inductance I_{LL} does not decrease in state 3 and surge voltage becomes relatively larger.

III. SURGE VOLTAGE APPLIED TO SWITCHING DEVICE

As described above, the current of leakage inductance I_{LL} decreases in state 3 and the surge voltage decreases in state 4 on the proposed converter. However, I_{LL} decreases with oscillating in state 3 as shown in Fig.3. I_{LL} at time t3 depends on the timing when D_1 began to flow the current. It means that I_{LL} at time t_3 depends on the many circuit parameters such as each component values, input and output condition etc. Therefore, in order to find optimum value of resonant capacitor C_{rp} and C_{rs}, the circuit operation is simulated with the equivalent circuit Fig.2 in some condition.

In each simulation, the common condition is listed in Table 1.

TABLE 1
CIRCUIT PARAMETERS OF SIMULATIONS

Device No.	Circuit parameter
V_{IN}	140Vdc
V'_o	110Vdc
L_m	366μH
L_L	5.6μH
R_P	10Ω
R'_S	10Ω

A. *Condition 1*

In condition 1, total value of resonant capacitor C_{rp} and C'_{rs} is fixed to 2000pF and Q_1 voltage is simulated under each combination of C_{rp} and C'_{rs}.

The result is shown in Fig.5

Vds of Q_1 becomes lowest under the condition that C_{rp} and C'_{rs} is the same value.

When C_{rp} is 2000pF, i.e. C'_{rs} is zero, Fig.5 shows the Vds of conventional converter. Vds of proposed converter is 19% lower than that of conventional converter.

B. *Condition 2*

In condition 2, C_{rp} is fixed to 1000pF and C'_{rs} is increased, then Q1 voltage is simulated.

The result is shown in Fig.6. In condition 2, V_{ds} becomes smallest when C'_{rs} is 1700pF. It means that the optimum value of C_{rp} and C'_{rs} exists and too large capacitor is not effective to reduce surge voltage of switching device.

The simulated Q_1 waveform at turn off is shown in Fig.7 and Fig.8. Fig.7 is under the condition of C'_{rs}=1700pF and Fig.8 is under the condition of C'_{rs}=0pF. As shown in simulated waveform, surge voltage is suppressed with optimum resonant capacitor.

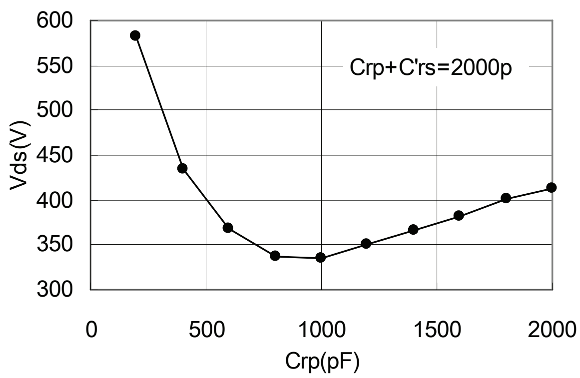

Fig.5 Simulated Q_1 voltage in condition 1

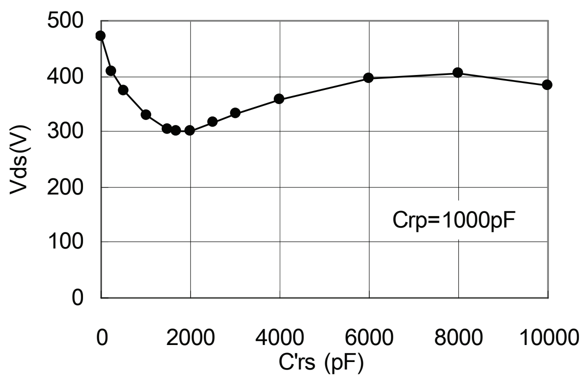

Fig.6 Simulated Q_1 voltage in condition 2

C. Condition 3

In condition 3, total value of C_{rp} and C'_{rs} is changed from 1000pF to 5000pF. The result is shown in Fig.9 and Fig.10.

From the result of Fig.9, we can find the optimum value of the ratio of Crp is approximately 0.4 to 0.6 to suppress surge voltage.

Fig.10 shows the result that surge voltage of proposed circuit with 0.5 of the C_{rp} ratio and that of conventional circuit. From the result of Fig.10, we can find that there is a optimum value of (C_{rp} + C'_{rs}) and too large (C_{rp} + C'_{rs}) is not effective to suppress surge voltage. In this condition, the surge voltage becomes smallest when the total value of C_{rp} and C'_{rs} is 3000pF. In addition, the effect of dividing resonant capacitor becomes smaller in comparison with conventional converter when large (C_{rp} + C'_{rs}) is too large.

D. Condition 4

In condition 4, proposed converter is simulated taking ON pulse width of switching device Q_1 as a parameter in order to confirm the relationship between output power of the converter and surge voltage. In this condition, C_{rp} and C'_{rs} is fixed to 1000pF. In addition, the conventional converter is simulated with Crp=2000pF.

As shown in Fig.11, surge voltage of proposed converter is smaller than that of conventional converter when ON pulse width is larger than 5μs. In other word, surge voltage is suppressed effectively when output power of the converter is large. Generally, surge voltage becomes large when output power is large. Therefore switching device with lower withstand voltage can be used in proposed converter.

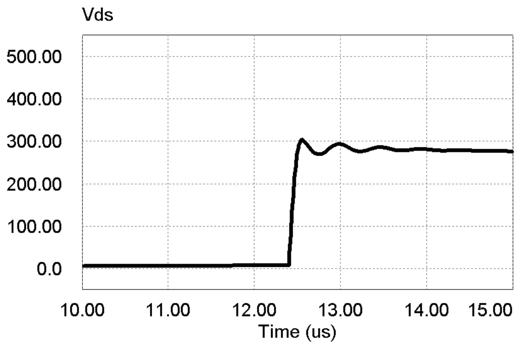

Fig.7 Simulated Q_1 voltage waveform in condition 2 (C'_{rs}=1700pF)

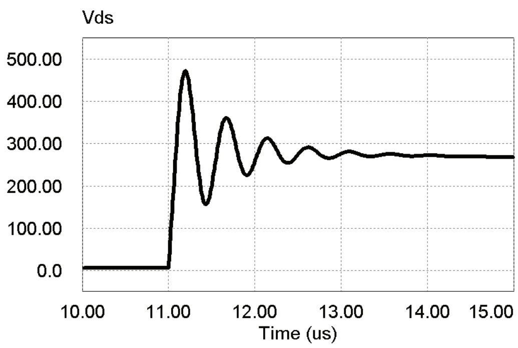

Fig.8 Simulated Q_1 voltage waveform in condition 2 (C'_{rs}=0pF)

E. Condition 5

In condition 5, the proposed converter is simulated with C_{rp}=C'_{rs}=500pF and C_{rp}=C'_{rs}=1000pF taking ON pulse width of switching device Q1 as a parameter. The result is shown in Fig.12.

In condition of C_{rp}=C'_{rs}=500pF, surge voltage is suppressed most effectively when ON pulse width is 5μs.

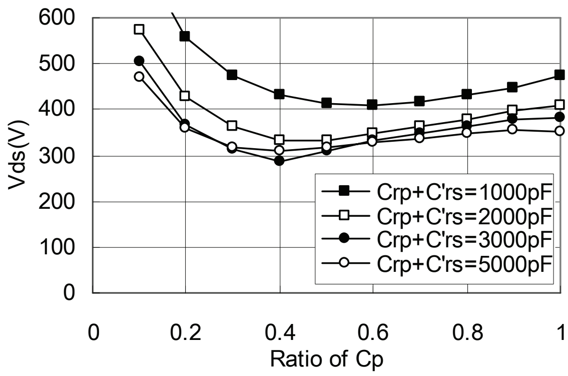

Fig.9 Simulated Q_1 voltage in condition 3 (1)

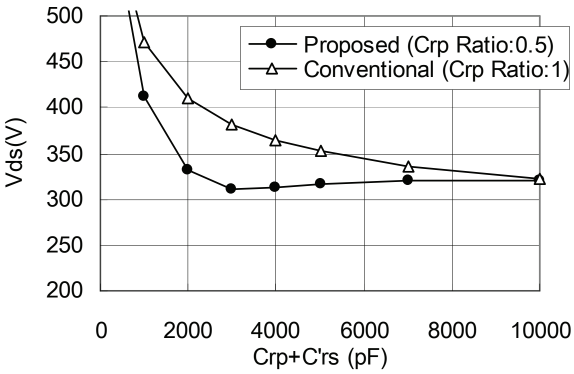

Fig.10 Simulated Q_1 voltage in condition 3 (2)

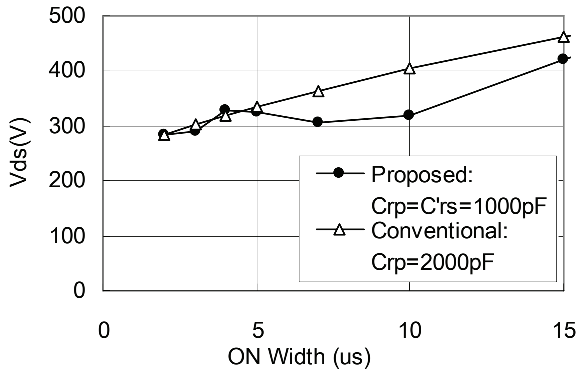

Fig.11 Simulated Q_1 voltage in condition 4

On the other hand, in condition of C_{rp}=C'$_{rs}$=1000pF, surge voltage is suppressed more effectively when ON pulse width is 10 µs.

From the result, we can find that larger resonant capacitor is better for large power and not always effective for smaller output power.

From the result of 5 condition simulation, we can conclude the characteristics of proposed converter as bellows.

- Proposed converter using divided resonant capacitor can suppress surge voltage applied to switching device more effectively than conventional converter.
- The optimum ratio of primary resonant capacitor C_{rp} to total resonant capacitor C_{rp}+C'$_{rs}$ is approximately 0.4 to 0.6.
- The proposed converter suppresses surge voltage more effectively in case of large output power in comparison with conventional converter.
- The large resonant capacitor is not always effective. When output power is relatively small, smaller resonant capacitor is better.

IV. EXPERIMENTAL RESULT OF PROTOTYPE

In order to verify the characteristics of proposed converter, a prototype is fabricated with the specification listed in TABLE 2. The input voltage of the prototype is AC voltage. The AC voltage is rectified, smoothed by capacitor and input to the proposed converter.

TABLE 2
SPECIFICATION OF THE PROTOTYPE CONVERTER

Items	Specification
Input voltage	100 to 240Vac
Output voltage	19Vdc
Output current	5A
Primary inductance	366uH
Windings of transformer	Primary: 57 turns Secondary: 10 turns

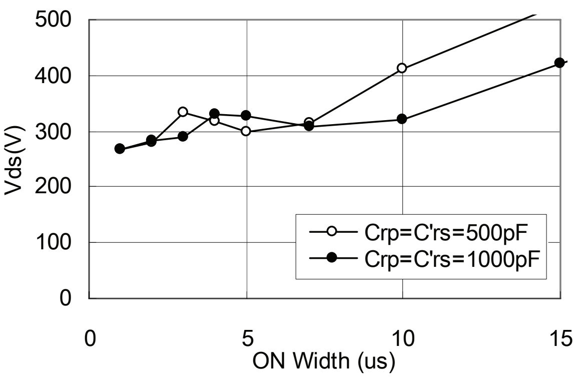

Fig.12 Simulated Q_1 voltage in condition 5

We tested the prototype under the similar condition to the condition 2 of simulation.

C_{rp} is fixed to 1000pF and C'$_{rs}$ is increased then Q_1 voltage is measured. In addition, we measured Vds voltage adding a capacitor equivalent to C'$_{rs}$ on the primary side as the conventional converter. The test result is shown in Fig.13.

The minimum V_{ds} of proposed converter is obtained at 2700pF of the total resonant capacitor, i.e. C_{rp}=1000pF and C'$_{rs}$=1700pF. The result shows good agreement with simulation.

In addition, it is found that V_{ds} of proposed converter is lower than that of conventional converter. In this test, V_{ds} of proposed is 26% lower than that of conventional converter.

Fig.14 shows the efficiency of the prototype. The efficiency of the proposed converter is 1% higher than that of conventional converter.

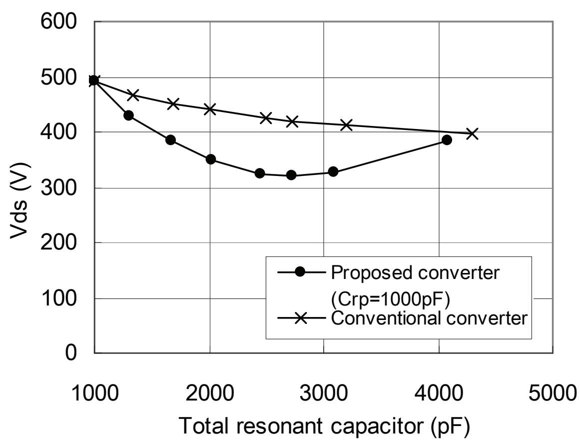

Fig.13 Measured Vds voltage of the prototype

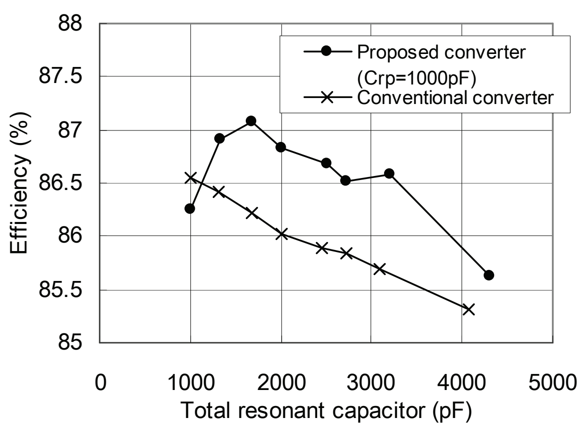

Fig.14 Measured efficiency of the prototype

Fig.15 and Fig.16 shows Vds waveform of the prototype.

Fig.15 is under the condition of C_{rp}=1000pF and C'_{rs}=1700pF. Fig.16 is under the condition of C_{rp}=1000pF + 1700pF which is equal to conventional converter.

It is found that surge voltage applied to switching device is suppressed in the proposed converter.

V. CONCLUSION

The quasi-resonant converter with divided resonant capacitors on primary and secondary of the isolation transformer has been presented.

According to analysis with the equivalent circuit and experimental result with the prototype, we conclude as follows:

1) The proposed quasi-resonant converter can reduce surge voltage applied to the switching device by the effect of the divided resonant capacitor.

In case of the prototype converter, the voltage applied to switching device is 26% lower than that of the conventional converter with optimum condition.

2) Efficiency is also improved with divided resonant capacitor. In case of the prototype converter, the efficiency of proposed converter is 1 % higher than that of conventional converter.

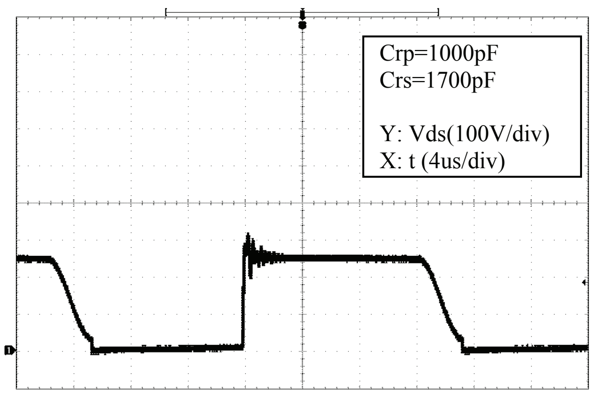

Fig.15 Vds waveform of proposed converter

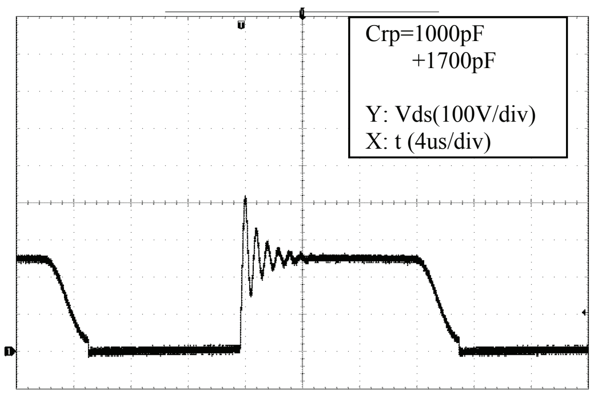

Fig.16 Vds waveform of conventional converter

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