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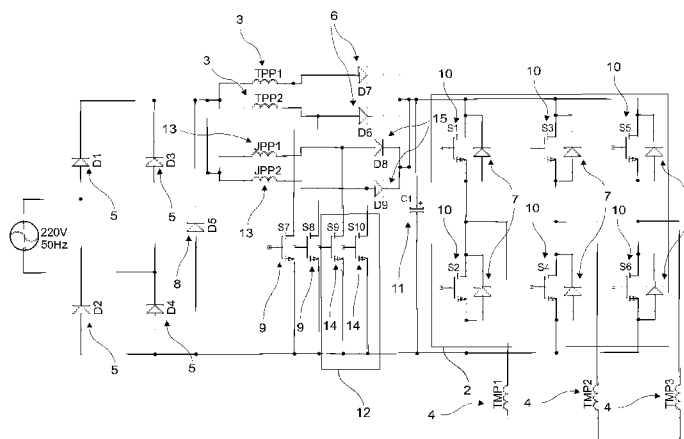
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(54) Title: DUAL UNIPOLAR AND BIPOLAR DOUBLE OR TRIPLE BRUSHLESS DC MOTOR INVERTER TOPOLOGY

Fig. 3



(57) Abstract: The present invention relates to a control circuit capable of simultaneously driving a plurality of brushless dc motors. The present invention more particularly relates to a converter circuit for driving a first brushless DC electric motor and a second brushless DC electric motor of an electrical household appliance, the converter circuit comprising a first motor driver block (1) controlling energy flow to the first brushless DC electric motor by means of first motor switching devices (9), each one energizing a respective first motor phase winding (3) in timed sequence and a second motor driver block (2) controlling energy flow to the second brushless DC electric motor by means of second motor switching devices (10), each one energizing a respective second motor phase winding (4) in timed sequence, the converter circuit having positive and negative supply rails across which a DC bus capacitor (11) is disposed thereinbetween.

Description**DUAL UNIPOLAR AND BIPOLAR DOUBLE OR TRIPLE BRUSHLESS DC
MOTOR INVERTER TOPOLOGY**

- [0001] The present invention relates to a control circuit capable of simultaneously driving a plurality of brushless dc motors.
- [0002] It is well-known that household appliances such as for instance washing machines are equipped with a plurality of electrical motors effectuating the operations of rotation of the drum, circulation of the processing water and water discharge. Small power brushless DC (BLDC) motors typically in the range of 100-120 W can be considered in some of these applications due to their limited torque in view of their compact size, high efficiency and silent operation.
- [0003] Brushless direct current electric motors are synchronous motors comprising a rotor generally with permanent magnets and a stator with windings timing and direction of the current flow through different phases of which is controlled to ensure the operation of the motor. In brushless DC motors, mechanical switching parts, i.e. brushes of the motor are replaced in the manner that an electronic control circuit typically accomplishes brushless DC motor control whereby the motor is electronically commutated during which the current is transferred from one phase to another.
- [0004] Brushless DC electric motors are powered by a DC electric source via a switching power supply such as bipolar or unipolar driver circuits. In a unipolar driver circuit, conduction occurs during the positive part of the back emf resulting in that a simpler switching circuit is used while a bipolar driver circuit requires an increased number of switching elements due to conduction occurring during positive and negative half-cycles.
- [0005] A conventional driver circuit topology suitable for effecting bipolar current flow through each phase of the stator windings provides a costlier yet more efficient electronic control. A bipolar driver circuit driving a three-phase brushless DC motor typically comprises six switching devices with integrated diodes, three of those requiring high-side switching gate drivers. On the other hand, phase currents being not reversed in a unipolar

driver circuit, a reduced number of switching devices will be necessary for the operation of the brushless DC motor.

- [0006] Referring to Fig. 1, a unipolar driver circuit, also driving a three-phase (P1, P2 and P3) brushless DC motor, comprises three switching devices (S2, S4, and S6). Each switching device is in series with a respective phase winding (P1, P2 and P3) and a respective Zener diode is provided in the freewheeling paths with diodes D2, D4 and D6, by which the stored magnetic energy in the respective phases is dissipated.
- [0007] Among others, a prior art publication in the technical field of the invention may be referred to as US5471353, which discloses a disk drive system for use in limited power applications. The disk drive includes a spindle motor having two or more windings, along with a spindle motor driver which can drive the spindle motor in any of a unipolar, bipolar or tripolar mode. The bipolar or tripolar mode is used to start the disk drive and then the unipolar mode is used to operate the disk drive while data is being retrieved. By combining the three drive modes a large start current reduction and high rotation velocities are achieved. Current consumption is minimized by transitioning from bipolar to unipolar modes.
- [0008] The present invention, on the other hand, addresses the situation where a plurality of semi-conductor devices are used in a dual mode unipolar and bipolar circuit topology simultaneously driving a plurality of brushless DC motors, including one higher power brushless DC motor and one or two lower power brushless DC motors. The lower power brushless DC motors are simultaneously drivable while the higher power brushless DC motor is at the same time driven with high efficiency.
- [0009] As cost minimization is critical to the large volume manufacture, the present invention provides an effective circuit solution by which the least number of semi-conductor switching devices are needed for simultaneously driving all brushless DC motors in an electrical household appliance. Therefore, the present invention is devised under the recognition that a more cost-efficient circuit topology for simultaneously driving two or three brushless DC motors remains a need.
- [0010] The present invention provides an inverter circuit, as provided by the

characterizing features defined in Claim 1.

- [0011] Primary object of the present invention is to provide an inverter circuit capable of simultaneously driving two or three brushless dc motors in an electrical household appliance, while unipolar and bipolar modes are supported and a higher power brushless DC motor is driven with high efficiency.
- [0012] The present invention proposes a converter circuit for optionally simultaneously driving a first brushless DC electric motor and a third brushless DC electric motor of an electrical household appliance, while a second brushless DC electric motor is also drivable by the same converter circuit independently from the first and third brushless DC electric motors.
- [0013] The present invention provides that a first or third brushless DC motors in parallel as two-phase discharge pump and circulation pump motors of a laundry machine and a second brushless DC motor thereof as a three-phase drum rotation motor can be simultaneously driven without using two bipolar inverters having ten switching devices, half of which requiring high-side switching gate drivers. If only one of the discharge pump and circulation pump motors is driven at a given interval, the non-energized motor windings can be used as an active PFC.
- [0014] Accompanying drawings are given solely for the purpose of exemplifying a control circuit capable of simultaneously driving a pair of brushless dc motors, whose advantages over prior art were outlined above and will be explained in brief hereinafter.
- [0015] The drawings are not meant to delimit the scope of protection as identified in the Claims, nor should they be referred to alone in an effort to interpret the scope identified in the Claims without recourse to the technical disclosure in the description of the present invention.
- [0016] Fig. 1 demonstrates a schematic of an inverter for a three-phase unipolar brushless DC motor.
- [0017] Fig. 2 demonstrates a schematic of a circuit topology for simultaneously driving two brushless DC motors according to the present invention.
- [0018] Fig. 3 demonstrates a schematic of a circuit topology for driving three brushless DC motors according to an alternative embodiment of the

present invention.

[0019] The following numerals are assigned to different part number used in the detailed description:

1. First motor driver block
2. Second motor driver block
3. First motor phase winding
4. Second motor phase winding
5. Rectifier diode
6. First motor freewheeling diode
7. Second motor freewheeling diode
8. Common freewheeling diode
9. First motor switching device
10. Second motor switching device
11. DC bus capacitor
12. Third motor driver block
13. Third motor phase winding
14. Third motor switching device
15. Third motor freewheeling diode

[0020] The present invention proposes a circuit topology for simultaneously driving a pair of brushless DC motors or according to an alternative embodiment three brushless DC motors in an electrical household appliance such as a laundry machine comprising a first electric motor (TP) responsible for effectuating water discharge from the household appliance, a second electric motor (TM) rotating the drum and a third electric motor (JP) circulating processing water.

[0021] In a brushless DC motor, the stator windings (inductive elements) are switched on and off depending on the rotor position. The magnetic fields of the stator and rotor, i.e. the rotating magnetic field created by timely changing the direction of the current flow through different phases of the stator windings with respect to the rotor's magnetic field are synchronized.

[0022] According to the present invention, a first motor driver block (1) controls the energy flow to the discharge pump motor (TP) windings and a second motor driver block (2) drives the drum motor (TM) as will be delineated

hereinafter. In contrast to a bipolar inverter which allows bipolar current flow through stator phase windings in a brushless DC motor, a unipolar inverter topology typically limits the windings to a single direction of current to energize the same and the energy stored in a respective winding is dissipated in the same winding through reverse-parallel diodes, thereby proving to be an economic but inefficient power conversion. It is yet to be noted that cost advantage is a critical issue as the inverter for the motor can be more expensive than the motor itself.

[0023] According to the present invention, the drum motor (TM) is preferably a three-phase motor with second motor switching devices 10 (S1, S2, S3, S4, S5 and S6), being typically IGBT, FET or MOSFET. Each switching device 10 energizes a respective second motor phase winding 4 (TM P1, TM P2, and TM P3). On the other hand, the discharge motor (TP) is a two-phase motor having two first motor switching devices 9 (S7 and S8), each one sequentially energizing a respective first motor phase winding 3 (TP P1 and TP P2).

[0024] According to the present invention, an alternating voltage source is rectified by four rectifier diodes 5 (D1, D2, D3 and D4) while first motor freewheeling diodes 6 (D6 and D7) are connected in series with the first motor phase windings 3 (TP P1 and TP P2). The AC source voltage is rectified through rectifier diodes 5 (D1, D2, D3 and D4) while the first motor switching devices 9 (S7 and S8) energizes in timed sequence the associated first motor phase windings (3). A respective first motor phase winding (3) is then deenergized through a respective first motor freewheeling diode (6) in series therewith. Fig. 2 demonstrates a schematic of a circuit topology with positive and negative supply rails forming common connection points.

[0025] According to the present invention, while current flows through the second motor phase windings (4) depending on the rotor position, the second motor switching devices 10 (S1, S2, S3, S4, S5 and S6) are turned on in timed sequence and the respective second motor phase winding (4) is energized. When a respective second motor switching device 10 (S1, S2, S3, S4, S5 and S6) is opened, associated freewheeling diodes (7) allow

current flow to charge a DC bus capacitor (11). The freewheeling current is therefore used in the manner that stored magnetic field energy in the phase windings is transferred to the DC bus capacitor (11) during operation of the first and second motors.

- [0026] The latter DC bus capacitor (11) is disposed across the positive and negative supply rails to smooth voltage ripple. The boosted DC bus voltage is advantageously effective in increasing the maximum speed of the second motor (TM).
- [0027] Fig. 3 demonstrates a second alternative embodiment according to the invention, by which an additional two-phase circulation pump (JP) with third motor phase windings (JP P1, JP P2) can be simultaneously driven. Similar to the first motor driving block (1), each one of the two third motor switching devices 14 (S9 and S10) sequentially energizes a respective third motor phase winding 13 (JP P1 and JP P2). Additionally an optional common freewheeling diode (8) is used in the circuits of Fig. 2 and 3.
- [0028] A conventional PWM scheme can be implemented to produce the desired Torque-Speed characteristics. The amplitude of the applied voltage is adjusted by controlling the duty cycle of PWM pulses in accordance with the voltage amplitude to keep the desired speed. Therefore, the present invention's circuit solution according to either Fig. 2 or 3 allows for independently controlling the three motors and their speed.
- [0029] The present invention provides a more efficient high-speed operation for the higher power drum motor (TM) as the circuit solution of the invention according to Fig. 2 or 3 produces the effect of boosting the DC bus voltage, which in turn increases the maximum speed of the second motor (TM) and minimizes harmonics drawn from the mains as it functions to generate power factor correction effect. The active PFC circuit is therefore effective in allowing for designing a simpler harmonic filter. The circuits of Fig. 2 or 3 are additionally effective in eliminating the need for additional components (inrush current limiter) such as NTC/PTC to limit the charging current to the DC bus capacitor (11). If only one of the two-phase motors (the first electric motor (TP) and the third electric motor (JP)) is driven at a given interval, the non-energized motor windings can be advantageously

used as an active PFC.

- [0030] According to the present invention, in the event that only one of the two-phase motors is driven, the circuit solution according to Fig. 3 additionally acts as a passive filter to comply with EMC/EMI requirements.
- [0031] In summary, the present invention proposes a converter circuit for driving a first brushless DC electric motor and a second brushless DC electric motor of an electrical household appliance, the converter circuit comprising a first motor driver block (1) controlling energy flow to the first brushless DC electric motor by means of first motor switching devices (9), each one energizing a respective first motor phase winding (3) in timed sequence and a second motor driver block (2) controlling energy flow to the second brushless DC electric motor by means of second motor switching devices (10), each one energizing a respective second motor phase winding (4) in timed sequence, the converter circuit having positive and negative supply rails across which a DC bus capacitor (11) is disposed thereinbetween.
- [0032] In one embodiment of the present invention, the converter circuit further comprises a third motor driver block (12) controlling energy flow to a third brushless DC electric motor by means of third motor switching devices (14), each one energizing a respective third motor phase winding (13) in timed sequence.
- [0033] In a further embodiment of the present invention, the third motor driver block (12) is in parallel with the first motor driver block (1) in the manner that each one of the first motor phase windings (3), the second motor phase windings (13) or both the first motor and the second motor phase windings (3, 13) are selectively energized independent from the second motor phase windings (4).
- [0034] In a further embodiment of the present invention, one of the first and the third motor is selectively driven independent from the second motor.
- [0035] In a further embodiment of the present invention, the first motor and the third motor are simultaneously driven independent from the second motor.
- [0036] In a further embodiment of the present invention, the first brushless DC electric motor and the third brushless DC electric motor are two-phase

motors and the second brushless DC electric motor is a three-phase motor.

- [0037] In a further embodiment of the present invention, an AC source voltage is rectified through rectifier diodes (5) while the first and third motor phase windings (3, 13) are connected to the output of circuit block of the rectifier diodes (5).
- [0038] In a further embodiment of the present invention, an electrical household appliance comprising a converter circuit is proposed.
- [0039] In a further embodiment of the present invention, the appliance is a laundry machine in the form of a washing, drying or washing and drying machine.
- [0040] Therefore, the present invention provides that a first or third brushless DC motors as two-phase discharge pump and circulation pump motors and a second brushless DC motor as a three-phase drum rotation motor can be simultaneously driven without using two bipolar inverters having ten switching devices, half of which requiring high-side switching gate drivers. Instead, the circuit topology according to the present invention affords a much more cost-effective circuit solution which involves eight switching devices, three of those requiring a high-side switching gate driver.
- [0041] Alternatively, the present invention provides that the two-phase discharge pump and circulation pump motors as well as the three-phase drum rotation motor is simultaneously driven. Apart from such economic and other technical advantages such as multiple-driving, passive filter and active PFC, other side-benefits include use of a smaller or single-sided PCB as well as the possibility for a more compact heat sink.

Claims

1. A converter circuit for driving a first brushless DC electric motor and a second brushless DC electric motor of an electrical household appliance, the converter circuit comprising a first motor driver block (1) controlling energy flow to the first brushless DC electric motor by means of first motor switching devices (9), each one energizing a respective first motor phase winding (3) in timed sequence and a second motor driver block (2) controlling energy flow to the second brushless DC electric motor by means of second motor switching devices (10), each one energizing a respective second motor phase winding (4) in timed sequence, the converter circuit having positive and negative supply rails across which a DC bus capacitor (11) is disposed thereinbetween, **characterized in that**
 - the converter circuit further comprises a third motor driver block (12) controlling energy flow to a third brushless DC electric motor by means of third motor switching devices (14), each one energizing a respective third motor phase winding (13) in timed sequence and
 - the third motor driver block (12) is in parallel with the first motor driver block (1) in the manner that each one of the first motor phase windings (3), the second motor phase windings (13) or both the first motor and the second motor phase windings (3, 13) are selectively energized independent from the second motor phase windings (4).
2. A converter circuit as in Claim 1, **characterized in that** one of the first and the third motor is selectively driven independent from the second motor.
3. A converter circuit as in Claim 1, **characterized in that** the first motor and the third motor are simultaneously driven independent from the second motor.
4. A converter circuit as in Claim 2 or 3, **characterized in that** the first brushless DC electric motor and the third brushless DC electric motor are two-phase motors and the second brushless DC electric motor is a three-phase motor.
5. A converter circuit as in Claim 4, **characterized in that** an AC source voltage is rectified through rectifier diodes (5) while the first and third motor phase windings (3, 13) are connected to the output of circuit block of the rectifier diodes (5).
6. An electrical household appliance comprising the converter circuit of Claim 1.

7. An electrical household appliance as in Claim 6 **characterized in that** the appliance is a laundry machine in the form of a washing, drying or washing and drying machine.

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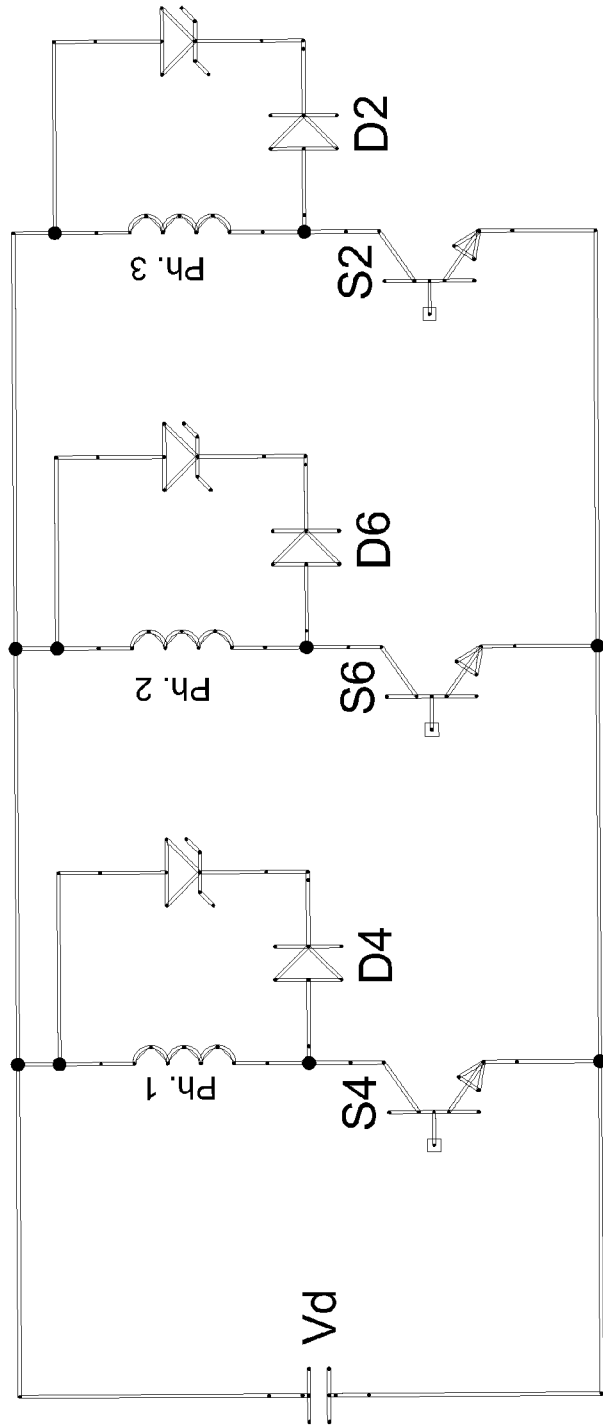


Fig. 1

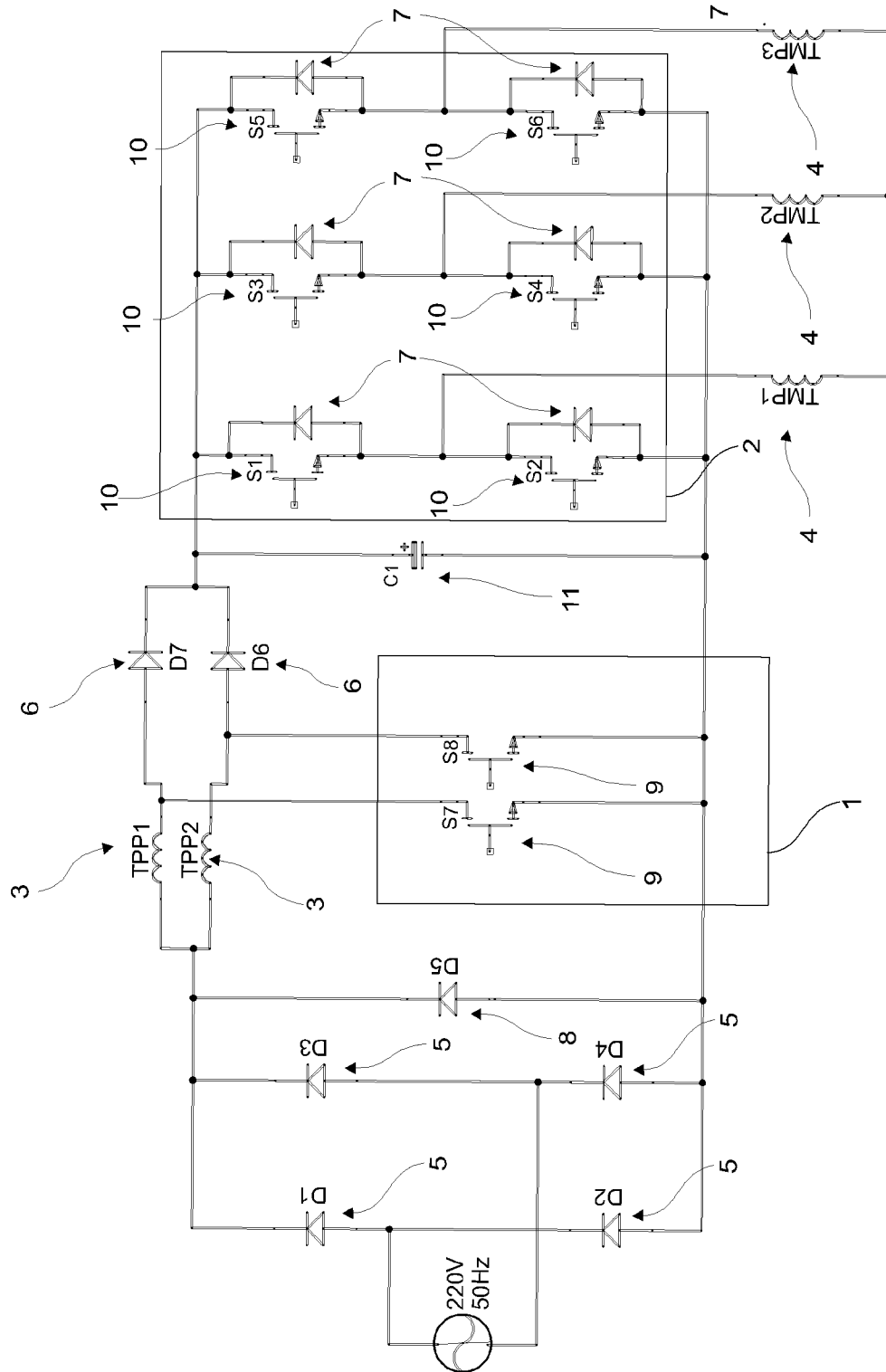


Fig. 2

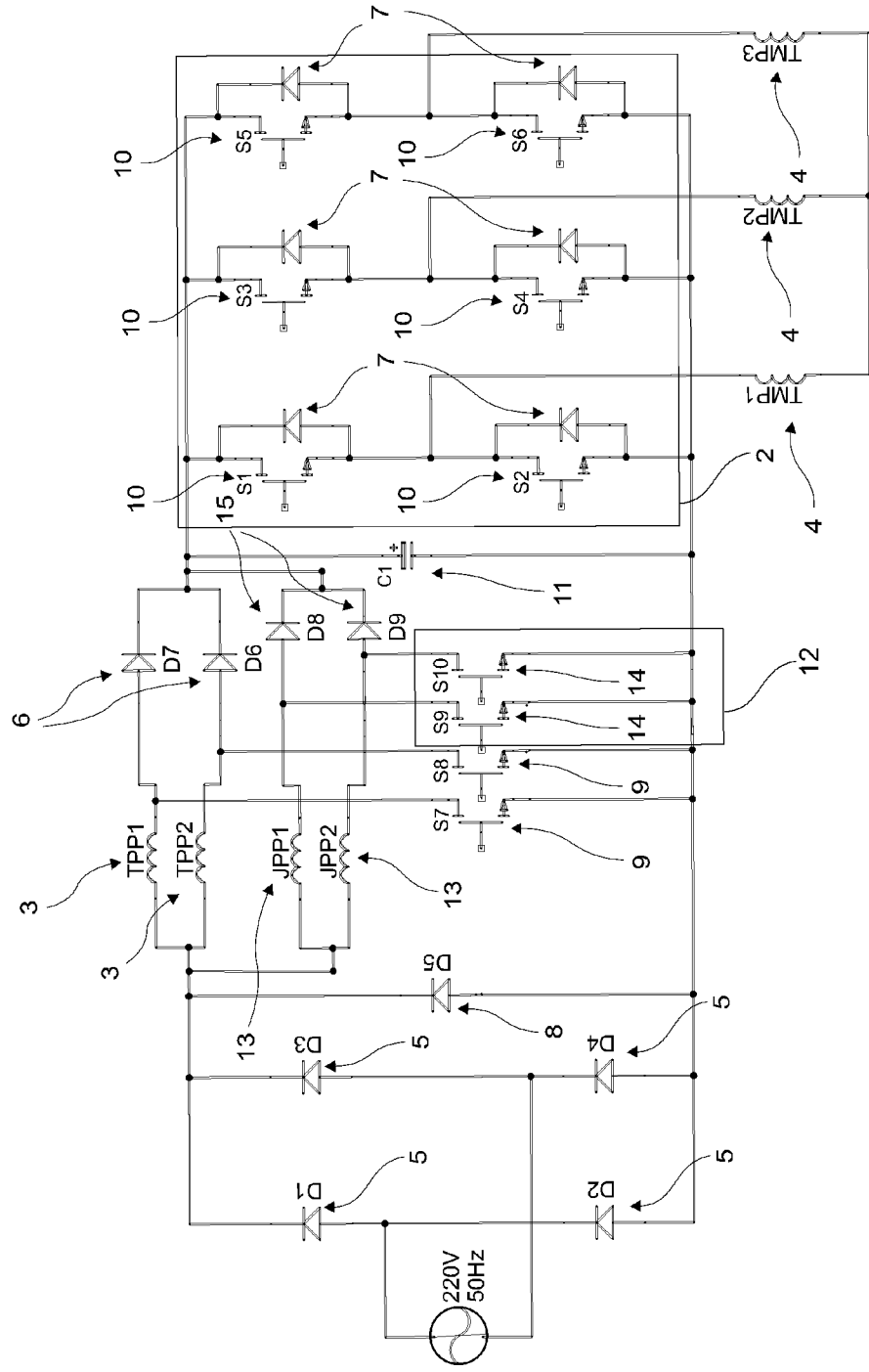


Fig. 3

INTERNATIONAL SEARCH REPORT

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A. CLASSIFICATION OF SUBJECT MATTER

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Minimum documentation searched (classification system followed by classification symbols)

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Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EP0-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2014/320052 A1 (ZHAO YONG [CN] ET AL) 30 October 2014 (2014-10-30) paragraph [0054] - paragraph [0069]; figures 4,5,9,17,18; examples 2,5,11 paragraph [0005] - paragraph [0009] -----	1-7
Y	WO 2009/023205 A1 (RAMU INC [US]; RAMU KRISHNAN [US]) 19 February 2009 (2009-02-19) page 6, line 9 - page 8, line 1; figures 2A - 2E,5 page 9, line 15 - page 11, line 9 page 2, line 1 - line 21 page 12, line 20 - page 13, line 3 ----- -/--	1-7



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INTERNATIONAL SEARCH REPORT

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2004/136133 A1 (YOUM JANG-HYOUN [KR]) 15 July 2004 (2004-07-15) paragraph [0005]; figures 2,4 paragraph [0036] - paragraph [0056] -----	1-7
Y	US 8 461 783 B2 (NAVARRA PIETRO [IT] ET AL) 11 June 2013 (2013-06-11) column 4, line 9 - column 5, line 52; figure 1 column 1, line 5 - line 21 -----	1-7

INTERNATIONAL SEARCH REPORT

Information on patent family members

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