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(71) Applicant(s)
NR Electric Co., Ltd;NR Engineering Co., Ltd

(72) Inventor(s)
Xie, Yeyuan;Cao, Dongming;Jiang, Tiangui;Zhu, Minglian;Yin, Guanxian

(74) Agent / Attorney
Madderns Patent & Trade Mark Attorneys, GPO Box 2752, ADELAIDE, SA, 5001, AU

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- (71) 申请人: 南京南瑞继保电气有限公司 (NR ELECTRIC CO., LTD) [CN/CN]; 中国江苏省南京市江宁区苏源大道 69 号, Jiangsu 211102 (CN)。南京南瑞继保工程技术有限公司 (NR ENGINEERING CO., LTD) [CN/CN]; 中国江苏省南京市江宁区苏源大道 69 号, Jiangsu 211102 (CN)。
- (72) 发明人: 谢晖源 (XIE, Yeyuan); 中国江苏省南京市江宁区苏源大道 69 号, Jiangsu 211102 (CN)。曹冬明 (CAO, Dongming); 中国江苏省南京市江宁区苏源大道 69 号, Jiangsu 211102 (CN)。姜田贵 (JIANG, Tiangu); 中国江苏省南京市江宁区苏源大道

69 号, Jiangsu 211102 (CN)。朱铭炼 (ZHU, Minglian); 中国江苏省南京市江宁区苏源大道 69 号, Jiangsu 211102 (CN)。殷冠贤 (YIN, Guanxian); 中国江苏省南京市江宁区苏源大道 69 号, Jiangsu 211102 (CN)。

(74) 代理人: 南京经纬专利商标代理有限公司 (NANJING JINGWEI PATENT & TRADEMARK AGENCY CO., LTD); 中国江苏省南京市鼓楼区中山路 179 号 12 楼 B 座, Jiangsu 210005 (CN)。

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(54) Title: MODULAR MULTILEVEL CONVERTER DRIVING SIGNAL MODULATION METHOD AND FAULT ISOLATION METHOD

(54) 发明名称: 模块化多电平换流器驱动信号调制方法及故障隔离方法

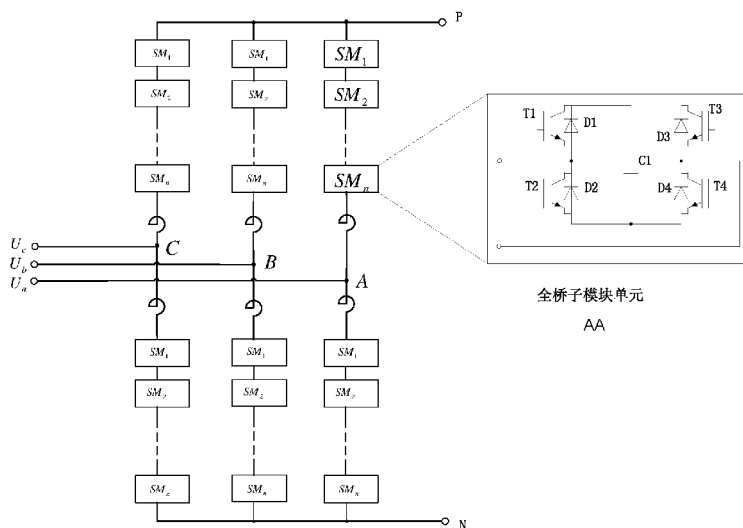


图 1

AA FULL-BRIDGE SUB-MODULE UNIT

(57) Abstract: A modular multilevel converter driving signal modulation method and a sub-module unit fault isolation method. The modular multilevel converter driving signal modulation method comprises a first mode and a second mode, the first mode and the second mode operating in a cyclical manner. In the first mode, a first power semiconductor switch (T1) and a second power semiconductor switch (T2) are turned on in an alternating manner, and at the same time, a third power semiconductor switch (T3) is turned off in a normal manner and a fourth power semiconductor switch (T4) is turned on in a normal manner. In the second mode, the third power semiconductor switch (T3) and the fourth power semiconductor switch (T4) are turned on in an alternating manner, and at the same time, the first power semiconductor switch (T1) is turned on in a normal manner and the second power semiconductor switch (T2) is turned off in a normal manner. The junction temperatures of the power semiconductor switches are balanced, increasing the operational safety margin of a converter. The capacity of a converter may be effectively in-

creased without increasing engineering costs, and performance is better in both economic and technical terms.

(57) 摘要:

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一种模块多电平换流器调制方法以及一种子模块单元故障隔离方法, 包括第一模式和第二模式; 第一模式和第二模式循环进行; 第一模式, 第一功率半导体开关 (T1) 和第二功率半导体开关 (T2) 交替导通; 同时第三功率半导体开关 (T3) 常态截止, 第四功率半导体开关 (T4) 常态导通; 第二模式, 第三功率半导体开关 (T3) 和第四功率半导体开关 (T4) 交替导通; 同时第一功率半导体开关 (T1) 常态导通, 第二功率半导体开关 (T2) 常态截止。其采用的功率半导体开关结温均衡, 增加了换流器运行安全裕度, 在不增加工程成本的前提下, 可有效提升换流器的容量, 在经济性和技术性上均有较好表现。

DRIVE SIGNAL MODULATION METHOD OF MODULAR MULTILEVEL CONVERTER AND FAULT ISOLATION METHOD

BACKGROUND

Field

5 The present specification relates to the field of VSC-HVDC, and particularly to a drive signal modulation method of a modular multilevel converter and a fault isolation method.

Background

10 The emergence of a modular multilevel converter (MMC) enables successful application of a multilevel converter in the field of VSC-HVDC. The converter of the MMC adopts a modular design and is composed of several basic unit modules having an identical structure in series, each of the modules being referred to as a converter module unit. By increasing the number of series modules and a current level in the converter, the converter can be applied to those occasions at different voltage and
15 power levels.

However, a traditional half-bridge module unit has an inherent defect in which a direct current (DC) fault cannot be effectively handled, and a full-bridge module capable of suppressing a DC fault current also has problems such as large losses and high costs. Thus, how to optimize the performance of the MMC becomes a key
20 technical factor for solving the problems in DC interconnection.

In view of this, the present inventors have conducted investigations and improvements on a drive signal modulation method of a modular multilevel converter, resulting in the present application.

SUMMARY

25 Embodiments described herein provide a drive signal modulation method of a modular multilevel converter and a fault isolation method, or at least provide a useful alternative to existing methods. In some embodiments the drive signal modulation

method of a modular multilevel converter can reduce thermal stress of a power semiconductor switch in the converter, increase the capacity of the converter, overcome shortcomings of a full-bridge submodule, and achieve better performance in both economic efficiency and technicality. The fault isolation method of a submodule unit can flexibly select a drive modulation method to effectively isolate a broken-down switching transistor. The method does not influence operation of the system and also reduces a fault rate of the submodule unit, and the availability of the overall system is increased.

According to a first aspect, there is provided: a drive signal modulation method of a modular multilevel converter, the modular multilevel converter including at least one bridge arm, the bridge arm including at least one full-bridge submodule unit, the full-bridge submodule unit including a first power semiconductor switch, a second power semiconductor switch, a third power semiconductor switch and a fourth power semiconductor switch, wherein:

the drive signal modulation method includes a first mode and a second mode; the full-bridge submodule unit firstly enters the first mode, then enters the second mode, reenters the first mode and so on; or firstly enters the second mode, then enters the first mode, reenters the second mode and so on;

in the first mode, an alternate drive signal is applied to the first power semiconductor switch and the second power semiconductor switch, such that the first power semiconductor switch and the second power semiconductor switch are turned on alternately in the same time sequence, while a complementary drive signal is applied to the third power semiconductor switch and the fourth power semiconductor switch, such that the third power semiconductor switch is turned off normally and the fourth power semiconductor switch is turned on normally; and

in the second mode, the alternate drive signal is applied to the third power semiconductor switch and the fourth power semiconductor switch, such that the third power semiconductor switch and the fourth power semiconductor switch are turned on alternately in the same time sequence, while the complementary drive signal is applied to the first power semiconductor switch and the second power semiconductor switch, such that the first power semiconductor switch is turned on normally and the fourth power semiconductor switch is turned off normally.

Further, the first power semiconductor switch includes a switching transistor T1 and a freewheel diode D1 in anti-parallel with the switching transistor T1; the second power semiconductor switch includes a switching transistor T2 and a freewheel diode D2 in anti-parallel with the switching transistor T2; the third power semiconductor switch includes a

switching transistor T3 and a freewheel diode D3 in anti-parallel with the switching transistor T3; and the fourth power semiconductor switch includes a switching transistor T4 and a freewheel diode D4 in anti-parallel with the switching transistor T4.

Further, each of the switching transistors T1 to T4 assumes an IGBT, an IGCT, a GTO, or a MOSFET.

Further, the drive signal modulation method includes the following steps:

1) a capacitor discharge state in the first mode: an on-signal is applied to the switching transistors T1 and T4, an off-signal is applied to the switching transistors T2 and T3, and the switching transistors T1 and T4 are turned on and an energy storage element C1 is discharged, at a forward current;

2) a forward bypass state in the first mode: an on-signal is applied to the switching transistors T2 and T4, an off-signal is applied to the switching transistors T1 and T3, and the freewheel diode D2 and the switching transistor T4 are turned on and the full-bridge submodule unit is bypassed, at a forward current;

3) a capacitor discharge state in the first mode: an on-signal is applied to the switching transistors T1 and T4, an off-signal is applied to the switching transistors T2 and T3, and the freewheel diodes D1 and D4 are turned on and the energy storage element C1 is charged, at a reverse current;

4) a reverse bypass state in the first mode: an on-signal is applied to the switching transistors T2 and T4, an off-signal is applied to the switching transistors T1 and T3, and the switching transistor T2 and the freewheel diode D4 are turned on and the full-bridge submodule unit is bypassed, at a reverse current;

5) capacitor discharge state in the second mode: an on-signal is applied to the switching transistors T1 and T4, an off-signal is applied to the switching transistors T2 and T3, and the switching transistors T1 and T4 are turned on and the energy storage element C1 is discharged, at a forward current;

6) a forward bypass state in the second mode: an on-signal is applied to the switching transistors T1 and T3, an off-signal is applied to the switching transistors T2 and T4, and the switching transistor T1 and the freewheel diode D3 are turned on and the full-bridge submodule unit is bypassed, at a forward current;

7) a capacitor discharge state in the second mode: an on-signal is applied to the

switching transistors T1 and T4, an off-signal is applied to the switching transistors T2 and T3, and the freewheel diodes D1 and D4 are turned on and the energy storage element C1 is charged, at a reverse current; and

8) a reverse bypass state in the second mode: an on-signal is applied to the switching transistors T1 and T3, an off-signal is applied to the switching transistors T2 and T4, and the freewheel diode D1 and the switching transistor T3 are turned on and the full-bridge submodule unit is bypassed, at a reverse current.

According to another aspect, there is provided: a fault isolation method of a submodule unit, the submodule unit being a full-bridge submodule unit, wherein when the drive signal modulation method of a modular multilevel converter described above is used to perform modulation, if a second power semiconductor switch or a third power semiconductor switch in the full-bridge submodule unit breaks down or if a drive circuit of the second power semiconductor switch or the third power semiconductor switch breaks down, the broken-down power semiconductor switch is isolated by changing the mode of the drive signal modulation, while the full-bridge submodule unit does not stop running.

Embodiments described herein enable thermal stress balancing of power semiconductor switches in a submodule by modulating a drive signal, thereby increasing the capacity of a converter, and changes current stress of switching transistors and anti-parallel diodes of the switching transistors by alternating a drive signal in a two-stage mode. Losses of the switching transistors and the anti-parallel diodes thereof are more uniform, junction temperatures of the power semiconductor switches are reduced, and an operation safety margin is greater. The capacity of the converter can be increased by reducing the junction temperatures of the power semiconductor switches.

Since the full-bridge submodule unit has one switching transistor in a blocking state either in the first mode or in the second mode, embodiments can select one of stages 1 and 2 in operation when detecting that any of switching transistors breaks down, where the broken-down switching transistor is set to be in the blocking state, the remaining three switching transistors still normally operate, and the full-bridge submodule unit is not bypassed. When any of switching transistors or a drive circuit thereof breaks down, a drive modulation method can be flexibly selected to

effectively isolate the broken-down switching transistor without influencing operation of the system. The full-bridge submodule unit can allow that one switching transistor or a drive circuit thereof breaks down and is not bypassed, thereby reducing a fault rate of the submodule unit and increasing the availability of the overall system.

5 In summary, compared with the prior art, embodiments described herein have advantageous effects such as: achieving thermal stress balancing of power semiconductor switches in a submodule unit, thereby increasing the capacity of a converter and reducing the cost of unit capacity of the converter; increasing an safety margin of the submodule unit and reliability of the system with no increase of
10 investment; and tolerating that any of IGBTs in a full-bridge submodule unit breaks down while normally operating, thereby reducing the risk of bypass of the full-bridge submodule unit and increasing the availability of the system.

Throughout the specification and the claims that follow, unless the context requires otherwise, the words “comprise” and “include” and variations such as
15 “comprising” and “including” will be understood to imply the inclusion of a stated integer or group of integers, but not the exclusion of any other integer or group of integers.

The reference to any prior art in this specification is not, and should not be taken as, an acknowledgement of any form of suggestion that such prior art forms part of
20 the common general knowledge.

It will be appreciated by those skilled in the art that the invention is not restricted in its use to the particular application described. Neither is the present invention restricted in its preferred embodiment with regard to the particular elements and/or features described or depicted herein. It will be appreciated that the invention is not
25 limited to the embodiment or embodiments disclosed, but is capable of numerous rearrangements, modifications and substitutions without departing from the scope of the invention as set forth and defined by the following claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a topology of a modular multilevel converter according to an
30 embodiment.

FIG. 2 is a schematic diagram of various operating conditions of a full-bridge

submodule unit at a stage 1 according to an embodiment:

- (a) forward current discharge loop;
- (b) forward current bypass loop;
- (c) reverse current charge loop; and
- 5 (d) reverse current bypass loop.

FIG. 3 is a schematic diagram of various operating conditions of a full-bridge submodule unit at a stage 2 according to an embodiment:

- (a) forward current discharge loop;
- (b) forward current bypass loop;
- 10 (c) reverse current charge loop; and
- (d) reverse current bypass loop.

DETAILED DESCRIPTION

The technical solutions of the various embodiments described herein are described in detail below with reference to the accompanying drawings.

15

Embodiment 1

Referring to FIGs. 1, 2 and 3, shown is a drive signal modulation method of a modular multilevel converter, the modular multilevel converter including at least one bridge arm, specifically six bridge arms in the present embodiment, the bridge arm including at least one full-bridge submodule unit, the full-bridge submodule unit including a first power semiconductor switch, a second power semiconductor switch, a third power semiconductor switch and a fourth power semiconductor switch, wherein the drive signal modulation method includes a first mode and a second mode; the full-bridge submodule unit firstly enters the first mode, then enters the second mode, reenters the first mode and so on, or firstly enters the second mode, then enters the first mode, reenters the second mode and so on;

in the first mode, an alternate drive signal is applied to the first power semiconductor switch and the second power semiconductor switch, such that the first power semiconductor switch and the second power semiconductor switch are turned on alternately in the same time sequence, while a complementary drive signal is applied to the third power semiconductor switch and the fourth power semiconductor switch, such that the third power semiconductor switch is turned off normally and the fourth power semiconductor switch is turned on normally; and

in the second mode, the alternate drive signal is applied to the third power semiconductor switch and the fourth power semiconductor switch, such that the third power semiconductor switch and the fourth power semiconductor switch are turned on alternately in the same time sequence, while the complementary drive signal is applied to the first power semiconductor switch and the second power semiconductor switch, such that the first power semiconductor switch is turned on normally and the fourth power semiconductor switch is turned off normally.

As a preferred embodiment, the first power semiconductor switch includes a switching transistor T1 and a freewheel diode D1 in anti-parallel with the switching transistor T1, the second power semiconductor switch includes a switching transistor T2 and a freewheel diode D2 in anti-parallel with the switching transistor T2, the third power semiconductor switch includes a switching transistor T3 and a freewheel diode D3 in anti-parallel with the switching transistor T3, and the fourth power semiconductor switch includes a switching transistor T4 and a freewheel diode D4 in anti-parallel with the switching transistor T4; and each of the switching transistors T1-T4 assumes an IGBT, an IGCT, a GTO, or a MOSFET.

Further, the drive signal modulation method of a modular multilevel converter includes the following steps:

1) a capacitor discharge state in the first mode: an on-signal is applied to the switching transistors T1 and T4, an off-signal is applied to the switching transistors T2 and T3, and the switching transistors T1 and T4 are turned on and an energy storage element C1 is discharged, at a forward current, as shown in FIG. 2a;

2) a forward bypass state in the first mode: an on-signal is applied to the switching transistors T2 and T4, an off-signal is applied to the switching transistors T1 and T3, and the freewheel diode D2 and the switching transistor T4 are turned on and the full-bridge submodule unit is bypassed, at a forward current, as shown in FIG. 2b;

3) a capacitor discharge state in the first mode: an on-signal is applied to the switching transistors T1 and T4, an off-signal is applied to the switching transistors T2 and T3, and the freewheel diodes D1 and D4 are turned on and the energy storage element C1 is charged, at a reverse current, as shown in FIG. 2c;

4) a reverse bypass state in the first mode: an on-signal is applied to the switching transistors T2 and T4, an off-signal is applied to the switching transistors T1 and T3, and the switching transistor T2 and the freewheel diode D4 are turned on and the full-bridge submodule unit is bypassed, at a reverse current, as shown in FIG. 2d;

5) a capacitor discharge state in the second mode: an on-signal is applied to the switching transistors T1 and T4, an off-signal is applied to the switching transistors T2 and T3, and the switching transistors T1 and T4 are turned on and the energy storage element C1 is discharged, at a forward current, as shown in FIG. 3a;

6) a forward bypass state in the second mode: an on-signal is applied to the switching transistors T1 and T3, an off-signal is applied to the switching transistors T2 and T4, and the switching transistor T1 and the freewheel diode D3 are turned on and the full-bridge submodule unit is bypassed, at a forward current, as shown in FIG. 3b;

7) a capacitor discharge state in the second mode: an on-signal is applied to the switching transistors T1 and T4, an off-signal is applied to the switching transistors T2 and T3, and the freewheel diodes D1 and D4 are turned on and the energy storage element C1 is charged, at a reverse current, as shown in FIG. 3c; and

8) a reverse bypass state in the second mode: an on-signal is applied to the switching

transistors T1 and T3, an off-signal is applied to the switching transistors T2 and T4, and the freewheel diode D1 and the switching transistor T3 are turned on and the full-bridge submodule unit is bypassed, at a reverse current, as shown in FIG. 3d.

Embodiment 2:

The present embodiment provides a fault isolation method of a submodule unit, the submodule unit being a full-bridge submodule unit. When the drive signal modulation method of a modular multilevel converter in the embodiment 1 is used to perform modulation, if the second power semiconductor switch in the full-bridge submodule unit breaks down or if a drive circuit of the second power semiconductor switch breaks down, the broken-down second power semiconductor switch is isolated by changing the mode of the drive signal modulation, while the full-bridge submodule unit does not stopping running and operates in the second mode, as shown in FIG. 3.

Embodiment 3:

The present embodiment provides a fault isolation method of a submodule unit, the submodule unit being a full-bridge submodule unit. When the drive signal modulation method of a modular multilevel converter described in the embodiment 1 is used to perform modulation, if the third power semiconductor switch in the full-bridge submodule unit breaks down or if a drive circuit of the third power semiconductor switch breaks down, the broken-down third power semiconductor switch is isolated by changing the mode of the drive signal modulation, while the full-bridge submodule unit does not stopping running and operates in the first mode, as shown in FIG. 2.

What is claimed is:

1. A drive signal modulation method of a modular multilevel converter, the modular multilevel converter comprising at least one bridge arm, the bridge arm comprising at least one full-bridge submodule unit, the full-bridge submodule unit comprising a first power semiconductor switch, a second power semiconductor switch, a third power semiconductor switch and a fourth power semiconductor switch, wherein:

the full-bridge submodule unit operates in two alternate operation modes, designated a first mode and a second mode;

firstly enters the first mode, then enters the second mode, reenters the first mode and so on;

or firstly enters the second mode, then enters the first mode, reenters the second mode and so on;

in the first mode, an alternate drive signal is applied to the first power semiconductor switch and the second power semiconductor switch, such that the first power semiconductor switch and the second power semiconductor switch are turned on alternately in the same time sequence, while a complementary drive signal is applied to the third power semiconductor switch and the fourth power semiconductor switch, such that the third power semiconductor switch remains in an off state and the fourth power semiconductor switch remains in an on state in the time sequence of the alternate turning-on of the first power semiconductor switch and the second power semiconductor switch; and

in the second mode, an alternate drive signal is applied to the third power semiconductor switch and the fourth power semiconductor switch, such that the third power semiconductor switch and the fourth power semiconductor switch are turned on alternately in the same time sequence, while a complementary drive signal is applied to the first power semiconductor switch and the second power semiconductor switch, such that the first power semiconductor switch remains in an on state and the second power semiconductor switch remains in an off state in the time sequence of the alternate turning-on of the third power semiconductor switch and the fourth power semiconductor switch.

2. The drive signal modulation method of a modular multilevel converter of claim 1, wherein: the first power semiconductor switch comprises a switching transistor T1 and a freewheel diode D1 in anti-parallel with the switching transistor T1; the second power semiconductor switch comprises a switching transistor T2 and a freewheel diode D2 in anti-parallel with the switching transistor T2; the third power semiconductor switch comprises a switching transistor T3 and a freewheel diode D3 in anti-parallel with the switching transistor T3; and the fourth power semiconductor switch comprises a switching transistor T4 and a freewheel diode D4 in anti-parallel with the switching transistor T4.

3. The drive signal modulation method of a modular multilevel converter of claim 1 or 2, wherein each of the switching transistors T1, T2, T3, and T4 assumes an IGBT, an IGCT, a GTO, or a MOSFET.

4. The drive signal modulation method of a modular multilevel converter of claim 2, comprising the following steps:

1) a capacitor discharge state in the first mode: an on-signal is applied to the switching transistors T1 and T4, an off-signal is applied to the switching transistors T2 and T3,

and the switching transistors T1 and T4 are turned on and an energy storage element C1 is discharged, at a forward current;

2) a forward bypass state in the first mode: an on-signal is applied to the switching transistors T2 and T4, an off-signal is applied to the switching transistors T1 and T3, and the freewheel diode D2 and the switching transistor T4 are turned on and the full-bridge submodule unit is bypassed, at a forward current;

3) a capacitor discharge state in the first mode: an on-signal is applied to the switching transistors T1 and T4, an off-signal is applied to the switching transistors T2 and T3, and the freewheel diodes D1 and D4 are turned on and the energy storage element C1 is charged, at a reverse current;

4) a reverse bypass state in the first mode: an on-signal is applied to the switching transistors T2 and T4, an off-signal is applied to the switching transistors T1 and T3, and the switching transistor T2 and the freewheel diode D4 are turned on and the full-bridge submodule unit is

bypassed, at a reverse current;

5) capacitor discharge state in the second mode: an on-signal is applied to the switching transistors T1 and T4, an off-signal is applied to the switching transistors T2 and T3, and the switching transistors T1 and T4 are turned on and the energy storage element C1 is discharged, at a forward current;

6) a forward bypass state in the second mode: an on-signal is applied to the switching transistors T1 and T3, an off-signal is applied to the switching transistors T2 and T4, and the switching transistor T1 and the freewheel diode D3 are turned on and the full-bridge submodule unit is bypassed, at a forward current;

7) a capacitor discharge state in the second mode: an on-signal is applied to the switching transistors T1 and T4, an off-signal is applied to the switching transistors T2 and T3, and the freewheel diodes D1 and D4 are turned on and the energy storage element C1 is charged, at a reverse current; and

8) a reverse bypass state in the second mode: an on-signal is applied to the switching transistors T1 and T3, an off-signal is applied to the switching transistors T2 and T4, and the freewheel diode D1 and the switching transistor T3 are turned on and the full-bridge submodule unit is bypassed, at a reverse current.

5. A fault isolation method of a submodule unit, the submodule unit being a full-bridge submodule unit, wherein: when the drive signal modulation method of a modular multilevel converter of any one of claims 1-4 is used to perform modulation, if a second power semiconductor switch or a third power semiconductor switch in the full-bridge submodule unit breaks down or if a drive circuit of the second power semiconductor switch or the third power semiconductor switch breaks down, the broken-down power semiconductor switch is isolated by changing the mode of the drive signal modulation, while the full-bridge submodule unit does not stop running.

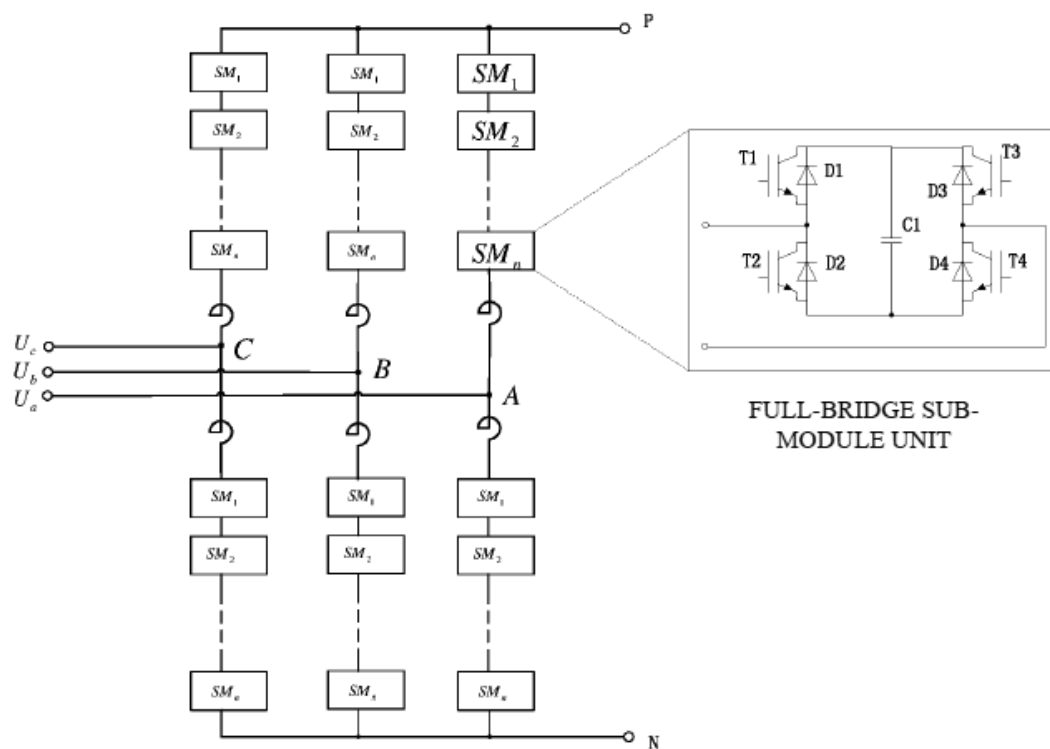


FIG.1

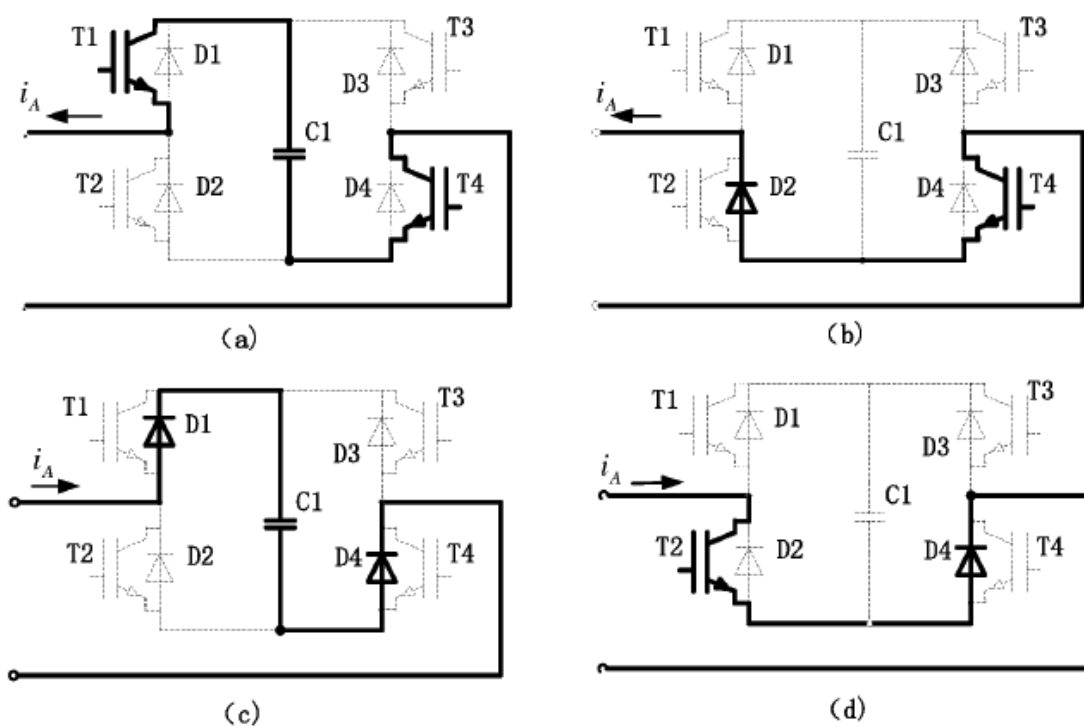


FIG.2

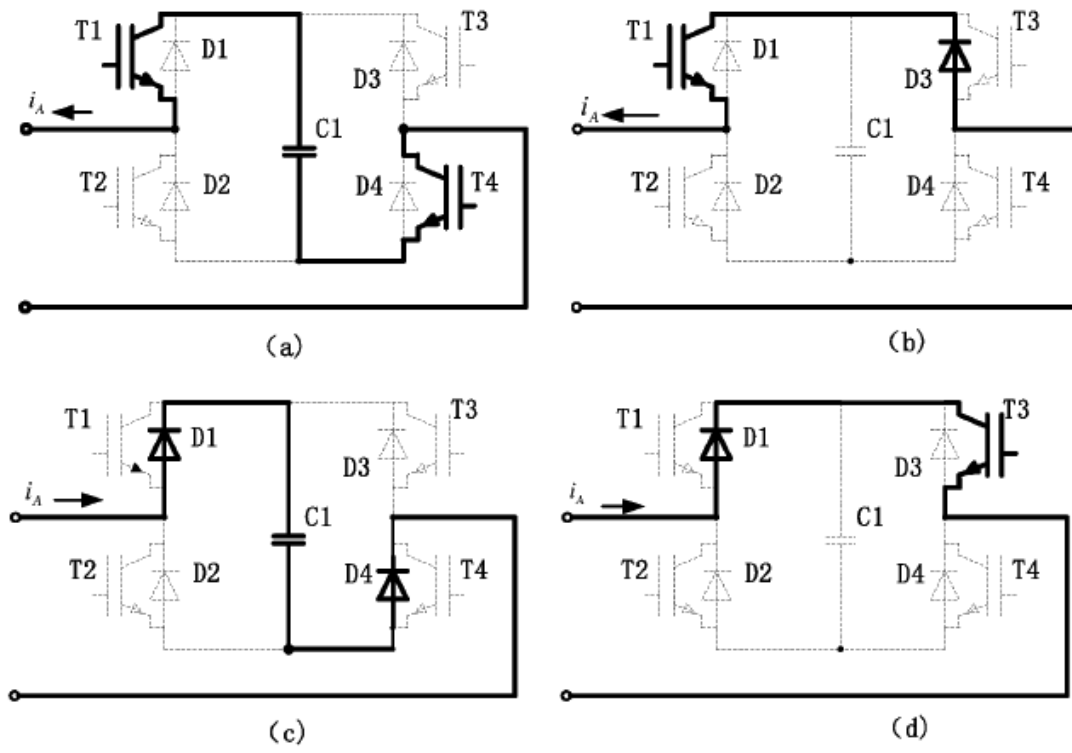


FIG.3