

Floating Output DC-DC Converter Using Single Winding Reactor and Its Applications

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1. Introduction

Networking based on a PC server is becoming increasingly popular and uninterruptible power supplies (UPS) need to be made more compact, lightweight and cheaper. The typical UPS now functions not only as a backup power supply during a power failure, but also improves the power factor and cleans the commercial power supply by absorbing the harmonics that are generated by equipment acting as loads.

To achieve such targets, various rectifier circuits have been developed for UPSs. Although Sanyo Denki has been marketing step-up chopper type and high frequency insulation type products, various problems as discussed in Chapter 2 of this paper make it difficult to use the products with 200 V input.

We report here on recent developments and a new product using a DC-DC converter ⁽¹⁾ that can generate an output that is floating (separated) from the input. The new product is the 3 kVA UPS using the technology in the rectifier circuit. The operating system of this DC-DC converter and UPS, and its characteristics are described.

2. Requirements for Rectifier Circuit of Compact UPS

The typical load of a compact UPS is a personal computer. This means that the compact UPS supplies AC power to the switching regulator of the power supply circuit of the personal computer. Therefore, the output of the UPS includes various harmonics having a high current crest value. At the same time, arresters and ceramic varistors are used to protect the system from surges, and a high frequency filter is inserted in the input circuit of the switching regulator to protect the system from noise. The earth line of the system and the neutral line of the input/output AC power line should have minimum potential difference so that the circuit components do not operate on an abnormal potential with regard to the earth potential.

For that purpose, the input circuit and output circuit of a UPS should not be separated, but the neutral lines of the input and output circuits should preferably be connected directly.

The circuit in which full wave rectification and a full bridge inverter are combined in the general purpose inverter is shown in [Fig. 1](#).

In this circuit, the DC voltage that exists in the middle of the output of the inverter is super-imposed on the output voltage. This makes it difficult to connect the input and output because of the potential difference between the neutral line of the input circuit and output circuit. Therefore, the circuit operation becomes unstable with regard to the earth potential and this can cause troubles such as burning of the varistor of the load circuit or troubles due to noise.

In order to connect the neutral lines of the input and output circuits, the input

could be isolated from the output.

The circuit configuration using an insulation transformer in the output circuit is shown in [Fig. 2](#). The circuit configuration of connecting an insulation transformer in the input circuit, or inserting a DC-DC converter between the input and output, has the same result, but insulation transformers are large, heavy and expensive. Use of the DC-DC converter makes the circuit configuration complicated, and manufacturing an insulation transformer for a large capacity inverter is difficult and limits application of this circuit configuration to small capacity inverters.

A circuit configuration using a voltage-doubler rectifier + half-bridge inverter is shown in [Fig. 3](#).

The rectifier circuit that is used in Fig. 3, is a high power factor converter circuit. The DC voltage in the middle of this circuit becomes as follows when taking fluctuation of the input voltage into consideration:

$$100V \times 1.15 \sqrt{2} \times 2 = 325V$$

When this circuit is used for 200 V, double the voltage of the above figure becomes necessary. This means that the semiconductors used in the latter stage of the inverter must have a high withstand voltage, which reduces the efficiency. Furthermore, it requires a larger air clearance and a longer creepage distance, which hinder the design of a compact unit.

In addition, the mid-point voltage of capacity fluctuates in the half-bridge inverter when an unbalanced load such as a half-wave rectifier load is connected. Fluctuation of the mid-point voltage of capacity can create deviations of magnetism and insufficient withstand voltage of the capacitor.

Each circuit system has its own merits and demerits as we have examined. We have developed a floating output DC-DC converter (FCON) in order to solve these problems for a UPS that operates on 200 V input and delivers output voltages of 3 kVA or more.

3. FCON Circuit

3.1 Operation of FCON

The FCON circuit that provides a floating output with respect to the input is shown in [Fig. 4 \(A\)](#).

The input energy is stored in the reactor L through the two semiconductor switches Q1 and Q2. The stored energy is discharged through the two diodes D1 and D2. This circuit operation is the same as that of a flyback converter or of a polarity-inverting chopper circuit except that an insulating transformer is not necessary. The spike voltage that is created normally in the polarity-inverting chopper circuit due to its leakage inductance, is absorbed by Cdc and is suppressed.

The principle of obtaining a floating output using FCON is described below.

Fig. 4 (B) shows the energy storage mode in the reactor L.

When Q1 and Q2 are turned on, current flows into reactor L from the DC power supply, and stores electromagnetic energy in L.

The capacity of the reactor that is required here is about 4% of the input impedance, and is fairly small compared with the transformer.

During storage mode, the diodes D1 and D2 are reverse-biased by the reactor L and the capacitor Cdc voltages, so that any current does not flow into the output side that is separated from the input side.

When Q1 and Q2 are turned off, the system enters energy discharge mode as shown in Fig. 4 (C). Energy that was stored in L during the storage mode is now discharged into capacitor Cdc and the load side circuit through D1 and D2.

Because Q1 and Q2 are turned off during the discharge mode, the output side is separated from the input side. This separation of the output from the input is obtained by repeating the two modes of (B) and (C).

The current patterns of the respective semiconductor devices constituting the circuit are shown in Fig. 4 (D). Current I_q of Q1 and Q2, and current I_d of D1 and D2 increase and decrease with the following slopes.

$$\frac{dI_q}{dt} = \frac{E_{in}}{L} \quad \dots(1)$$

$$\frac{dI_d}{dt} = -\frac{E_{out}}{L} \quad \dots(2)$$

The relationship between the switching duty ratio D of Q1 and Q2, and the output voltage can be expressed by the following equations assuming that voltage drop due to semiconductor devices is 0 and assuming that the resistive component is 0.

$$\frac{E_{in}}{E_{out}} = \frac{D}{1-D} \quad \dots(3)$$

$$D = \frac{t_{on}}{t_{on} + t_{off}} \quad \dots(4)$$

The relationship between the input/output and duty ratio is shown in Fig. 4 (E). The input voltage can be stepped up or down by changing the duty as shown in Fig. 4 (E). However, non-linearity increases and controllability deteriorates when the duty ratio exceeds 0.5.

3.2 Limitations of FCON

The single winding reactor that is used in FCON can be easily manufactured because it does not have the leakage inductance problem, and so should be useful for large-capacity systems.

However, the conversion to the floating output of FCON has a limitation compared with the transformer that is a passive component. The floating output of FCON is obtained by switching the semiconductor switch and diode in a time-shared manner.

Among the switching elements, the diode turns on depending on external conditions because it is a passive element even during the period in which it must be turned off. In other words, it can create a mode in which the input and output are directly connected, thus losing the separation of input from output that is required for floating output.

The conditions that are inhibited during use of FCON are shown in [Fig. 5](#).

When external voltage E_x is applied as shown in Fig. 5, diode D1 conducts when IGBT or FET or transistor is used for switch Q1 because it cannot prevent the circuit from reverse voltage.

In the same manner, when voltage E_y is applied, diode D2 conducts so that the input and output circuits are directly connected and floating output cannot be obtained. When a snubber circuit or equivalent is connected in parallel with Q1 and Q2, or D1 and D2, the input and output circuits are connected through it. The structure of the snubber must be considered carefully.

4. Application of FCON to UPS

4.1 Structure of Rectifier Circuit

FCON is equipped with a floating output that is necessary for the UPS rectifier as described in Chapters 2 and 3. No rush current suppression circuit is necessary because the rush current to capacitor C_{dc} during start-up can be suppressed by implementing soft-start of the semiconductor switches Q1 and Q2 that are used to

separate the input side. At the same time, because the fundamental operation of this circuit is that of a flyback converter, this circuit can be operated as a high power factor converter by comparing the current flowing through the reactor L with the input voltage as reference voltage, and by controlling the current flowing through L into a sine wave current.

The circuit structure as a high power factor converter is shown in [Fig. 6](#)

The characteristics as a high power factor converter are, from the above circuit, Input power factor: 99.3% when input and output powers are rated power, and Conversion efficiency: 88.4% when input and output powers are rated power.

[Fig. 7](#) Waveforms at key circuits when FCON is used as a high power factor converter

4.2 UPS using FCON

The structure of the UPS using FCON is shown in [Fig. 8](#).

The output voltage of the rectifier circuit as described in section 4.1, is sent to the inverter consisting of a full bridge structure, and the inverter outputs a sine wave AC voltage of constant frequency and constant voltage. This output is floating from the input of the UPS by FCON.

LO and CO that are connected to the AC input circuit constitute a filter that suppresses ripples caused by switching of semiconductor switches Q1 and Q2, and absorbs high frequency noise.

The AC filter forms a circuit that connects the DC bus and the AC output terminal with a capacitor. This assures the reverse bias voltage of the diode D1 and D2 which prevents leakage of noise into this circuit.

The neutral line of the AC input power supply and one of the output lines are connected in common. This connection solves the problems related to earth as described in Chapter 2.

The next section considers whether the common connection line as described above causes any problems for the FCON operation.

An unnecessary forward bias must not be applied to the diode for the correct functioning of FCON as described before. The bias status of the diode is explained by the bias modes of the FCON diodes in [Fig. 9](#).

Figs. 9 (A) and (B) illustrate the bias status of diode D1. In the mode shown in Fig. 9 (A), the voltage across AC filter capacitor C1 is applied to D1 as a reverse bias via the input/output connection line. This connection cannot work as a forward bias. In the mode shown in Fig. 9 (B), the sum of voltages across AC filter capacitor C0 and C2 is applied to D1 as a reverse bias. The modes shown in Figs. 9 (C) and (D) are the bias mode for diode D2. In the mode shown in Fig. 9 (C), the sum of the voltages across C0 and C2 are applied as a reverse bias. In the mode shown in Fig. 9 (D), the C2 voltage is applied as a reverse bias.

As explained above, diodes D1 and D2 cannot be forward-biased while the main power is on. This allows the FCON UPS to deliver its full performance.

The newly developed 3 kVA UPS and the conventional 3 kVA UPS are compared below.

Contents	New UPS	Conventional UPS
Volume	51 liters	101 liters
Mass	75 kg	125 kg
Input power factor	99.3 %	99 %
Input voltage range	170 V to 265 V	176 V to 224 V
Overall efficiency	84.3 %	78.9 %
Noise specification	VCCI approved	Conforms to VCCI

5. Conclusion

We have verified the floating output DC-DC converter (FCON) using a single winding reactor with a UPS. The floating output DC-DC converter is a high power factor converter and is used as the rectifier circuit of a UPS of single-phase, 200 V, 2 kVA output.

The floating output DC-DC converter with single winding reactor has the following features:

- (1) Because FCON uses a single winding reactor to obtain the floating output, the DC-DC converter is easy to manufacture, and an inverter having a large power conversion capacity can be manufactured.
- (2) Because FCON can be stepped up and down, an inverter having a wide range of input voltage deviations is realized.
- (3) Because the conventional inverter uses a transformer, equipment is large and heavy. The new inverter is compact and light.
- (4) Transformers running at commercial frequency are expensive. Since the transformer is no longer needed, the cost of the new inverter is lower.

We intend to apply this new technology to three-phase circuits, increase the efficiency, and so on in future. Further development of this technology will be based on its unique characteristics.

References

- (1) Sekino, Yamazaki: "Floating Output DC-DC Converter Using Single Winding Reactor". The Institute of Electronics, Information and Communication Engineers Technical Report, EE98-1 (1998-6)
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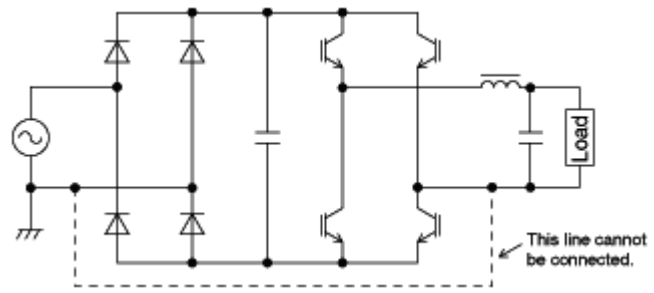


Fig. 1 Full wave rectification + full bridge inverter

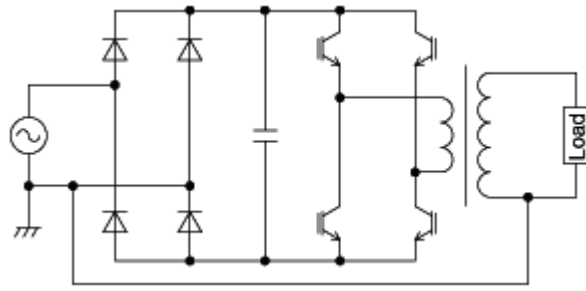


Fig. 2 Connecting an insulation transformer

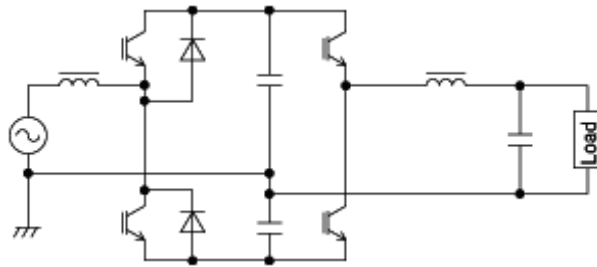


Fig. 3 Voltage-doubler rectifier + half-bridge inverter

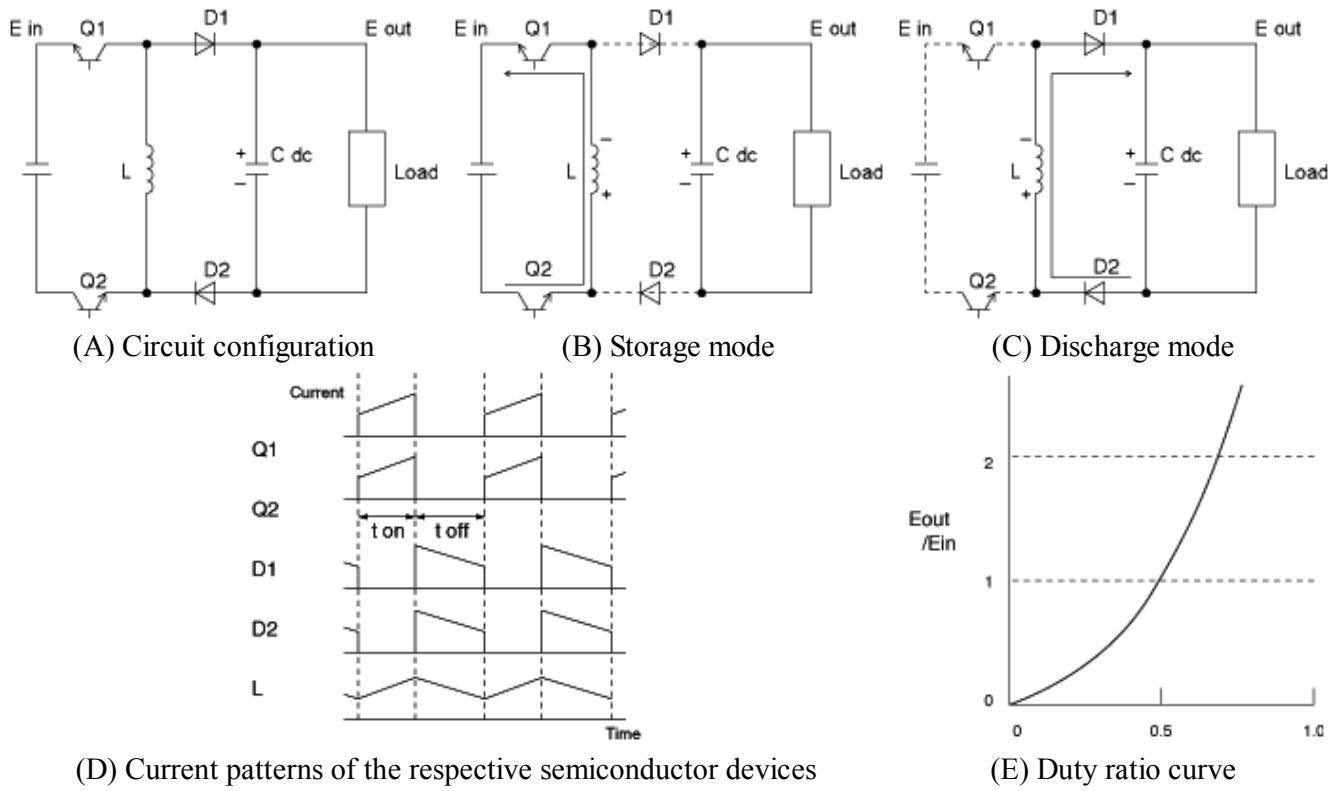


Fig.4 F4 FCON circuit and its operating principle

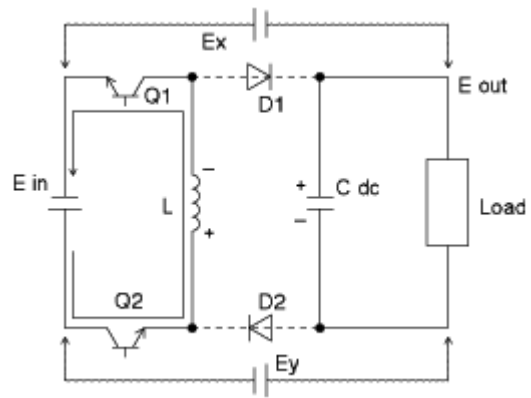
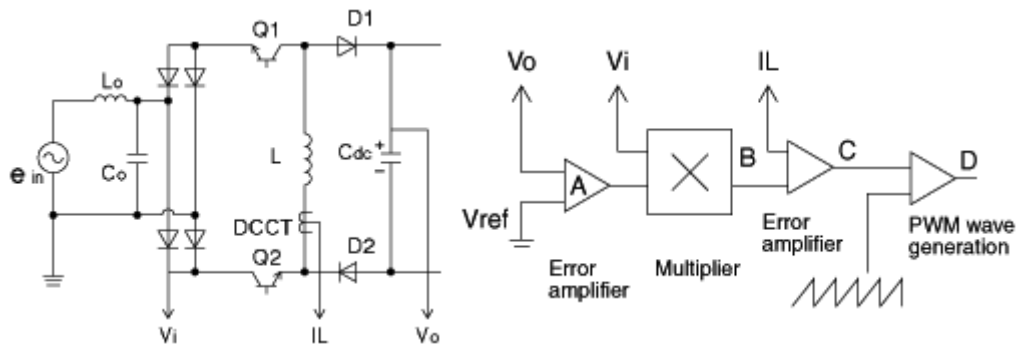
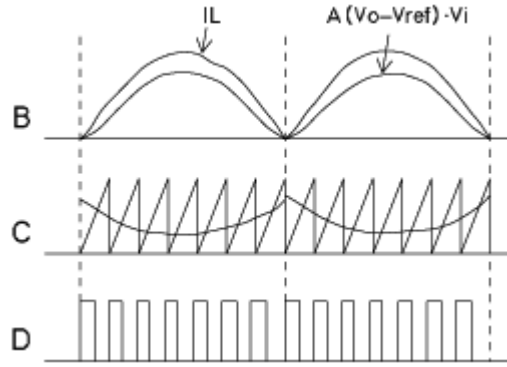


Fig. 5 Conditions that are inhibited during use of FCON



(A) Main circuit structure

(B) Structure of control circuit



(C) Description of operation

Fig. 6 Circuit structure as a high power factor converter

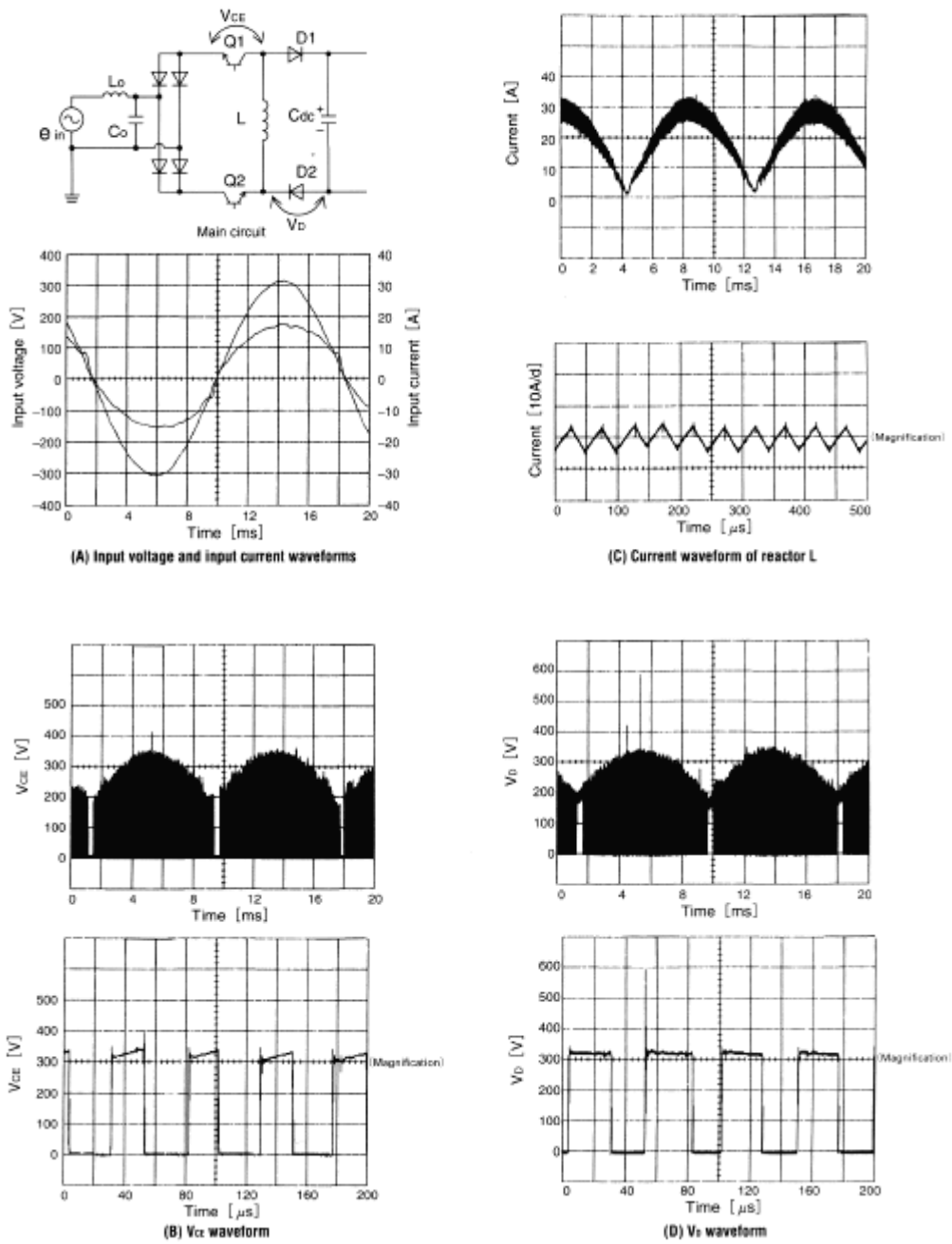


Fig.7 Waveforms at key circuits when FCON is used as a high power factor converter

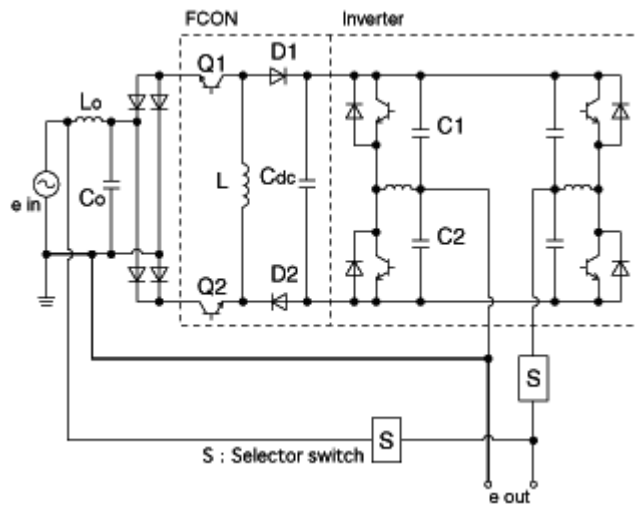


Fig. 8 Structure of UPS using FCON

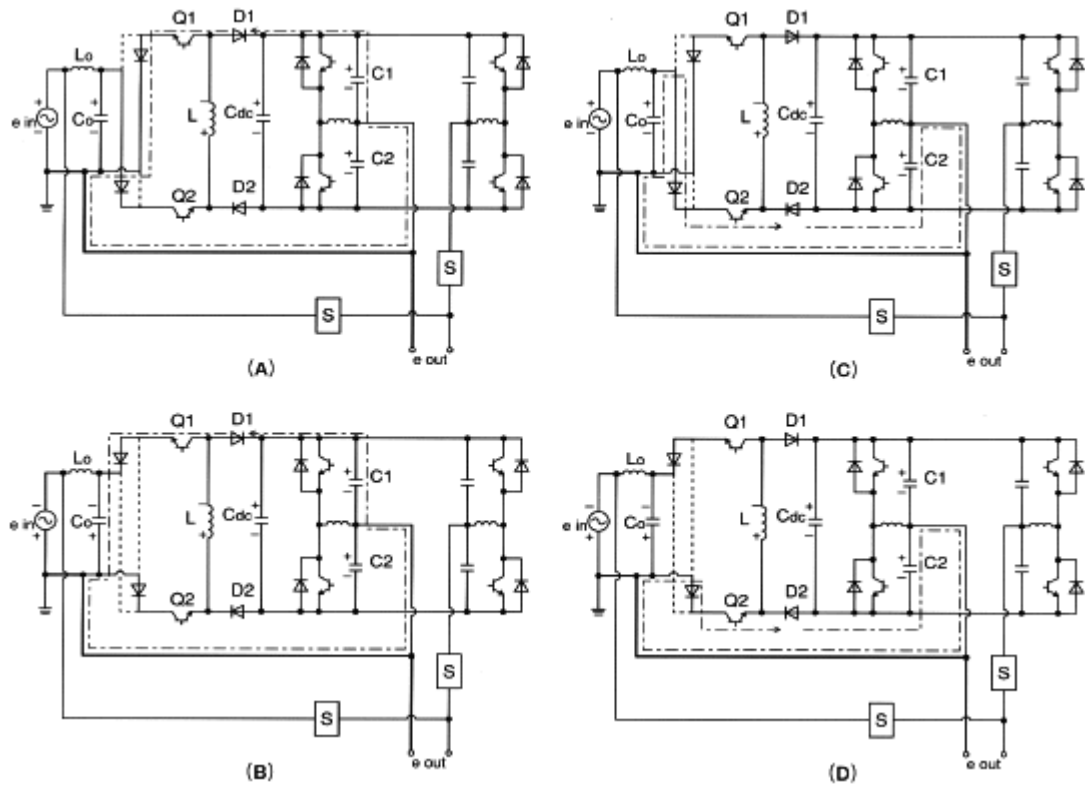


Fig. 9 Bias modes of the FCON diodes