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部品点数を低減した直接ＡＣ－ＤＣ変換器

Direct AC-DC Converter with Small Number of Components

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Abstract : This paper proposes two new circuits which convert AC voltage to DC voltage directly using much fewer components than conventional converters that use rectifiers, a DC-DC converter, and ripple filter. The first new circuit proposed uses only one switch, four diodes, one inductor and one capacitor. The second is a forward-isolated AC-DC converter. We present their circuit topologies, operation principles and simulation results.

Key Words： AC-DC Converter, Buck converter, Isolated converter, Switched-mode power supply

１． Introduction

The AC-DC converter is an indispensable part of all electronic devices, from cell phones to large machines [1]. The AC-DC converter converts alternating current to a steady direct current. Conventional converters rectify the input voltage, and this high DC voltage drives a high-frequency switching circuit connected to a transformer, and the output is rectified DC at the desired voltage. This kind of converter is bulky and has low efficiency, because it contains rectifiers, a switching DC-DC converter, and a transformer.

We have already proposed a circuit which realizes direct AC-DC conversion [2,3]. In this paper, we present two direct AC-DC converters with fewer components: a buck-buck converter, and a forward-isolated AC-DC converter.

２． Buck –Buck　AC-DC Converter

2.1 Proposed Circuit and Operation

The proposed buck-buck AC-DC Converter is shown in Fig.1 and Fig.2; the red solid line demonstrates the current flow when the inductor is charged, and the broken line shows the current flow when the inductor is discharged. The switch operates at a frequency of 100kHz and the operation modes vary with the polarity of the input voltage and the “charging” or “discharging” of the inductor.

When the input voltage is positive, as shown in Fig.1 and Fig.3, first, S1 turns on for a time of D·Ts (D represents the on duty interval and Ts represents the switching period) and the inductor is “charged”. Then S1 turns off, and the inductor “discharges” to the capacitor and resistor. For a positive input, S1 alternately turns on and off as is shown in Fig.3. The operation is just like the common buck converter, and we can obtain a steady output.

Fig.2 shows the situation when the input voltage is negative, and the timing chart is

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illustrated in Fig 3. First, S1 turns on, and the inductor is “charged”. For this condition, there is a problem in that the direction of the inductor current reverses when the voltage crosses zero volts. Then S1 turns off. The energy stored in the inductor is discharged to the capacitor and resistor. As a result, with the same duty ratio (to be more precise, when the input stay at positive or negative, the switch duty ratio at positive will be same as the negative one), we can turn the alternating current into steady direct current.

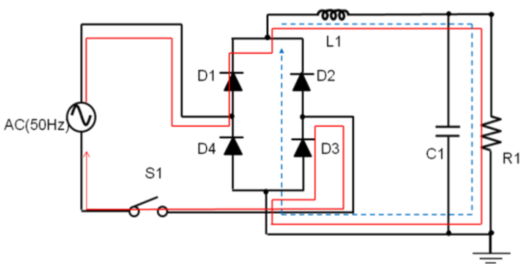


Fig. 1 Buck-Buck AC-DC converter.

（Current when Vin＞０）

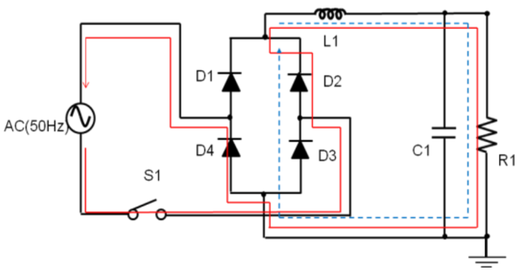
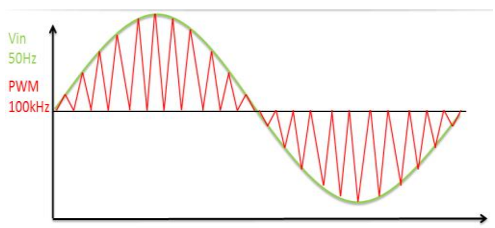


Fig.2 Buck-Buck AC-DC converter.

（Current when Vin<０）



Vin＞０ Vin＜０

Fig.3 Timing chart of switches.

2.2 Simulation Results

The circuit schematic for simulation is illustrated in Fig.4. The input voltage is 100Vrms with a frequency of 50Hz and we use PWM operating at 100kHz. The other parameters are shown in Table 1. We set the output voltage to 24V and the output resistor current to Io=0.1A.

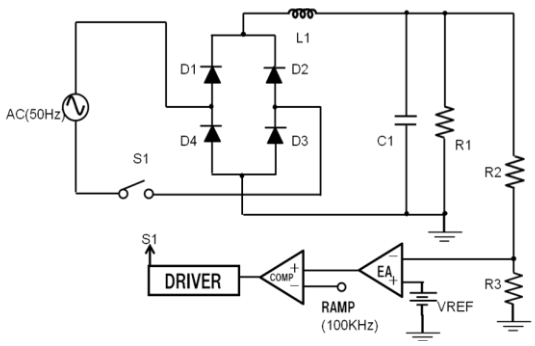


Fig.4 Schematic circuit for simulation.

Table 1 Circuit parameters.

C	220 uF
R1	270 Ω
R2	2.2 kΩ
R3	2.2 kΩ
L	47 uH
VREF	12.0V

The waveform of input voltage Vi and the output voltage, the output voltage ripple and the load transient response are shown in Fig.5, Fig.6, Fig.7 and Fig.8 respectively. The output voltage ripple is under 5mVpp. Fig.8 shows the output transient response when the load current changes from 0.1A to 0.2A. The transient response may also vary a little with changes in the input voltage. This figure shows the transient response when the input voltage is near its peak. When the output current changes by ⊿Io=0.1A from 0.2A, the output voltage ripple is ⊿V=30mVpp and the offset voltage is ⊿VDC＝10mV. The output ripple may seems a little big, but the ratio of voltage ripple to output voltage is⊿V/Vo=0.0006, which is very small.

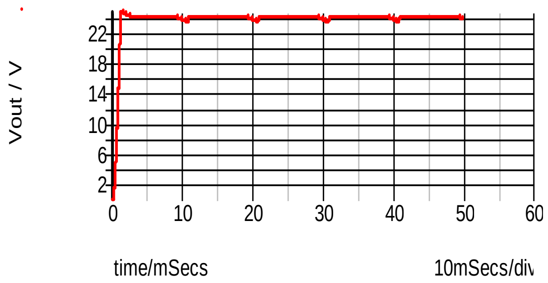


Fig.5 Waveform of input and output voltages.

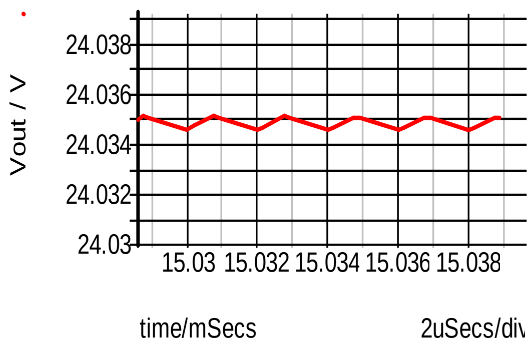


Fig.6 Output voltage ripple.

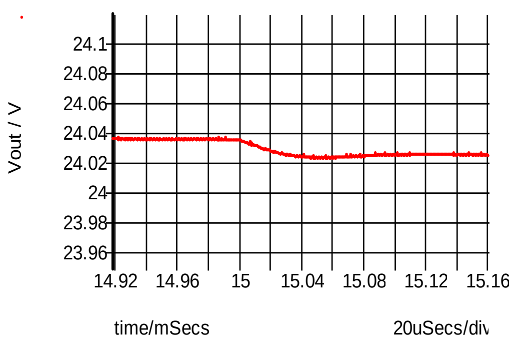


Fig.7 Load transient response from 0.1A to 0.2A.

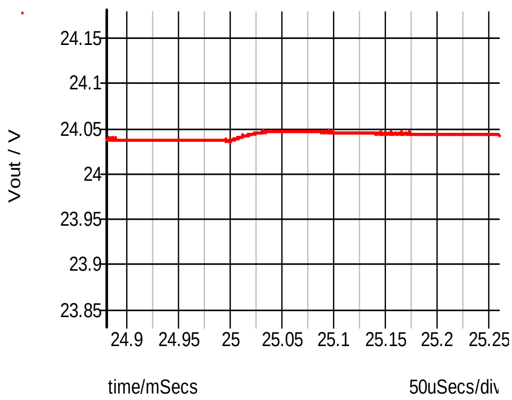


Fig.8 Load transient response for a load change from 0.2A to 0.1A.

3 Forward isolated AC-DC converter without diode full-bridge

3.1 Proposed Circuit and Operation

Isolated AC-DC adapters are most commonly used in Japan because of their safety. But conventional isolated-type AC-DC adapters are very bulky, with a lot of devices. Here we propose using a familiar DC-DC converter, forward converter, to convert AC to DC directly.

When the input voltage is positive, as shown in Fig.9, first, Q1 turns on for a time of D·Ts (D represents on duty interval, and Ts represents the switching period) and the inductor is "charged". Then Q1 turns off, the transformer can be reset (to be more precise, the transformer magnetizing current is reset to zero when the Q1 is in the off-state)., and the inductor will "discharge" to the capacitor and resistor. For a positive input, Q1 alternately turns on and off. The operation is just like the common buck converter, and we can get a steady output.

Fig.10 shows the situation when the input

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voltage is negative, and the timing chart is illustrated in Fig 11. Firstly, Q2 is on and the inductor is “charged”. Then S1 is off, the transformer can be reset, and the energy stored in the inductor is discharged to the capacitor and resistor. As a result, with the same duty ratio, we can turn the alternating current into steady direct current.

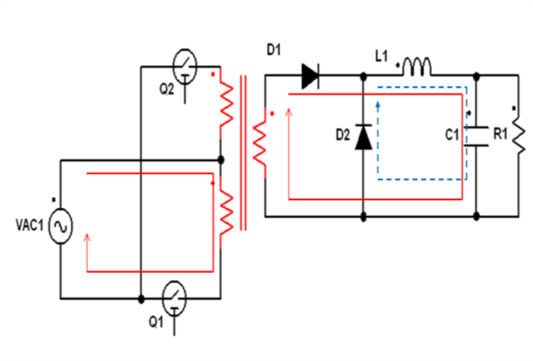


Fig.9 Forward isolated AC-DC converter without diode full-bridge (Vin＞０）.

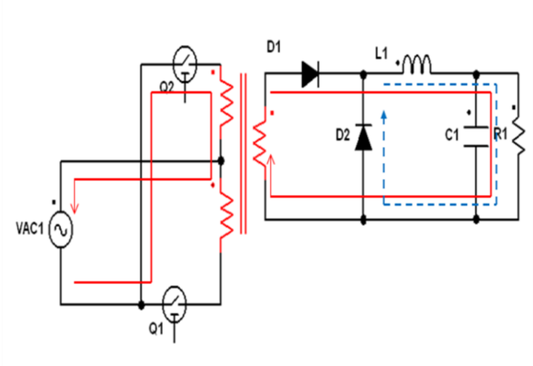
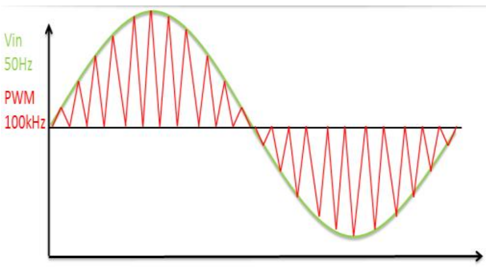


Fig.10 Forward isolated AC-DC converter without diode full-bridge（Vin<０）.



（a） Vin＞０ （b） Vin＜０

Fig. 11 Timing chart of switches.

3.2 Voltage-Conversion Ratio

Compared with the clock frequency of PWM, the frequency of the input sine wave is very low and the instantaneous input voltage can be considered as almost constant. At this time, the output voltage Vo can be calculated as follows:

$$V_0 = DV_i$$

$$V_0 = \sqrt{2} DV_{rms} \bullet \sin(\theta)$$

$$D(\theta) = \frac{1}{1 + \sqrt{2}/M \bullet \sin(\theta)}$$

Here D stands for the duty and M is given by

$$M = V_0 / V_{rms}$$

Therefore we can calculate the average duty D* in the half period.

$$D^* = \frac{1}{\pi} \int_0^{\pi} D(\theta) d(\theta)$$

$$D^* = \frac{1}{\pi} \int_0^{\pi} \frac{1}{1 + \sqrt{2}/M \bullet \sin(\theta)} d(\theta)$$

3.3 Simulation Results

The input voltage, output load and feedback circuit are the same as those of buck/boost-buck/boost converter and the simulation circuit is shown in Fig.16. Parameters are shown in Table 2.

The waveforms of input and output voltage, the output ripple, transient response are shown in Fig.17, Fig.18, Fig.19 and Fig.20 respectively.

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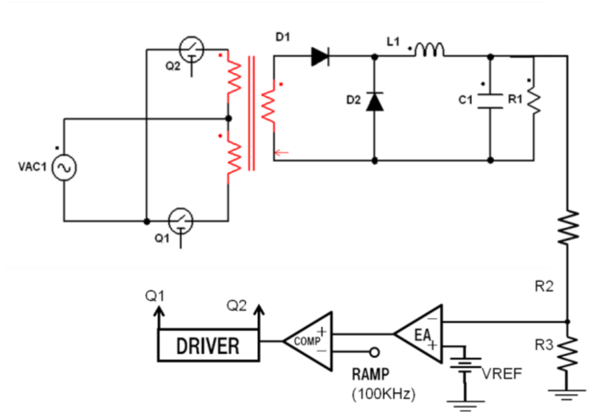

Fig.16 Simulation circuit.

Table 2 Circuit parameters

C	220 uF
R	100 Ω
R1	9 kΩ
R2	1 kΩ
L	220 uH
VREF	5.0V

In the steady state, the output voltage ripple is very small, just 1mV.

For the transient response, we set the current change from 0.1A to 0.2A, just as the previous one in Section 2. The voltage ripple is 1mVpp at output load current of 0.1A, which is very small compared with the output voltage.

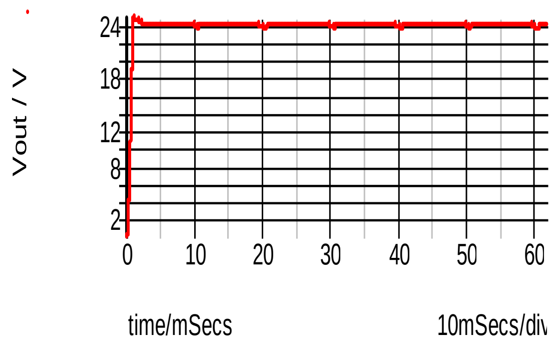

Fig.17 Waveforms of input and output voltage.

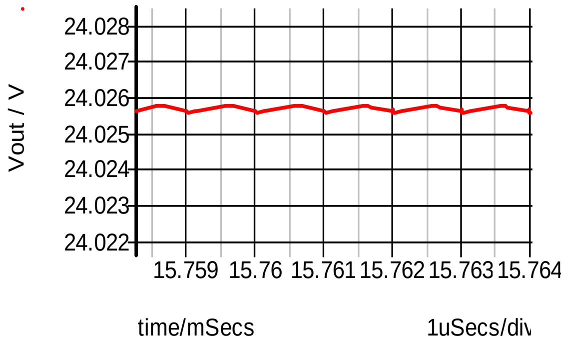

Fig.18 Output voltage ripple.

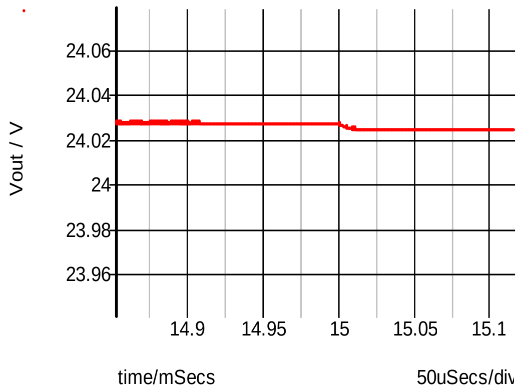

Fig.19 Load transient response for load change from 0.1A to 0.2A.

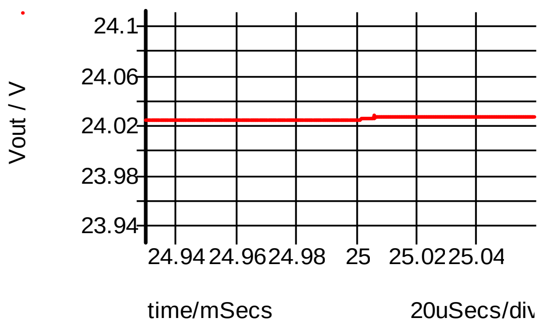

Fig.20 Load transient response from 0.2A to 0.1A.

4. Conclusion

In this paper, we have applied the principles of the DC-DC converter to an AC-DC converter, and proposed two novel AC-DC converters with a small number of devices (a buck -buck AC-DC Converter and a forward-isolated AC-DC converter). We have explained their operation principles and verified their basic operation by simulations.

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