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Novel Composite Resonance 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 96.1% 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.2.1 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. Cv and Ci are the voltage and current resonance capacitors. L1 and L2 are inductances of the primary and secondary windings of the transformer T. The leakage inductance Li 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 Cd and Co. 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.
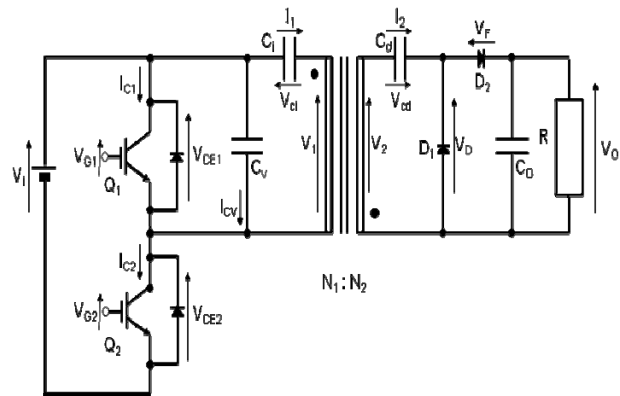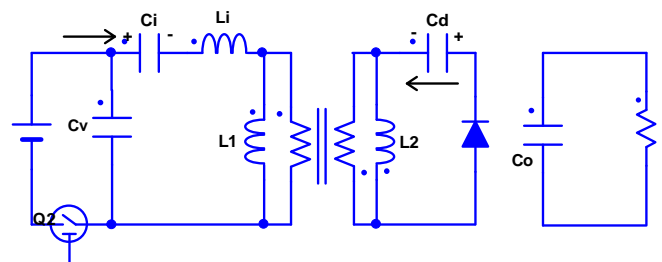

Fig.2.1 Proposed voltage and current resonance DC- DC converter with the voltage doubler rectifier.

III.STATE OF OPERATION AND OPERATIONAL MODE

(A) Operational Mode 1

STATE- 1

(a)state-1 (D1 and Q2 only are on)
Fig.3.1

The current Ic2 flowing in the IGBT switch Q2 is in the state of the current resonance by capacitance Ci and inductance L1. at this time , on the secondary side, diode D1 is on and the charge is charged to capacitance Cd for the voltage doubler. From state-1,the input voltage and primary winding current become the next expressions.

$$V_i = (L_i + L_1)\frac{dI_1}{dt} + V_{Ci} \qquad 3\text{-}(1)$$

$$I_1 = C_i \frac{dV_{Ci}}{dt} \qquad 3\text{-}(2)$$

From these expressions, primary windings current and the voltage across current resonance capacitance Ci become the next expressions.

$$I_1 = \frac{V_i}{Z_1}\sin\omega_i t \qquad 3\text{-}(3)$$

$$V_{Ci} = V_i(1 - \cos\omega_i t) \qquad 3\text{-}(4)$$

Moreover the secondary windings current and the voltage across capacitance Cd for the voltage doubler become the next expressions.
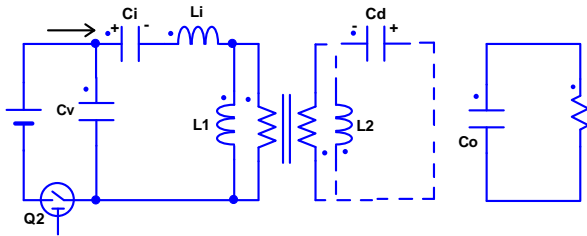
$$I_2 = C_d \frac{dV_{Cd}}{dt} \qquad 3\text{-}(5)$$

$$V_{Cd} = -L_2 \frac{dI_2}{dt} \qquad 3\text{-}(6)$$

ωi and Zi are as follows.

$$\omega i = \frac{1}{\sqrt{(L_i + L_1)C_i}} \qquad 3\text{-}(7)$$

$$Z_i = \sqrt{\frac{(L_i + L_1)}{C_i}} \qquad 3\text{-}(8)$$

STATE-2

(b)state-2 (Only Q2 is on)
Fig.3.1

As well as state-1, it is in the state of the current resonance by capacitance Ci and inductance L1. However, diode D1 is off by charge charged capacitance Cd, and the current doesn't flow to the secondary side. As a result, the change disappears almost as for the voltage and the current on the primary side.

STATE-3

The IGBT switch Q2 is off, and the voltage VCE1 between the drain and the source is in the state of the voltage resonance by the capacitance Cv and the self-inductance of transformer connected with the IGBT switch Q2 in parallel. The voltage across

voltage resonance capacitor Cv and the primary winding current become the next expressions.

$$V_{Cv} = (L_i + L_1)\frac{dI_1}{dt} + V_{Ci} \qquad 3\text{-}(9)$$

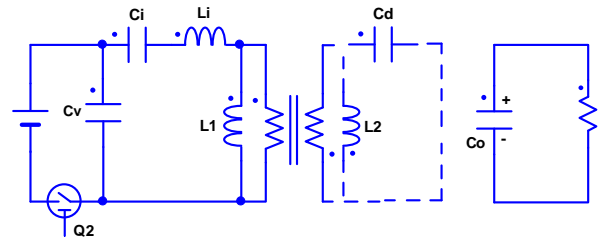$$I_1 = -C_V \frac{dV_{Ci}}{dt} \qquad 3\text{-}(10)$$

From these expressions, the voltage across capacitance Cv becomes the next expression..

$$V_{Cv} = V_{Ci}\omega_v \sin\omega_v t \qquad 3\text{-}(11)$$

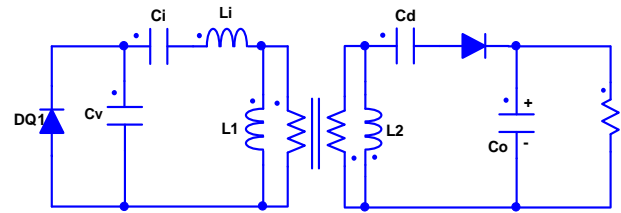It is understood that it is in the state of the voltage resonance from this expression.
ωi is as follow.

$$\omega_v = \frac{1}{\sqrt{(L_i + L_1)C_V}} \qquad 3\text{-}(12)$$

(c) state-3 (All of IGBTs and diodes are off)
Fig.3.1

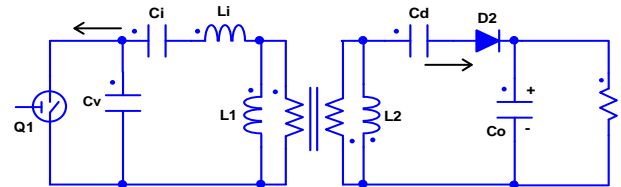*STATE-4*

(d) state-4 (Only DQ1 and D2 are on)
Fig.3.1

The state of the voltage resonance works end, and the diode D1 and D2 are on. The period of these、 the state-3 and the state-4 are the dead time. And the voltage of VCE1 turns and after it becomes zero volt , the IGBT switch Q2 is on and it is in the state of zero voltage switching.

STATE-5

(e)state-5 (Only Q1 and D2 are on)
Fig.3.1

The IGBT switches Q2 and diode D2 are on and on the primary side, the charge charged capacitance Ci is discharged as a result, it is in the state of the current resonance by the leakage inductance Li. And on the secondary side, the charge charged capacitance Cd for the voltage doubler flows into the output. At this time, the secondary output voltage and the secondary winding current become the next expressions.

$$V_O = L_2 \frac{dI_2}{dt} + V_{Cd} \qquad 3\text{-}(13)$$

$$I_2 = C_d \frac{dV_{Cd}}{dt} \qquad 3\text{-}(14)$$

From these expressions, the secondary winding current becomes the next expression.

$$I_2 = \frac{V_O}{Z_2} \sin \omega_2 t \qquad 3\text{-}(15)$$

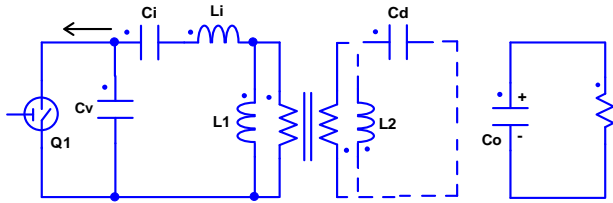On the secondary side, it is understood that it is in the state of the current resonance from this expression.
Z2 and ω2 are as follows.

$$Z_2 = \sqrt{\frac{L_2}{C_d}} \qquad 3\text{-}(16)$$

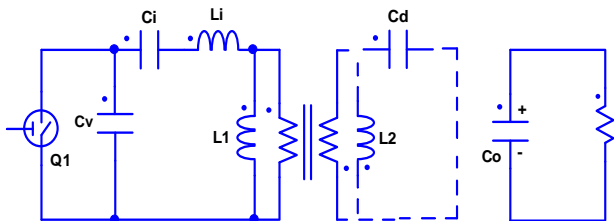$$\omega_2 = \frac{1}{\sqrt{L_2 C_d}} \qquad 3\text{-}(17)$$

STATE-6

(f)state-6 (Only Q1 is on)
Fig.3.1

The diode D2 is off by the charge charged capacitance Co, and the secondary winding current I2 doesn't flow.
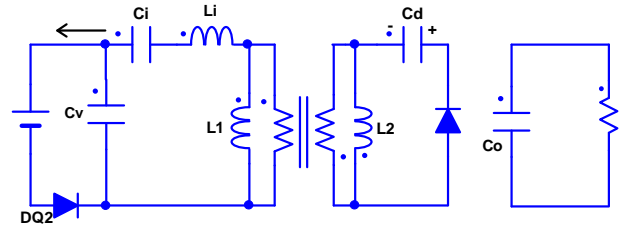
STATE-7

(g) state-7 (All of IGBTs and diodes are off)
Fig.3.1

All of IGBTS and diodes are off, and it is in the state of the voltage resonance by capacitance Cv.

STATE-8

(h) state-8 (Only DQ2 and D1 are on)
Fig.3.1

Only DQ2 and D1 are on and it is in the state of zero voltage switching.

(B) Operational Mode 2
In the state-1 and the state-5 of Fig.3.2, the same circuit as the state-1 and the state-5 of operational mode 1 operate.

STATE-9
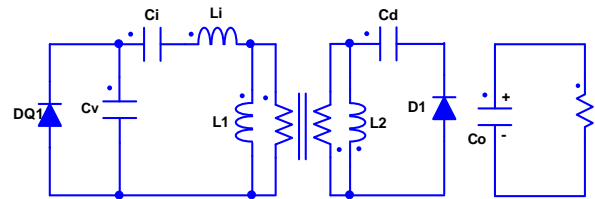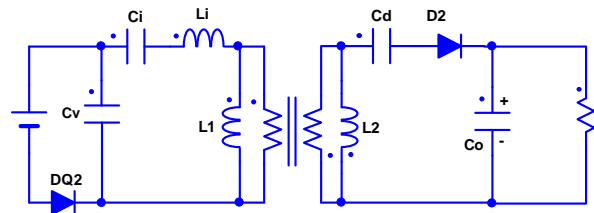

(i)state9 (Only DQ1 and D1 are on)
Fig.3.1

Only DQ1 and D1 are turned-on , it is in the voltage resonance by the capacitance Cv.

STATE-10
Only DQ1 and D2 are on ,and it is in the voltage resonance.

(j)state-10 (Only DQ2 and D2 are on)
Fig.3.1 Equivalent circuit of Fig.2.1

Q1 V$_{GS}$ 10V/div

Q2 V$_{GS}$ 10V/div

Q1 V$_{CE1}$ 200V/div

Q1 I$_{C1}$ 20A/div

Q2 V$_{CE2}$ 200V/div

Q2 I$_{C2}$ 20A/div

Voltage across Ci
100V/div

Primary winding current
50A/div

Primary winding voltage
200V/div

Secondary winding voltage
200V/div

Secondary winding current
20A/div

voltage across secondary diode D1
200v/div

Current through Cv
20A/div

state-1

state-2

state-5

state-6

state-3

state-4

state-7

state-8

Fig.3.2   Simulation waveforms of operational   mode 1

Q1 V$_{GS}$ 10V/div

Q2 V$_{GS}$ 10V/div

Q1 V$_{CE1}$ 200V/div

Q1 IC1   20A/div

Q2 V$_{CE2}$ 200V/div

Q2 I$_{C2}$ 20A/div

Voltage across Ci
100V/div

Primary winding current
50A/div

Primary winding voltage
200V/div

Secondary winding voltage
200V/div

Secondary winding current
20A/div

Voltage across secondary diode D1
200v/div

Current through Cv
20A/div

state-1

state-5

state-9
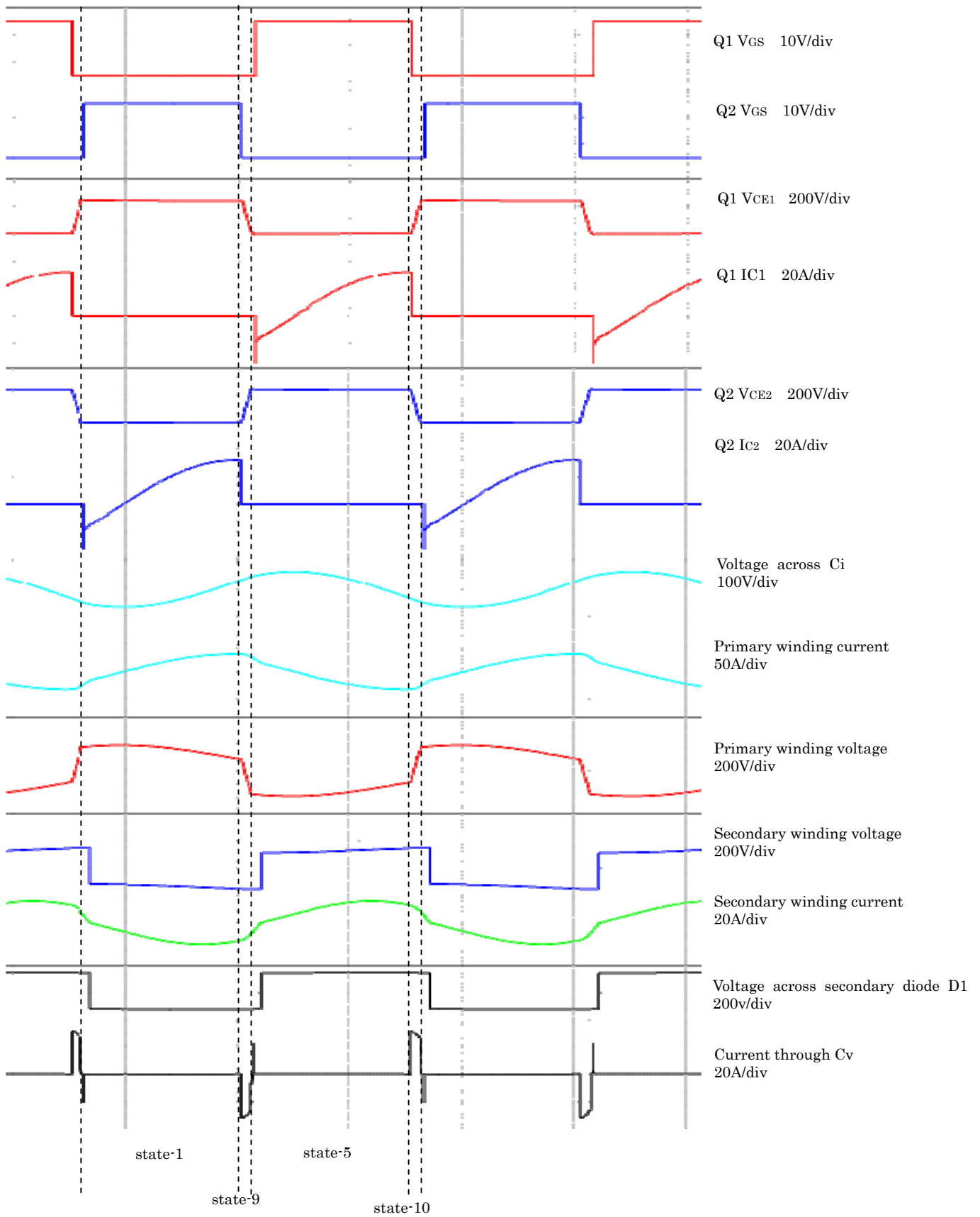
state-10

Fig.3.3   Simulation waveforms of operational mode 2

IV.COMPARISON BETWEEN MEASURING WAVEFORM AND SIMULATION RESULT

Fig.4.1 shows the simulation and observed waveforms. It is seen Fig.4.1 that the simulation result is agreed well with the observed one.
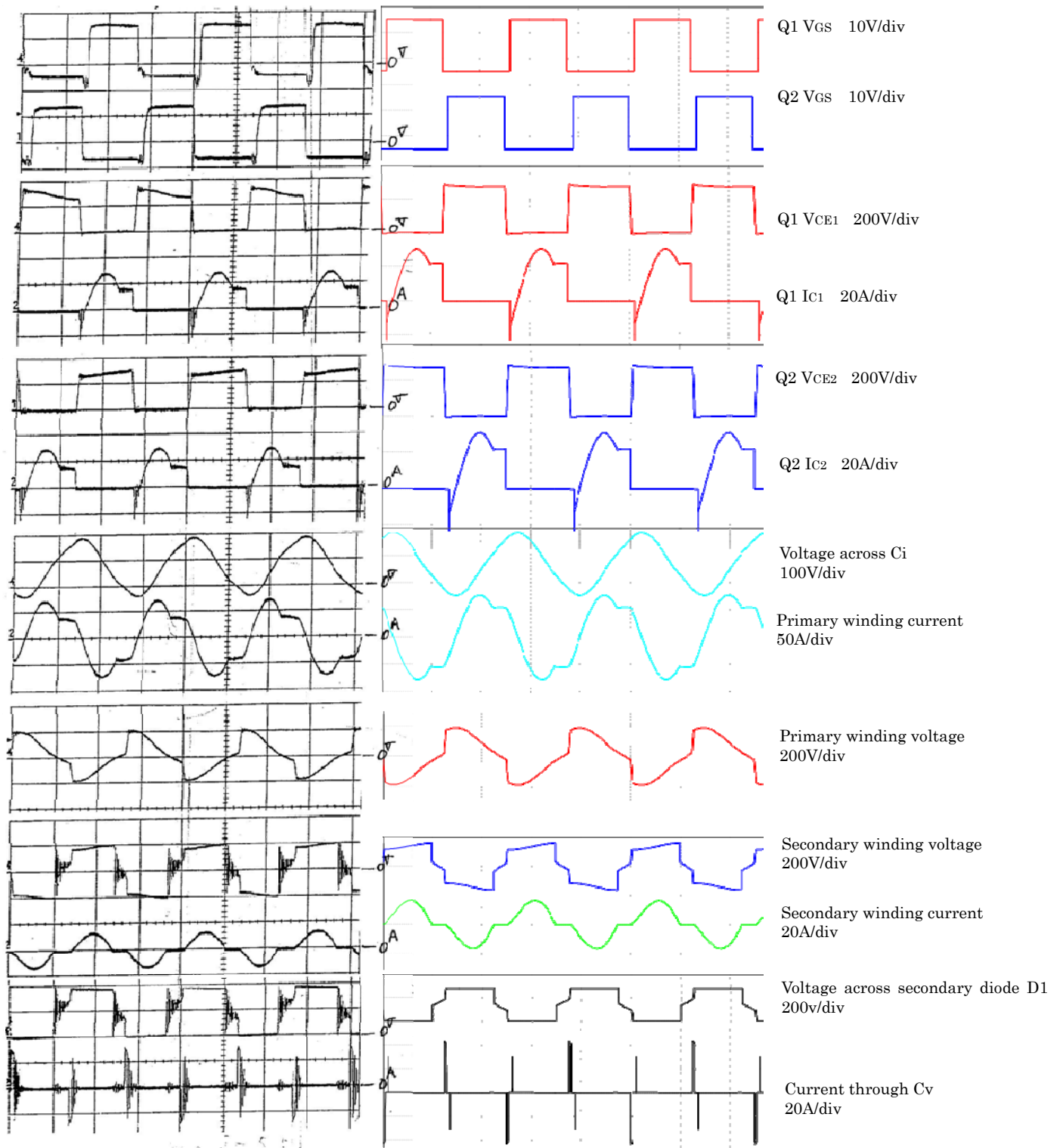

	Q1 V$_{GS}$ 10V/div
	Q2 V$_{GS}$ 10V/div
	Q1 V$_{CE1}$ 200V/div
	Q1 I$_{C1}$ 20A/div
	Q2 V$_{CE2}$ 200V/div
	Q2 I$_{C2}$ 20A/div
	Voltage across Ci 100V/div
	Primary winding current 50A/div
	Primary winding voltage 200V/div
	Secondary winding voltage 200V/div
	Secondary winding current 20A/div
	Voltage across secondary diode D1 200v/div
	Current through Cv 20A/div

Fig.4.1   Simulation and observed waveforms

V.POWER EFFICIENCY

(A) Under Heavy－Load Condition

Fig.5.1 shows the power efficiency characteristics under the heavy-load of the proposed DC-DC converter. The maximum power efficiency is 95.7% at 230V DC of the input voltage and 900W of the output power.

(B) Under Light-Load Condition

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.Fig.5.2 shows the power efficiency characteristics under the light-load of the proposed DC-DC converter. The maximum power efficiency is 95.2 % at 240V DC of the input voltage and 400W of the output power and is 93.2% at 300V DC of the input voltage and 200W of the output power. The drop of the efficiency at 200W of the output can be improved by adjusting the burst —oscillation condition.

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 96.1% can be realized at 290V DC of the output voltage and 600W of the output power.

VII.REFERENCES

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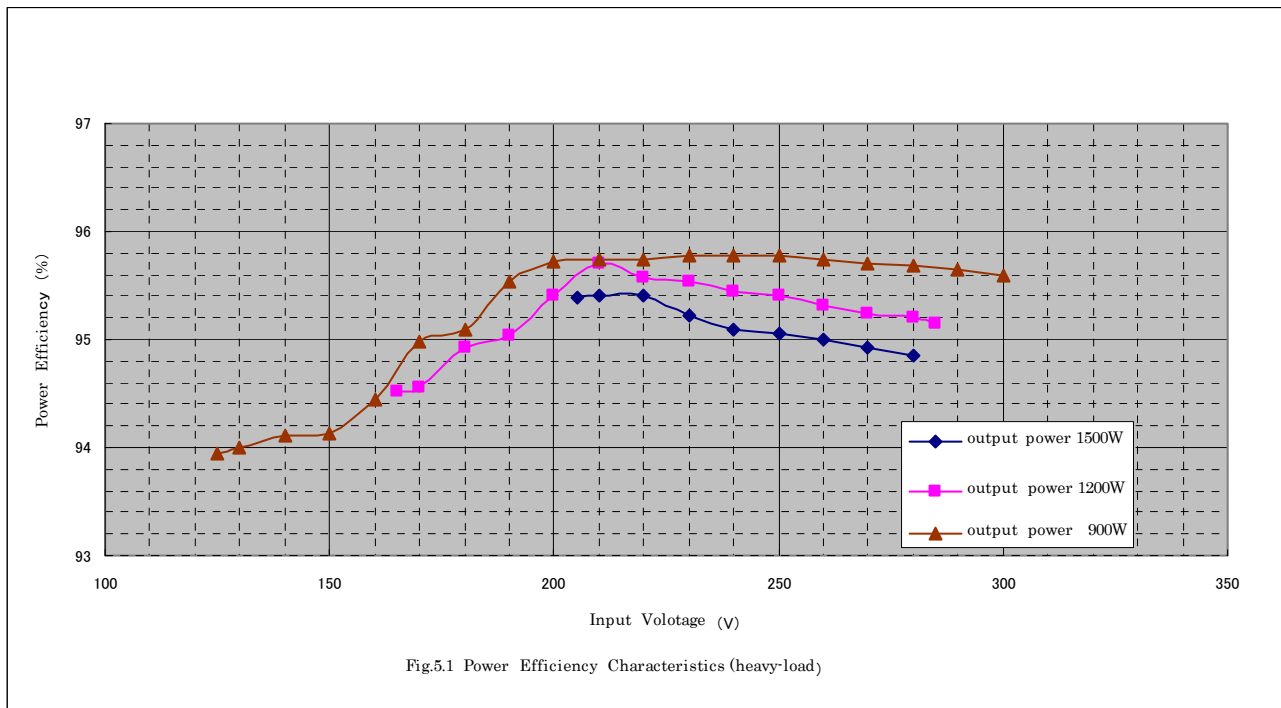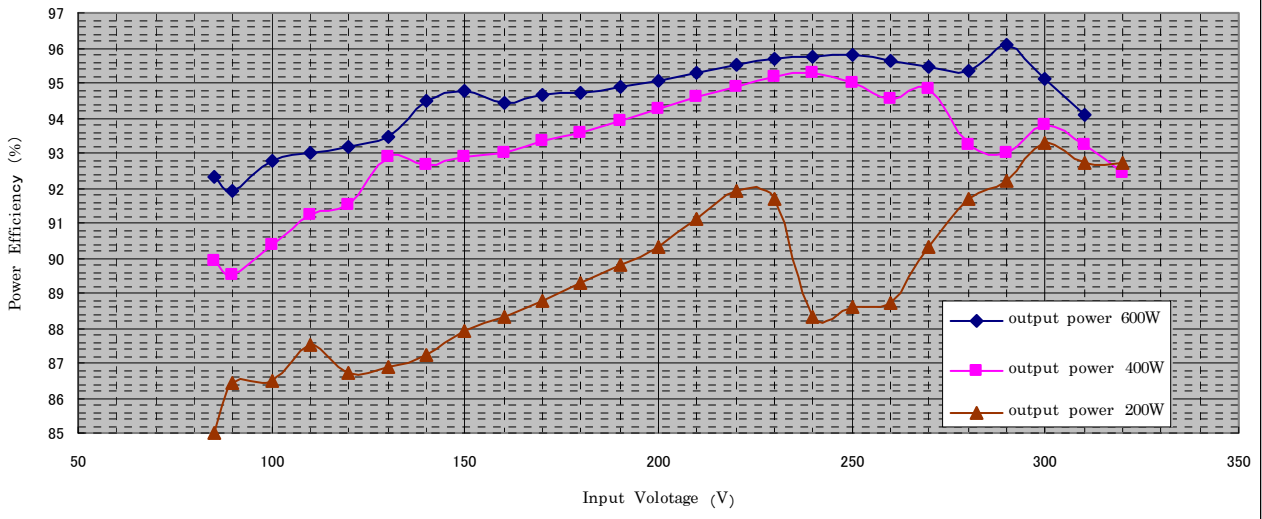
Fig.5.1 Power Efficiency Characteristics (heavy-load)

Fig.5.2 Power Efficiency Characteristics (light-load)