(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
09 August 2018 (09.08.2018)

WIPO | PCT

(10) International Publication Number
WO 2018/141394 A1

(51) International Patent Classification:
H02P 6/15 (2016.01) *H02P 6/182* (2016.01)

(21) International Application Number:
PCT/EP2017/052312

(22) International Filing Date:
03 February 2017 (03.02.2017)

(25) Filing Language: English

(26) Publication Language: English

(71) Applicant: **ARCELIK ANONIM SIRKETI** [TR/TR]; E5 Ankara Asfalti Uzeri, Tuzla, 34950 ISTANBUL (TR).

(72) Inventors: **OZDEMIR, Mehmet Cahit**; E5 Ankara Asfalti Uzeri, Tuzla, 34950 Istanbul (TR). **SALMAN, Emrah**; E5 Ankara Asfalti Uzeri, Tuzla, 34950 Istanbul (TR). **YAMAN, Onur**; E5 Ankara Asfalti Uzeri, Tuzla, 34950 Istanbul (TR).

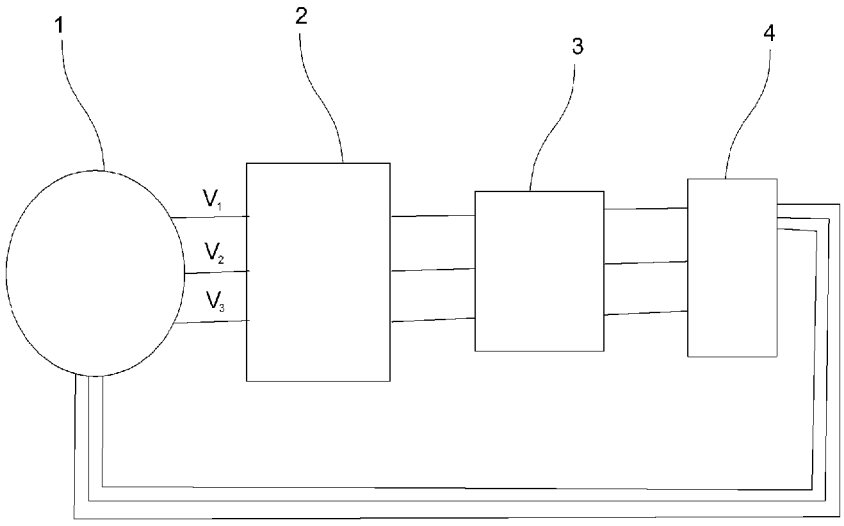
(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report (Art. 21(3))*

(54) **Title:** HOUSEHOLD APPLIANCE WITH BRUSHLESS DC MOTOR SENSORLESS CONTROL SCHEME

Fig. 1



(57) **Abstract:** The present invention relates to an electrical household appliance with a brushless DC motor sensorless control scheme. The present invention more particularly relates to an electrical household appliance comprising at least one electric motor, a three-phase inverter driver circuit (4) capable of driving said at least one electric motor, said three-phase inverter driver circuit (4) comprising a converter that converts AC mains voltage to DC voltage and a driver circuit inverter stage that inverts the direct current.

WO 2018/141394 A1

Description

HOUSEHOLD APPLIANCE WITH BRUSHLESS DC MOTOR SENSORLESS CONTROL SCHEME

[0001] The present invention relates to an electrical household appliance with a brushless DC motor sensorless control scheme.

[0002] It is well-known that a synchronous machine is an electrical machine with a rotating stator magnetic flux and a rotor flux locked therewith to rotate in the synchronous frequency. A brushless DC (BLDC) motor is a kind of synchronous motor that has trapezoidal back-EMF voltage shape.

[0003] It is also well-known that synchronous motors are widely used in rotary household appliances and especially in refrigerators, dishwashers and laundry treatment appliances. For instance, washing machines may have a jet pump for spraying water jets into the rotary drum targeting at specific regions inside it, at which the laundry may tend to adhere within the same, as well as a discharge pump for discharging the water contained in the drum. Likewise, a washing and/or drying machine may have a discharge pump as well as a circulation pump for circulating a refrigerant fluid.

[0004] A three-phase inverter driver circuit can typically be used to drive the BLDC motor. An inverter has six semiconductor switches with the inverter drivers collected in a single package in the form of an integrated power module (IPM). The semiconductors in the power module or inverter can be of different types such as; MOSFET, IGBT, etc.

[0005] One of the well-known six step trapezoidal BLDC control method involves positionment control of the rotor by a microcontroller. The BLDC motor is used in various applications due to its compact size and easy controllability. It is usually operated with one or more rotor-position sensors. However, the motor control can be performed without making use of Hall sensors in the manner that timing to commutate the motor-drive voltages are determined by way of sensing the BEMF voltage on a not driven motor terminal. In this case, for each step of 60 electrical degrees, two windings are energized and one winding is not energized.

[0006] Among others, one of the prior art disclosures in the technical field of the present invention can be referred to as WO2012053027, which discloses a

boost DC-to-DC converter capable of changing a voltage ratio between an input voltage and an output voltage smoothly in a wide range. Two pairs of one reactor and one battery is connected by a parallel switch. The parallel switch and one pair of the reactor and the battery are short-circuited by the first parallel switch. The parallel switch and the other pair of the reactor and the battery are short-circuited by the second parallel switch. The switched reluctance motor has a transient period while a freewheeling current is flowing from a phase winding of the switched reluctance motor. In a first half of transient period, the boost DC-to-DC converter applies a boost voltage to the bridge converter.

[0007] The present invention, on the other hand, provides a control scheme according to which commutation times are determined by shifting zero-crossing points back or forth so that motor speed can be regulated. This is achieved thanks to a capacitor controlled by a switching element whose base or gate is driven through PWM signals so as to obtain variable speed control.

[0008] Primary object of the present invention is therefore to provide an electrical household appliance with a BLDC motor control scheme by which variable speed control can be performed in a sensorless control scheme.

[0009] The present invention proposes an electrical household appliance comprising an inverter power module driving a brushless DC motor, in the form of a six-switch three-phase inverter connected to a DC link. A rotor position detecting and phase shifting circuit has a switched phase-shifting circuit such that phase difference between current waveform of the motor at its actual speed and at the desired speed thereof is determined and commutation is performed based on the waveform of the current at the desired speed. Commutation points are determined by shifting zero-crossing points back and forth to control motor speed. A switching element controls charging and/or discharging amount of a capacitor such that motor speed is regulated in accordance with charging and discharging time of said capacitor. said capacitor is controlled by said switching element whose base or gate is driven through PWM signals.

[0010] Accompanying drawings are given solely for the purpose of exemplifying a

household appliance having a BLDC motor and a control scheme whose advantages over prior art were outlined above and will be explained in brief hereinafter.

[0011] 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 said claims without recourse to the technical disclosure in the description of the present invention.

[0012] Fig. 1 demonstrates a general block diagram of the motor with control components according to the present invention. Motor phases are shown with phase voltages V_1, V_2 and V_3.

[0013] Fig. 2 demonstrates circuit stages for brushless DC motor sensorless control scheme according to the present invention.

[0014] Fig. 3 demonstrates phase shifting stage circuit blocks for brushless DC motor sensorless control scheme according to the present invention.

[0015] The following numerals being referred to are used in the detailed description of the invention:

1. Brushless DC motor
2. Rotor position detecting and phase shifting circuit
3. Microcontroller
4. Three-phase inverter driver circuit
5. Voltage divider circuit
6. First filter
7. Switched phase-shifting circuit
8. Third level filter
9. Waveform comparator
10. Three-phase commutation signal
11. Capacitor
12. Switching element
13. Trapezoidal/sinusoidal waveform

[0016] The present invention proposes an electrical household appliance and particularly a refrigerator, a washing machine, a dishwasher, a drying machine or a combo drying and washing machine, which might contain an electric motor in the form of a brushless DC (BLDC) motor to fulfill various

functions for instance in a washing machine, such as for instance driving a jet pump for spraying water jets into the rotary drum targeting at specific regions inside the same, at which the laundry may tend to adhere within the same, driving a discharge pump for discharging the water contained in the drum or driving a discharge pump as well as a circulation pump for circulating a refrigerant fluid.

[0017] The electrical household appliance comprises a power module in the form of a three-phase inverter driver circuit (4) driving a brushless DC motor (1) having three phases. High side power switches and low side power switches of the power module are typically provided with freewheeling diodes allowing reverse current to flow therethrough to be dissipated. Phase windings are thereby deenergized through respective freewheeling diodes and the stored magnetic energy in the respective phases is dissipated.

[0018] The six step trapezoidal BLDC control method can be conventionally performed without making use of Hall sensors such that timing to commutate the drive voltages are determined by way of sensing the BEMF voltage on a not driven motor terminal. For each step (60 electrical degrees), two windings are energized and one winding is not energized. In a sensorless configuration, thanks to the back-EMF sensing principle, the commutation moments can be derived from the zero-crossings of the back-EMF. Timing to commutate the motor-drive voltages are determined by way of sensing the BEMF voltage on a not driven motor terminal. A microcontroller (3) conventionally detects phase voltage and bus voltage when they are equal to each other. The phase zero crossing can be detected at the moment when the phase voltage crosses the half DC-bus voltage. The respective commutation moment is then configured as being shifted in accordance with the speed of the motor. In practice, all terminal voltages of the motor being connected to respective input pins of the microprocessor (3), the voltage of the respective floating terminal is sampled at the end of the PWM off time. This information being compared with a minimal value, the commutation state of the motor is determined. Commutation will not be achieved at the zero-crossing point but this event

is used as reference point to determine where the rotor is positioned.

[0019] In accordance with the present invention, the respective commutation moment is configured as being shifted as will be delineated hereinafter. To this end, the brushless DC motor (1) is connected to a rotor position detecting and phase shifting circuit (2), which in turn comprises a voltage divider circuit (5) stage, a first level filter (6), a switched phase-shifting circuit (7) also acting as a second level filter, a third level filter (8) and a comparator (9). According to the present invention, phase difference between current waveform of the motor at its actual speed and at the desired speed thereof is first determined and commutation is performed based on the waveform of the current at the desired speed. Commutation points are determined by shifting zero-crossing points back or forth by which motor speed is regulated. It is to be noted that it is possible to increase motor speed by bringing the zero-crossing points closer to one another and to decrease motor speed by taking the same apart from one another.

[0020] In accordance with the present invention, phase voltages in the three phases of the motor are measured by the voltage divider circuit (5) through a reference resistor. The achieved voltage values are both connected to a capacitor (11) through a switching element (12) and to a waveform comparator (9) in order to perform a comparison with the previously determined zero-crossing point. A three-phase commutation signal (10) is thereby obtained.

[0021] Accordingly, when said switching element (12) is in operation, said capacitor (11) is charged so that motor speed is regulated in accordance with charging and discharging time of said capacitor (11). More precisely, phase waveform corrected in accordance with desired motor speed is obtained in accordance with charging and discharging time of said capacitor (11). When it is aimed at decreasing motor's speed, time between zero-crossing points, i.e. charging and discharging time of the capacitor (11) is increased and in the event that motor speed is desired to be increased, time between zero-crossing points (i.e. charging and discharging time) is decreased.

[0022] In a nutshell, the present invention proposes an electrical household appliance comprising at least one electric motor, a driver circuit capable of driving said at least one electric motor, said driver circuit comprising a converter that converts AC mains voltage to DC voltage, a driver circuit inverter stage that inverts the direct current, said driver circuit inverter stage comprising a inverter power module. Said electric motor is a brushless DC motor (1) and said power module comprises high side and low side power switches with freewheeling diodes. Said inverter power module is a six-switch three-phase inverter connected to a DC link. Said electrical household appliance is a refrigerator, washing machine, a dishwasher, a drying machine or a combo drying and washing machine. The third level filter (8) typically suppresses fluctuations occurring due to switching element (12).

[0023] In one embodiment of the present invention, an electrical household appliance comprising at least one electric motor, a three-phase inverter driver circuit (4) capable of driving said at least one electric motor is proposed. Said three-phase inverter driver circuit (4) comprises a converter that converts AC mains voltage to DC voltage and a driver circuit inverter stage that inverts the direct current.

[0024] In a further embodiment of the present invention, said electric motor is a brushless DC motor (1) connected to a rotor position detecting and phase shifting circuit (2), the latter circuit comprising a switched phase-shifting circuit (7) and a comparator (9) such that phase difference between current waveform of the motor at its actual speed and at the desired speed thereof is determined and commutation is performed based on the waveform of the current at the desired speed.

[0025] In a further embodiment of the present invention, commutation points are determined by shifting zero-crossing points being determined by way of sensing back EMF voltage on a not driven motor terminal back or forth, by which motor speed is regulated.

[0026] In a further embodiment of the present invention, motor speed is increased by bringing said zero-crossing points closer to one another and decreased by taking said zero-crossing points apart from one another.

[0027] In a further embodiment of the present invention, back EMF voltage on a not driven motor terminal is sampled at the end of a PWM off time.

[0028] In a further embodiment of the present invention, said position detecting and phase shifting circuit (2) comprises a voltage divider circuit (5) stage measuring phase voltages in the three phases of the motor through a reference resistor.

[0029] In a further embodiment of the present invention, commutation moments are configured to be shifted in accordance with the speed of the motor to be adjusted in the manner that phase voltages in the three phases of the brushless DC motor (1) are connected to a capacitor (11) through a switching element (12).

[0030] In a further embodiment of the present invention, said switching element (12) controls charging and/or discharging amount of said capacitor (11).

[0031] In a further embodiment of the present invention, phase voltages in the three phases of the brushless DC motor (1) are connected to a waveform comparator (9) through said capacitor (11).

[0032] In a further embodiment of the present invention, said waveform comparator (9) compares waveforms obtained by phase-shifting.

[0033] In a further embodiment of the present invention, when said switching element (12) is in operation, said capacitor (11) is charged so that motor speed is regulated in accordance with charging and discharging time of said capacitor (11).

[0034] In a further embodiment of the present invention, charging and discharging time of the capacitor (11) is increased to decrease motor's speed and charging and discharging time of the capacitor (11) is decreased to increase motor's speed.

[0035] In a further embodiment of the present invention, said capacitor (11) is controlled by said switching element (12) whose base or gate is driven through PWM signals.

[0036] In a further embodiment of the present invention, said electrical household appliance is a refrigerator, a washing machine, a dishwasher, a drying machine or a combo drying and washing machine.

[0037] In a further embodiment of the present invention, a brushless DC motor (1)

having a rotor position detecting and phase shifting circuit (2) is proposed

[0038] Accordingly, the present invention ensures a control scheme according to which commutation points are determined by shifting zero-crossing points back or forth so that motor speed can be regulated. This is achieved thanks to a capacitor controlled by a switching element whose base or gate is driven through PWM signals so as to obtain variable speed control.

Claims

1. An electrical household appliance comprising at least one electric motor, a three-phase inverter driver circuit (4) capable of driving said at least one electric motor, said three-phase inverter driver circuit (4) comprising a converter that converts AC mains voltage to DC voltage and a driver circuit inverter stage that inverts the direct current, **characterized in that**;
said electric motor is a brushless DC motor (1) connected to a rotor position detecting and phase shifting circuit (2), the latter circuit comprising a switched phase-shifting circuit (7) and a comparator (9) such that phase difference between current waveform of the motor at its actual speed and at the desired speed thereof is determined and commutation is performed based on the waveform of the current at the desired speed.
2. An electrical household appliance as in Claim 1, **characterized in that** commutation points are determined by shifting zero-crossing points being determined by way of sensing back EMF voltage on a not driven motor terminal back or forth, by which motor speed is regulated.
3. An electrical household appliance as in Claim 2, **characterized in that** motor speed is increased by bringing said zero-crossing points closer to one another and decreased by taking said zero-crossing points apart from one another.
4. An electrical household appliance as in Claim 3, **characterized in that** back EMF voltage on a not driven motor terminal is sampled at the end of a PWM off time.
5. An electrical household appliance as in Claim 3 or 4, **characterized in that** said position detecting and phase shifting circuit (2) comprises a voltage divider circuit (5) stage measuring phase voltages in the three phases of the motor through a reference resistor.
6. An electrical household appliance as in Claim 3, 4 or 5, **characterized in that** commutation moments are configured to be shifted in accordance with the speed of the motor to be adjusted in the manner that phase voltages in the three phases of the brushless DC motor (1) are connected to a capacitor (11) through a switching element (12).
7. An electrical household appliance as in Claim 6, **characterized in that** said switching element (12) controls charging and/or discharging amount of said

capacitor (11).

8. An electrical household appliance as in Claim 6 or 7, **characterized in that** phase voltages in the three phases of the brushless DC motor (1) are connected to a waveform comparator (9) through said capacitor (11).
9. An electrical household appliance as in Claim 8, **characterized in that** said waveform comparator (9) compares waveforms obtained by phase-shifting.
10. An electrical household appliance as in Claim 8 or 9, **characterized in that** when said switching element (12) is in operation, said capacitor (11) is charged so that motor speed is regulated in accordance with charging and discharging time of said capacitor (11).
11. An electrical household appliance as in Claim 10, **characterized in that** charging and discharging time of the capacitor (11) is increased to decrease motor's speed and charging and discharging time of the capacitor (11) is decreased to increase motor's speed.
12. An electrical household appliance as in Claim 7, **characterized in that** said capacitor (11) is controlled by said switching element (12) whose base or gate is driven through PWM signals.
13. An electrical household appliance as in any preceding Claims, **characterized in that** said electrical household appliance is a refrigerator, a washing machine, a dishwasher, a drying machine or a combo drying and washing machine.
14. A brushless DC motor (1) having a rotor position detecting and phase shifting circuit (2) as in Clam 1.

Fig. 1

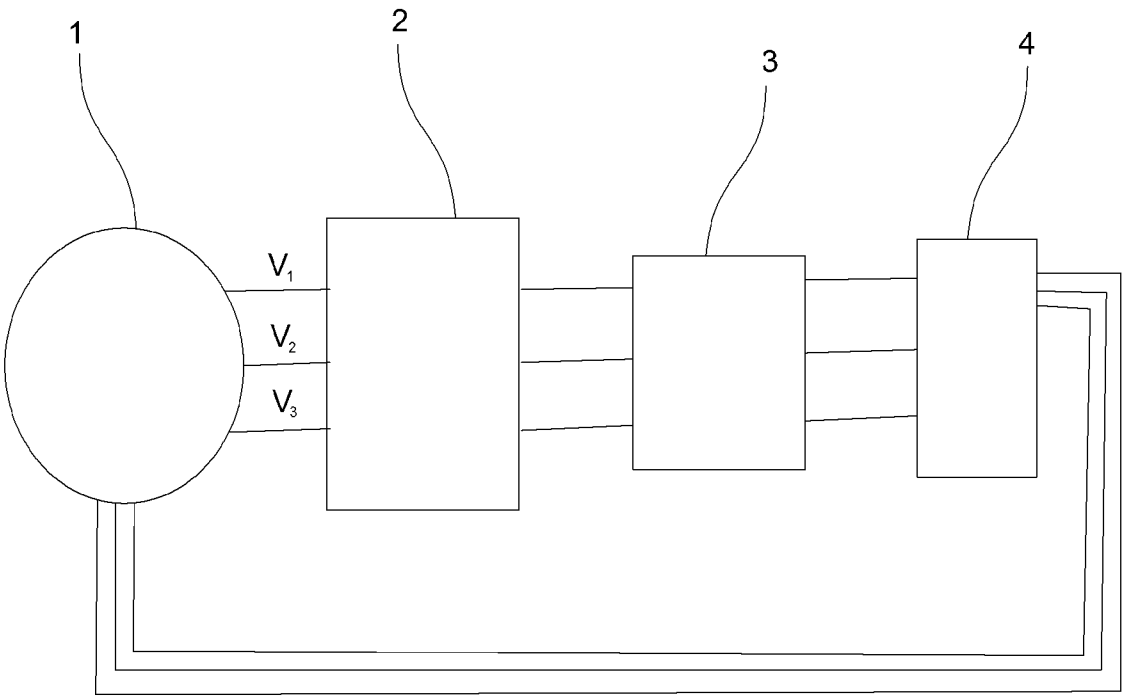


Fig. 2

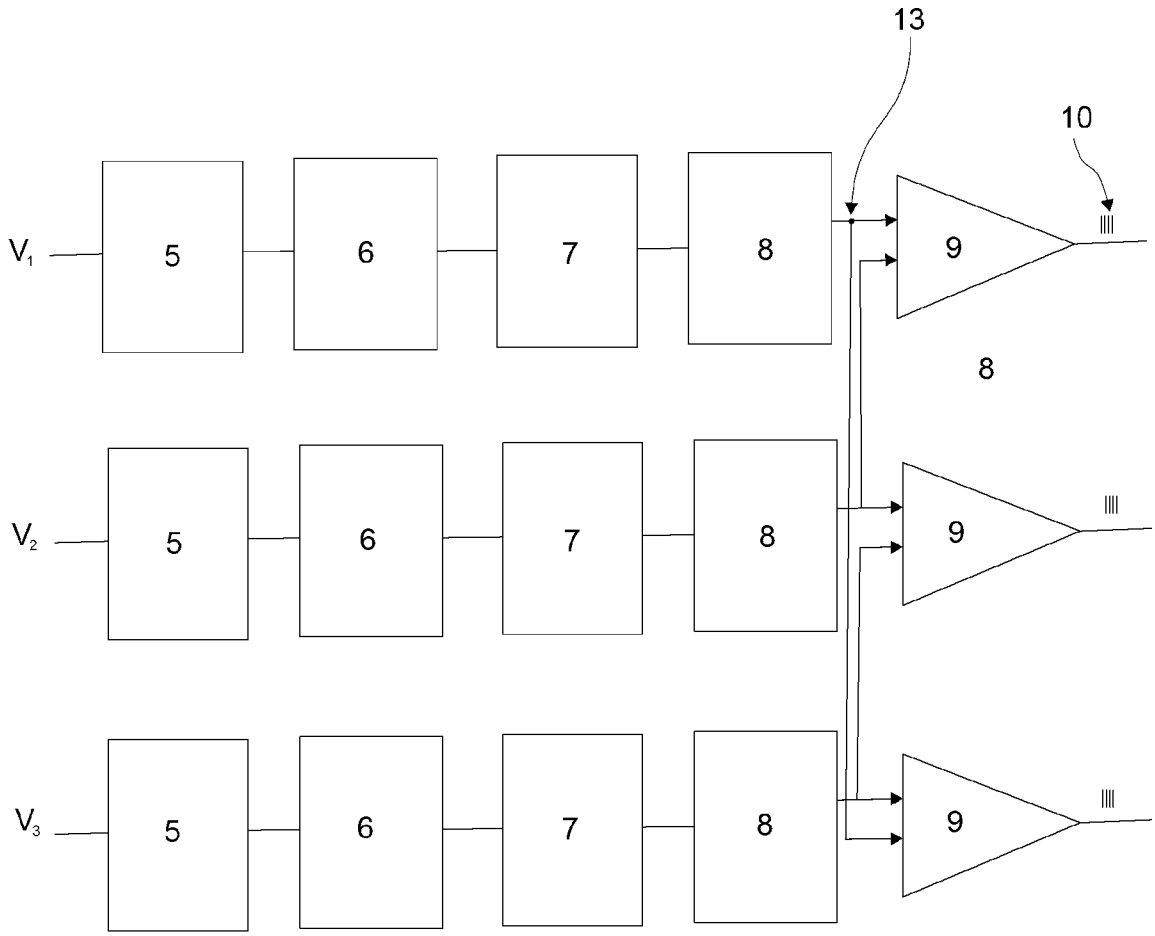
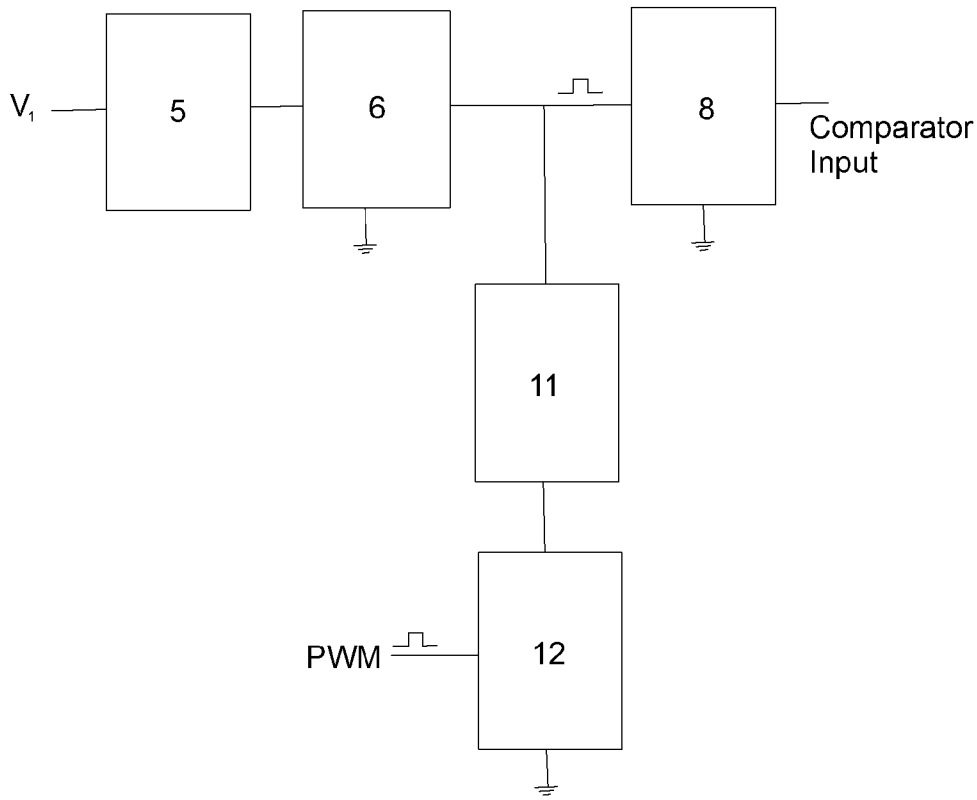


Fig. 3



INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/052312

A. CLASSIFICATION OF SUBJECT MATTER
INV. H02P6/15 H02P6/182
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H02P

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)
EPO-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 2006/132075 A1 (LEE KWANG W [KR] ET AL) 22 June 2006 (2006-06-22) paragraph [0081]; figures 1,4	1-14
X	US 2014/232311 A1 (HILL MARTIN [GB]) 21 August 2014 (2014-08-21) the whole document	1-14
A	US 2014/167666 A1 (ALCORN WILLIAM BOYD [US] ET AL) 19 June 2014 (2014-06-19) the whole document	1-14
A	US 2014/176031 A1 (PAEK HYUN [KR] ET AL) 26 June 2014 (2014-06-26) the whole document	1-14

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
26 September 2017	09/10/2017

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Schneider, Gernot

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2017/052312

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2006132075 A1	22-06-2006	AU 2005203077 A1	06-07-2006
		KR 20060069120 A	21-06-2006
		US 2006132075 A1	22-06-2006
US 2014232311 A1	21-08-2014	CN 105531917 A	27-04-2016
		EP 2959573 A2	30-12-2015
		KR 20150122701 A	02-11-2015
		TW 201448448 A	16-12-2014
		US 2014232311 A1	21-08-2014
		WO 2014130601 A2	28-08-2014
US 2014167666 A1	19-06-2014	JP 6158948 B2	05-07-2017
		JP 2016501509 A	18-01-2016
		KR 20150097548 A	26-08-2015
		US 2014167666 A1	19-06-2014
		WO 2014099215 A2	26-06-2014
US 2014176031 A1	26-06-2014	JP 5709933 B2	30-04-2015
		JP 2014124075 A	03-07-2014
		US 2014176031 A1	26-06-2014