

# Novel Series Resonant DC-DC Converter with Voltage Doubler Rectifier

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**Abstract**-This paper deals with a novel composite resonance DC-DC converter with the voltage doubler rectifier, which is developed to be applied to the power conditioner of the photovoltaic generation system. The proposed DC-DC converter has the current and voltage resonance functions. Therefore, the output voltage regulation can be achieved for the large variations of the input voltage and load. Also, this converter has the high power efficiency. The maximum power efficiency 97.7% can be realized.

## I. INTRODUCTION

Recently, there is an increasing spread in the photovoltaic generation system [1,2] all over the world because many persons are interested in the clean energy system from the viewpoint of the ecological problem. In this paper, a novel composite resonance DC-DC converter is proposed and developed, in which the current and voltage resonances [3-5] and the voltage doubler rectifier are employed as the power conditioner of the photovoltaic generation system. The output voltage can be regulated for the large variations of the input voltage and load because of the current and voltage resonance circuits. Also, the high power efficiency can be achieved by using not only the composite resonance but also the voltage doubler rectifier. Furthermore, the burst oscillation control is used to improve the power efficiency under the condition that the input voltage is high and the load is light.

## II. CIRCUIT CONFIGURATION

Fig.1 shows the proposed composite resonance DC-DC converter with the voltage doubler rectifier, in which the current and voltage resonance circuits are employed. In this figure, Q1 and Q2 are main switches of IGBTs. C<sub>v</sub> and C<sub>i</sub> are the voltage and current resonance capacitors. L<sub>1</sub> and L<sub>2</sub> are inductances of the primary and secondary windings of the transformer T. The leakage inductance L<sub>i</sub> is used, which exists between the primary and secondary windings of T. The voltage doubler rectifier is composed of the diodes D1 and

D2, and capacitances C<sub>d</sub> and C<sub>o</sub>. The IGBT switches Q1 and Q2 are turned-on and turned-off alternatively. There exists the short dead time between the on-times of Q1 and Q2.

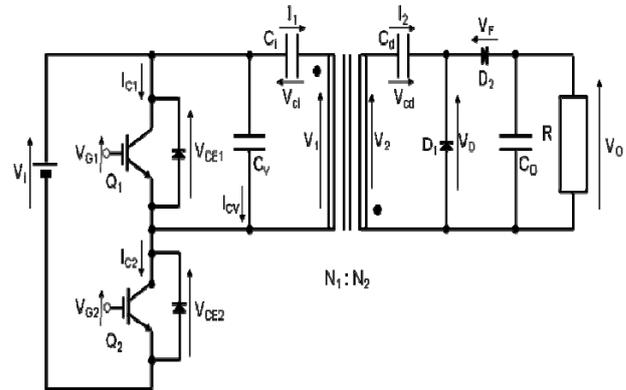


Fig.1 Proposed voltage and current resonance DC-DC converter with the voltage doubler rectifier.

## III. STATE OF OPERATION AND OPERATION MODE

### (A) Operational Mode 1

State-1: The equivalent circuit of state-1 is shown in Fig.2(a).

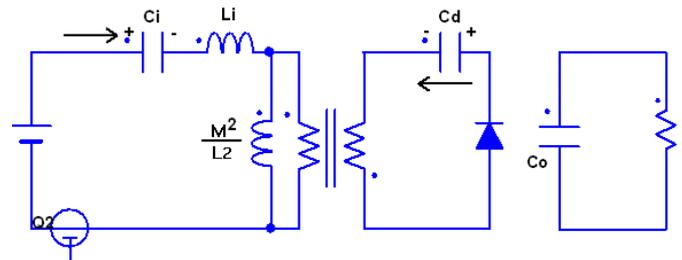


Fig. 2(a) State-1 (Only D1 and Q2 are on)

The current I<sub>c2</sub> flowing in the IGBT switch Q2 is in the state of the current resonance by capacitance C<sub>i</sub> and inductance L<sub>1</sub>. At this time, on the secondary side, diode D1 is on and the charge is charged to capacitance C<sub>d</sub> for the voltage doubler. From

Fig. 2(a) state-1, relations of the input voltage  $V_i$ , primary and secondary winding currents  $I_1$  and  $I_2$  and voltage  $V_{ci}$  and  $V_{cd}$  across  $C_i$  and  $C_d$  are expressed as follows:

$$V_i = L_1 \frac{dI_1}{dt} + M \frac{dI_2}{dt} + V_{C_i} \quad (1)$$

$$0 = L_2 \frac{dI_2}{dt} + M \frac{dI_1}{dt} + V_{C_d} \quad (2)$$

$$I_1 = C_i \frac{dV_{C_i}}{dt} \quad (3)$$

$$I_2 = C_d \frac{dV_{C_d}}{dt} \quad (4)$$

$$L_i = L_1 - \frac{M^2}{L_2} \quad (5)$$

State-2: The equivalent circuit of state-2 is shown in Fig. 2(b).

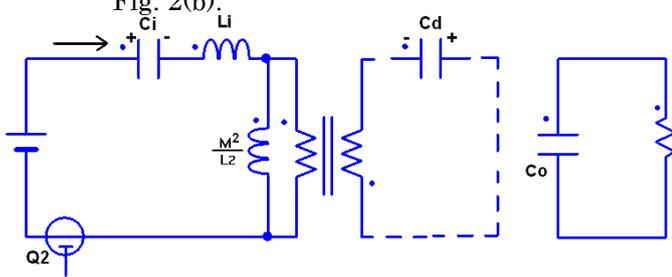


Fig. 2(b) State-2 (Only Q2 is on)

As well as state-1, it is in the state of the current resonance by capacitance  $C_i$  and inductance  $L_1$ . However, diode  $D_1$  is off by voltage charged capacitance  $C_d$ , and the current doesn't flow to the secondary side. From Fig. 2(b), the relations of  $V_i, I_1$  and  $V_{ci}$  are expressed as follows:

$$V_i = L_1 \frac{dI_1}{dt} + M \frac{dI_2}{dt} + V_{C_i} \quad (6)$$

$$I_1 = C_i \frac{dV_{C_i}}{dt} \quad (7)$$

State-3: The equivalent circuit of state-3 is shown in Fig. 2(c).

The IGBT switch  $Q_2$  is off, and the voltage  $V_{CE1}$  between the drain and the source is in the state of the voltage resonance by the capacitance  $C_v$  and the self-inductance of transformer connected with the IGBT switch  $Q_2$  in parallel. From Fig. 2(c), the relations of  $V_{cv}, V_{ci}$  and  $I_1$  are expressed as follows:

$$0 = L_1 \frac{dI_1}{dt} + V_{C_i} + V_{C_v} \quad (8)$$

$$I_1 = C_v \frac{dV_{C_v}}{dt} \quad (9)$$

$$I_1 = C_i \frac{dV_{C_i}}{dt} \quad (10)$$

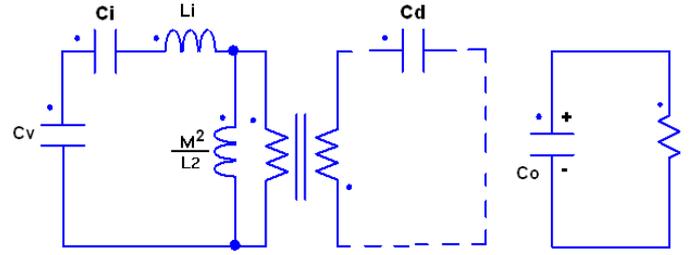


Fig. 2(c) State-3 (All of IGBTs and diodes are off)

State-4: The equivalent circuit of state-4 is shown in Fig. 2(d).

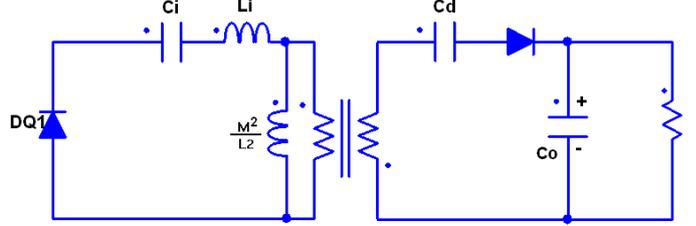


Fig. 2(d) State-4 (Only DQ1 and D2 are on)

The state of the voltage resonance works end, and the diode  $D_1$  and  $D_2$  are on. The period of these, the state-3 and the state-4 are the dead time. And the voltage of  $V_{CE1}$  turns and after it becomes zero volt, the IGBT switch  $Q_2$  is on and it is in the state of zero voltage switching. From Fig. 2(d), the relations of  $I_1, I_2, V_{ci}$  and  $V_{cd}$  are expressed as follows:

$$0 = L_1 \frac{dI_1}{dt} + M \frac{dI_2}{dt} + V_{C_i} \quad (11)$$

$$V_0 = L_2 \frac{dI_2}{dt} + M \frac{dI_1}{dt} + V_{C_d} \quad (12)$$

$$I_1 = C_i \frac{dV_{C_i}}{dt} \quad (13)$$

$$I_2 = C_d \frac{dV_{C_d}}{dt} \quad (14)$$

State-5: The equivalent circuit of state-5 is shown in Fig. 2(e).

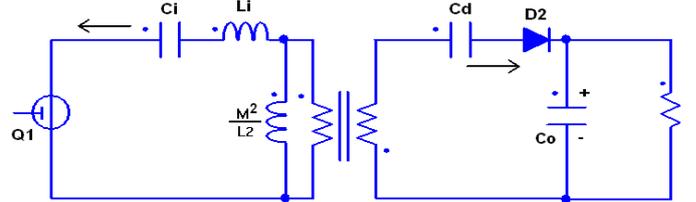


Fig. 2(e) State-5 (Only Q1 and D2 are on)

The IGBT switches  $Q_2$  and diode  $D_2$  are on and on the primary side, the charge charged capacitance  $C_i$  is discharged as a result, it is in the state of the current resonance by the leakage inductance  $L_i$ . And on the secondary side, the charge charged capacitance  $C_d$  for the voltage doubler flows into the output. From Fig. 2(e), the relations of  $I_1, I_2, V_{ci}, V_{cd}$  and  $V_0$  are expressed as follows

$$0 = L_1 \frac{dI_1}{dt} + M \frac{dI_2}{dt} + V_{C_i} \quad (15)$$

$$V_0 = L_2 \frac{dI_2}{dt} + M \frac{dI_1}{dt} + V_{Cd} \quad (16)$$

$$I_1 = C_i \frac{dV_{Ci}}{dt} \quad (17)$$

$$I_2 = C_d \frac{dV_{Cd}}{dt} \quad (18)$$

State-6: The equivalent circuit of state-6 is shown in Fig.2(f).

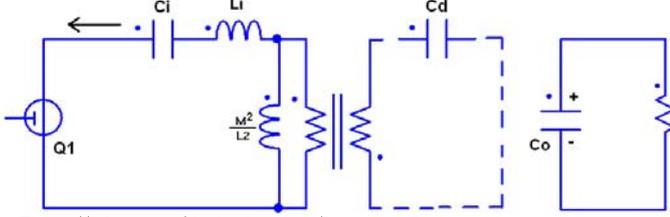


Fig. 2(f) State-6 (Only Q1 is on)

The diode D2 is off by the charge charged capacitance Co, and the secondary winding current I2 doesn't flow. From Fig. 2(f), the relations of Vci and I1 are expressed as follows:

$$0 = L_1 \frac{dI_1}{dt} + V_{Ci} \quad (19)$$

$$I_1 = C_i \frac{dV_{Ci}}{dt} \quad (20)$$

State-7: The equivalent circuit of state-7 is shown in Fig.2(g).

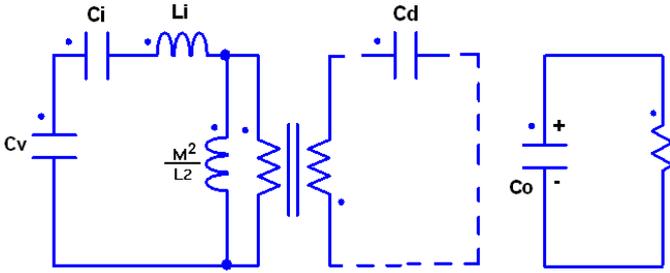


Fig. 2(g) State-7 (All of IGBTs and diodes are off)

All of IGBTs and diodes are off, and it is in the state of the voltage resonance by capacitance Cv. From Fig. 2(g), the relations of Vcv, Vci and I1 are expressed as follows

$$0 = L_1 \frac{dI_1}{dt} + V_{Ci} + V_{Cv} \quad (21)$$

$$I_1 = C_v \frac{dV_{Cv}}{dt} \quad (22)$$

$$I_1 = C_i \frac{dV_{Ci}}{dt} \quad (23)$$

State-8: The equivalent circuit of state-8 is shown in Fig.2(h).

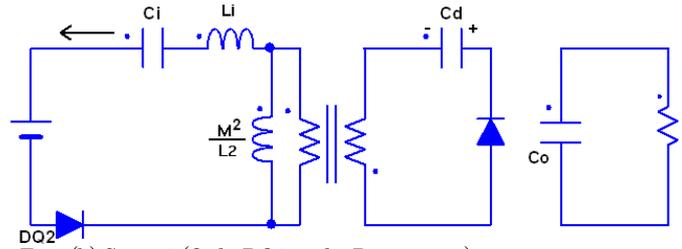


Fig.2(h) State-8 (Only DQ2 and D1 are on)

Only DQ2 and D1 are on and it is in the state of zero voltage switching. From Fig. 2(h), the relations of Vi, Vci, Vcd, I1, I2 and Vo are expressed as follows:

$$V_i = L_1 \frac{dI_1}{dt} + M \frac{dI_2}{dt} + V_{Ci} \quad (24)$$

$$0 = L_2 \frac{dI_2}{dt} + M \frac{dI_1}{dt} + V_{Cd} \quad (25)$$

$$I_1 = C_i \frac{dV_{Ci}}{dt} \quad (26)$$

$$I_2 = C_d \frac{dV_{Cd}}{dt} \quad (27)$$

The voltage and current waveforms of operation mode 1 are shown in Fig.3. There exist 8 states in the operation mode 1, which is the sequence of state 1 through state 8.

#### (B) Operational Mode 2

There exist 4 states in the operation mode 2, which is the sequence of state-1, state-9, state-5 and state-10. The equivalent circuits of state-9 and state-10 are shown in Fig. 2(i) and Fig. 2(j), respectively.

State-9: The equivalent circuit of state-9 is shown in Fig.2(i)

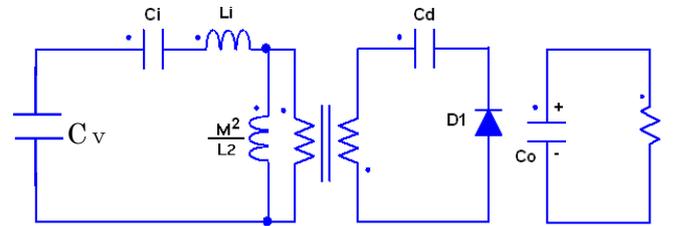


Fig.2(i) State9 ( D1 are on)

Only D1 are turned-on, it is in the voltage resonance by the capacitance Cv.

State-10: The equivalent circuit of state-10 is shown in Fig.2(j)

Only DQ1 and D2 are on, and it is in the voltage resonance.

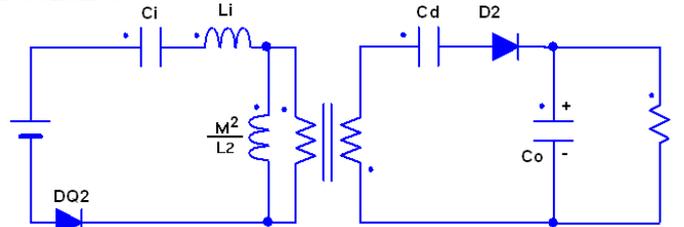


Fig.2(j) State-10 (Only DQ2 and D2 are on)

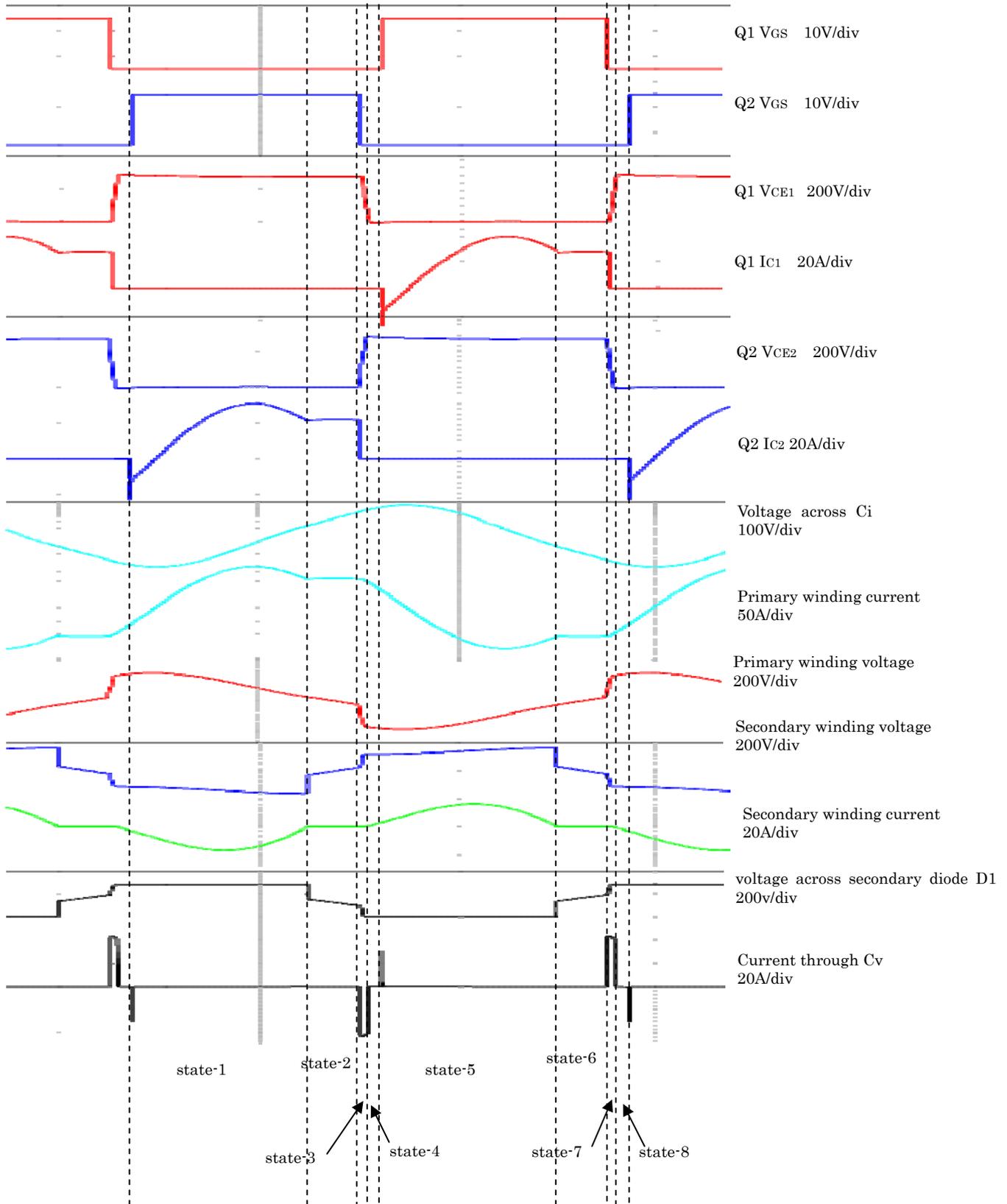


Fig.3 Simulation waveforms of operational mode

#### IV.COMPARISON BETWEEN OBSERVED WAVEFORMS AND SIMULATED ONES

Fig.4 shows the simulation and observed waveforms. It is seen in Fig.4 that the simulation result is agreed well with the observed one. In this case, the DC input voltage is 140V, output voltage is 350V and

output power is 1kW. The switching frequency is about 20 kHz and dead time is about  $2 \mu$  sec.

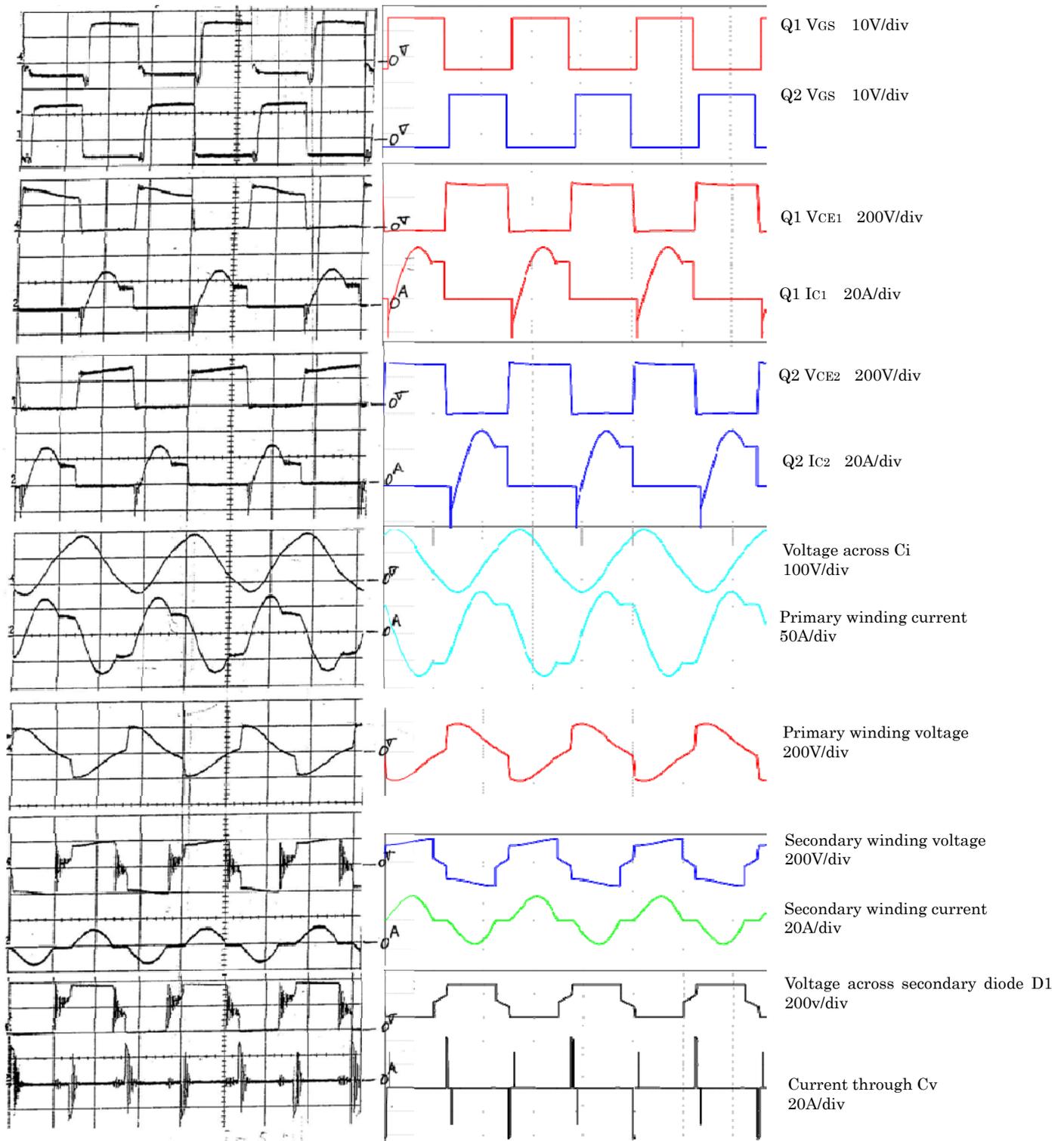


Fig.4. Simulation and observed waveforms

## V. POWER EFFICIENCY

Fig.5 shows the power efficiency characteristics. The maximum power efficiency is 97.7% at 280V DC of the input voltage and 1167W of the output power.

Under the condition that the input voltage is high and the load is light the burst oscillation control is used to improve the power efficiency and to expand the sphere of control.

## VI. CONCLUSION

It proposed a novel composite resonance DC-DC converter with the voltage rectifier for the power conditioner of the photovoltaic generation system. The maximum power efficiency 97.7% can be realized at 280V DC of the output voltage and 1167W of the output power.

## REFERENCES

- [1]Yosimi Horiuchi,Hironori Nisihara,Takashi Ujiie," New Energy Power Generating System at Fuji Electric Co., Ltd. Ability Development Center", Fuji Electric Co., Ltd. Technical Report, Vol.75 No.5,pp.281-284, 2002
- [2]Hiroaki Endo, Shinya Yokoyama, Takafumi Takuma, Masahide Yamaguchi, Haruhiko Mizuta, Yasuhito Sugimura,"Application of Battery Combined Photovoltaic Generation System for Disaster-Proof House," Journal of Japan Institute of Power Electronics, Vol.31,pp.109-114, March 2006
- [3]C.F.Jin, T.Ninomiya, S.Tomioka,"Dynamic Characteristics of LLC Current-Resonant DC-DC Converter", IEICE Technical Report, EE2008-35, pp.1-6, October 2008
- [4]Koichi Morita," Ultra Low-noise switch-mode Power Supply", Journal of Japan Institute of Power Electronics Electronics, Vol.30, pp.4-11, March 2004
- [5]Masakazu Gekinozu, yukihiro Nishikawa, Takeshi Nozawa, "DC-DC Transformational Technology for Switching Power Supply", Fuji Electric Co., Ltd. Technical Report, Vol.75 No.8, pp. 456-459 2002

