

(51) International Patent Classification:
G01R 35/00 (2006.01)(21) International Application Number:
PCT/EP2008/064176(22) International Filing Date:
21 October 2008 (21.10.2008)

(25) Filing Language: English

(26) Publication Language: English

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CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, 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, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL, NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— with international search report (Art. 21(3))

(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, BR, BW, BY, BZ,

(54) Title: A METHOD AND A DEVICE FOR COMPENSATING GAIN ERRORS OF CURRENT SENSORS IN A THREE-PHASE INVERTER

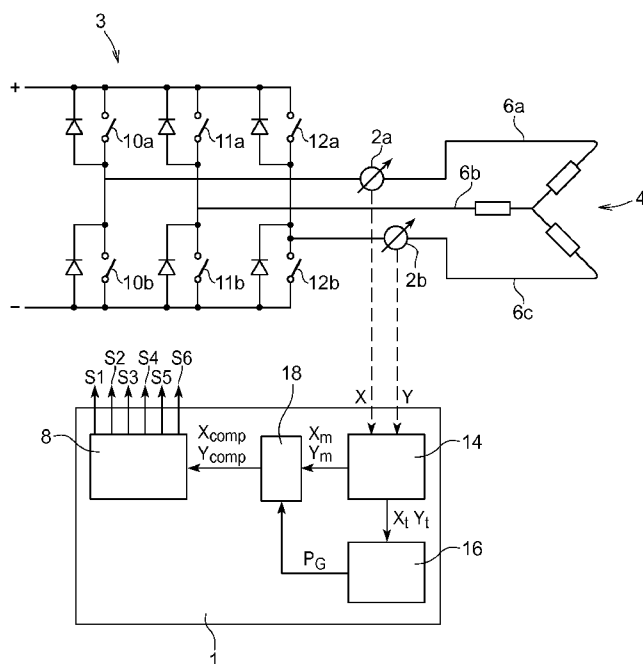


Fig. 1

(57) Abstract: The present invention relates to a device for compensating gain errors of current sensors used in a three-phase inverter (3). The inverter comprises a plurality of switches (10a-b, 11a-b, 12a-b) configured to switch the current in the three phases in response to control signals (S1-S6). The current in a first phase (6a) is measured by a first current sensor (2a) and the current in a second phase (6b) is measured by a second current sensor (2b). The device comprises: a control unit (8) configured, during a calibration period, to generate control signals to control the switches so that the same current is running through the first and second phases, a data storage (14) configured to store sensor values (X,Y) from the first and second current sensors during the calibration period, a computing unit (16) configured to calculate at least one gain compensating parameter (P_G) based on said stored sensor values, and a compensating unit (18) configured, during normal operation of the inverter, to compensate for differences in gain between the first and second sensors based on said gain compensating parameter.

5 **A METHOD AND A DEVICE FOR COMPENSATING GAIN ER-**
 RORS OF CURRENT SENSORS IN A THREE-PHASE IN-
 VERTER

FIELD OF THE INVENTION

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The present invention relates to a method and a device for compensating for gain errors of current sensors used in a three-phase inverter. In addition to those above, the invention also relates to the use of such a method and device for compensation
15 of gain errors in a drive unit of an industrial robot including a three-phase inverter and two current sensors arranged to measure the current in two of the phases.

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The invention is useful for compensation of gain errors between current sensors in any type of three phase inverter which implements drive control on a three-phase AC motor, for example robots, CNC-machines, and tool equipment.

PRIOR ART

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A three-phase inverter converts DC current into a variable alternating current, which is fed to a motor. The inverter comprises a plurality of switches configured to switch the current in the three phases in response to control signals. The switches are for example transistors. In order to control the current, the current in the different phases has to be known. Thus, the currents in the phases are measured by current sensors. Three current sensors can be used for measuring the current in the three phases. However, since the sum of the currents in the three phases is zero, according to Kirchhoff's first law, it is enough to measure the current in two of the phases. The current in the third phase can be calculated based on the two measured currents. One

area in which such inverters with current sensors are used is industrial robots.

Current sensors are important components for good three-phase
5 motor control. In normal current sensors there are two major errors: gain and offset errors. The present invention relates to calibration of the gain errors. The gain error is the difference in gain between two current sensors. Ideally, the two current sensors measuring the two phases have the same gain, but in reality the gain often differs between the two current sensors. If the
10 two current sensors have a difference in gain between each other, the result will be a current ripple in the current feed to the motor. This current ripple may cause vibrations, extra forces on components driven by the motors, a small temperature rise in the system and give poor path performance for a robot. The absolute gain error for a current sensor does not affect the current
15 ripple, only the difference in gain between the sensors.

OBJECTS AND SUMMARY OF THE INVENTION

20 The object of the present invention is to provide a method and a device to measure and compensate differences in gain between two current sensors measuring a three-phase current in an inverter.

25 This object is achieved by a method as defined in claim 1.

Such a method comprises: running during a calibration period the same current through the first and second phase and at the
30 same time reading sensor values from the first and second current sensors, calculating at least one gain compensating parameter based on the read sensor values, and using said gain compensating parameter for compensating for differences in gain between the first and second sensors during normal operation
35 of the inverter.

The basic idea of the invention is to run exactly the same amount of current through both the current sensors. Preferably, no current is going through the phase which is not measured. This can, for example, be done by operating the switches in a special way. For example, all switches are set in a steady on/off state except for one which is controlling the current. With the same current (but opposite directions) going through the sensors, the sensor values are read and used to calculate at least one gain compensating parameter. For example, the sensor values from the first and the second sensor are divided by each other to form a gain quota. This is done during a calibration period, suitably before start of normal operation of the inverter. The measurement values read from the sensors during normal operation of the inverter are then compensated for the difference in gain between the sensors by performing a mathematical operation between the sensor values and the gain compensating parameter. For example, the measurement values read from one of the sensors are multiplied by the gain quota to compensate for difference in gain between the sensors.

According to an embodiment of the invention, the method further comprises: running during the calibration period the same current, but in an opposite direction, through both phases and reading the sensor values from the first and second current sensors, and calculating said gain compensating parameter (P_G) based on the sensor values read when running the current in both directions. This embodiment improves the accuracy of the calibration.

This object is also achieved by a device as defined in claim 8.

Such a device comprises: a control unit configured, during a calibration period, to generate control signals to control the switches so that the same current is running through the first and second phases, a data storage configured to store sensor values from the first and second current sensors during the cali-

bration period, a computing unit configured to calculate at least one gain compensating parameter based on said stored sensor values, and a compensating unit configured, during normal operation of the inverter, to compensate for differences in gain between the first and second sensors based on said gain compensating parameter.

An advantage with the invention is that no extra hardware is needed to do the gain compensation and the compensation can be done automatically in the control system. Only some modification of the software of the control system is needed. With improved current measurement a reduction of current ripple in the current fed to the motor can be achieved, or cheaper current sensors or motors can be used.

The method and device according to the invention are suitable for compensation of gain error in a drive unit of an industrial robot including a three-phase inverter and two current sensors arranged to measure the current in two of the phases. An advantage is that a better path performance of the robot can be achieved.

Further developments of the device are characterized by the features of the additional claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be explained more closely by the description of different embodiments of the invention and with reference to the appended figures.

Fig. 1 shows a device for compensating gain errors of current sensors according to an embodiment of the invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS OF THE INVENTION

Figure 1 shows a device 1 for compensating gain errors of current sensors 2a-b used in a three-phase inverter 3 according to an embodiment of the invention. The inverter 3 controls a motor 4 including three phases 6a-c. The inverter is configured to convert DC current to a variable alternating current (AC) in dependence on control signals S1,S2,S3,S4,S5,and S6 from a control unit 8. The current sensors 2a-b are arranged to measure the current in the inverter 3, which current is fed to the motor 4. The current sensors are, for example, LEM current sensors. The control unit 8 comprises a processor and software for generating the control signals to the switches.

The inverter 3 comprises a plurality of switches 10a-b, 11a-b, 12a-b configured to switch the current in the three phases in response to the control signals S1-S6. The switches are, for example, transistors. Traditionally, an inverter for an industrial robot is made up of six switches, such as IGBTs, which are switched on and off in response to the control signals. The current in each phase of the motor is controlled by two switches; for example, the current in phase 6a is controlled by the switches 10a-b, the current in phase 6b is controlled by the switches 11a-b, and the current in phase 6c is controlled by the switches 12a-b. The current in phase 6a is measured by the current sensor 2a and the current in phase 6c is measured by the current sensor 2b. The current in the phase 6b is calculated based on the measurement values from the current sensors 2a-b. The inverter further includes diodes arranged in parallel with the switches for free wheeling of the current.

The device 1 comprises a control unit 8 configured to generate control signals to the switches during a calibration period, so that the switches are controlled so that the same current is running through the phase 6a and the phase 6c, which currents are measured by the current sensors 2a-b, and no current is going through the phase 6c which is not measured. During the calibra-

tion period, sensor values are read from both sensors 6a-b. The length of the calibration period can be rather short, but must be long enough to enable the device 1 to read at least one sensor value from each current sensor 2a-b. For example, the calibration period is selected to be at a point in time before the inverter 3 is put into normal operation. The calibration can also be done during power down of a DC-link including the inverter, i.e. when the DC link is discharging and has a lower power. The calibration can be repeated during the life time of the sensors, for example the calibration can be done automatically at power up or power down of the DC-link including the inverter. Alternatively, the calibration can be done once before delivery of the inverter and the gain compensating parameter or parameters can be stored in a non volatile memory.

In this embodiment, the same control unit 8, which is used for generating control signals to the switches during normal operation of the inverter, is used for generating control signals to the switches during the calibration period. In an alternative embodiment, two separate control units may be used.

For the inverter 3 shown in figure 1, the switches are in a state in which the same current is running through the phase 6a and the phase 6c, and no current is going through the phase 6b, for example, when the switches 10b and 12a are closed and all the other switches 10a, 11a-b, 12b are open, or the switches 10a and 12b are closed and all the other switches 10b, 11a-b, 12a are open. Thus, the amount of current running through the two phases 6a-b is the same, but the directions of the currents are opposite in the two phases. With a high DC voltage, the switches will run a special PWM (Pulse Width Modulation) pattern during the calibration period, which means that the switches will quickly change between open and closed during the calibration period. Also in this mode the switches 11a-b are always open. With a low DC voltage, the PWM pattern will saturate and give constant open or closed switches. Measuring without PWM

switching can result in a better accuracy. Measuring a multiple of times during DC-voltage discharge gives a number of measurements with decreasing currents. By statistical calculations, such as mean value calculations, on a number of measurements a better calibration can be achieved.

The device 1 is configured to receive sensor values X,Y from the current sensors 2a-b during the calibration period and during normal operation of the inverter 3. The device 1 includes a data storage 14 configured to store the sensor values from the current sensors during the calibration period. Preferably, the same data storage 14 is also used for storing sensor values during normal operation of the inverter 3. At least one value from each current sensor 2a-b is stored. The device 1 further includes a computing unit 16 configured to calculate at least one gain compensating parameter P_G based on the stored sensor values X_t , Y_t from the calibration period, and a compensating unit 18 configured to compensate, during normal operation of the inverter, for differences in gain between the first and second sensors 2a-b based on the gain compensating parameter.

The gain compensating parameter can be calculated in different ways. In one embodiment of the invention, the gain compensating parameter is calculated as the absolute value of the quota between the sensor values during the calibration period:

$$P_G = |X_t / Y_t|$$

X_t is a sensor value read from sensor 2a during the calibration period.

Y_t is a sensor value read from sensor 2b during the calibration period.

Although the same amount of current is going through both sensors, the directions of the currents are opposite. Thus, the read sensor values will have opposite signs. Therefore, the gain com-

compensating parameter is calculated as the absolute value of the quota between the sensor values.

5 If more than one sensor value is stored from each sensor, it is advantageous to calculate a mean value or average value for the current measured by the sensor based on the sensor values. The gain compensating parameter is a measure of the difference in gain between the two sensors 2a-b. If the gain is approximately the same for both sensors, the gain compensating parameter will become equal to or close to 1. If the gain of sensor 10 2a is larger than the gain of sensor 2b, the gain compensating parameter will be larger than 1. If the gain of the sensor 2a is less than the gain of sensor 2b, the gain compensating parameter will be smaller than 1.

15 During normal operation of the inverter, the sensor values are compensated for the differences in gain between the sensors by multiplying the sensor values from sensor 2b with the gain compensating parameter P_G .

20
$$X_{\text{comp}} = X_m$$
$$Y_{\text{comp}} = Y_m * P_G$$

25 X_m is a sensor value read from sensor 2a during normal operation of the inverter.

Y_m is a sensor value read from sensor 2b during normal operation of the inverter.

30 In an alternative embodiment, one gain compensating parameter is calculated for each of the sensors based on the sensor values measured during the calibration period. For example, if the gain difference is to be equally distributed the gain compensating parameter can be calculated according to the following:

35
$$P_{Gx} = (|X_t / Y_t| + 1) / 2$$

$$P_{Gy} = (|Y_t / X_t| + 1) / 2$$

$$X_{comp} = X_m * P_{Gx}$$

$$Y_{comp} = Y_m * P_{Gy}$$

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This embodiment distributes the gain error equally between the sensors, and can be advantageous since the absolute gain error it is not known for any of the sensors.

10 In an alternative embodiment of the invention, a number of different sensor values are read for different current levels. A plurality of gain compensation parameters are then calculated and for the different current levels. The gain compensation parameters are stored, for example, in a table or as parameters in a
15 more advanced mathematical function. The compensation for the gain is then done in dependence on the level of the current. Which one of the gain compensation parameters to be used depends on the level of the measured current. This embodiment is particularly advantageous if the sensors are non-linear.

20

The compensated current values are then used for control of the motor. For example, the control unit 8 may include a current controller controlling the current to the motor based on the measured current in the phases. In that case the compensated
25 current values are transferred to the control unit 8. The control signals S1-S6 to the switches of the inverter are calculated based on the output from the compensated current values.

The invention is, for example, useful for compensation of gain error in a drive unit of an industrial robot including a three-phase inverter and two current sensors arranged to measure the current in two of the phases. An industrial robot is programmed to carry out work along an operating path. In order to program or teach the robot the work, the robot is manipulated to positions
35 along the desired operating path. These positions are stored as instructions in a control program in a memory in a robot control-

ler. During operation of the robot, the control program is executed, thereby making the robot operate as desired.

5 An industrial robot includes a mechanical structure, also denoted a manipulator, and a control system for controlling the movements of the manipulator. The manipulator has a plurality of arms that are movable relative to each other about a plurality of axes. The movements of the axes are driven by motors mounted on each axis. Typically, a robot consists of six axes.
10 However, robots with other numbers of axes also exist. The speeds and accelerations of the axes are controlled by the control system of the robot, which comprises a robot controller generating control signals to drive units based on the instructions in the control program. The control signals to the drive units determine motor torque, motor speed, and drive currents for the
15 axis.

The drive units control the motors by converting DC current to a variable alternating current in dependence on the control signals
20 from the robot controller. The drive units are supplied with AC power. Each drive unit includes a rectifier converting the supplied AC power into DC power, and one or more inverters converting the DC power to AC power in response to the control signal from the robot controller. The robot controller also comprises a servo controller for controlling the position of the motor.
25 The servo controller includes a current controller for controlling the current to the motors. The motors are equipped with current sensors for measuring the current to the motors. The current sensor values are transferred to the current controller.

30 The arrangement shown in figure 1 is suitable for controlling a motor for one axis of an industrial robot. In such a case the device 1 is a part of the robot controller. The robot controller comprises necessary hardware for carrying out normal robot controller functions, such as a process or and data storage. The computing unit 16 and the compensating unit 18 are, for example,
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implanted as software modules running on the processor of the robot controller, and the data storage 14 is a part of the data storage of the robot controller. The control unit 8 is a part of the servo controller of the robot controller.

5

A standard offset compensation is done before the gain compensation calibration. The offset of the sensors are read when the voltage of the DC-link is zero.

10 The present invention is not limited to the embodiments disclosed but may be varied and modified within the scope of the following claims. For example, in order to improve the accuracy of the calibration, a current of a first direction is run through both phases and the sensor values from the first and second
15 current sensors are read, and then the same current, but in an opposite direction, is run through both phases, and the sensor values from the first and second current sensors are read. The gain compensating parameter is then calculated based on the read sensor values from both measurements.

20

CLAIMS

1. A method for compensating gain errors of current sensors (2a-b) used in a three-phase inverter (3) converting DC current into a variable alternating current, the inverter comprising a plurality of switches (10a-b,11a-b,12a-b) configured to switch the current in the three phases in response to control signals (S1-S6), wherein the current in a first phase (6a) is measured by a first current sensor (2a) and the current in a second phase (6c) is measured by a second current sensor (2b), **characterized in** that the method comprises:
- running during a calibration period the same current through the first and second phases (6a,6c) and at the same time reading sensor values from the first and second current sensors (2a-b),
- calculating at least one gain compensating parameter (P_G) based on the read sensor values, and
- using said gain compensating parameter for compensating for differences in gain between the first and second sensors during normal operation of the inverter.
2. The method according to claim 1, wherein the said switches (10a-b,11a-b,12a-b) are controlled so that the same current is running through the two phases during said calibration period.
3. The method according to claim 1 or 2, wherein the calculation of the gain compensating parameter (P_G) comprises dividing one or more sensor values from the first sensor by one or more sensor values from the second sensor.
4. The method according to any of the previous claims, wherein said compensation for differences in gain between the first and second sensors is done by performing a mathematical operation between sensor values from at least one of the sensors and said gain compensating parameter.

5. The method according to claim 4, wherein the sensor values from at least one of the sensors are multiplied by the gain compensating parameter.
- 5 6. The method according to any of the previous claims, wherein the method further comprises:
- running during the calibration period the same current, but in an opposite direction, through both phases and reading the sensor values from the first and second current sensors,
- 10 calculating said gain compensating parameter (P_G) based on the sensor values read when running the current in both directions.
7. Use of the method according to any of the claims 1-6 for compensation of gain error in a drive unit of an industrial robot including a three-phase inverter with two current sensors arranged to measure the current in two of the phases.
- 15 8. A device for compensating gain errors of current sensors used in a three-phase inverter (3) for converting DC current into a variable alternating current, the inverter comprising a plurality of switches (10a-b,11a-b,12a-b) configured to switch the current in the three phases in response to control signals (S1-S6), wherein the current in a first phase (6a) is measured by a first
- 20 current sensor (2a) and the current in a second phase (6c) is measured by a second current sensor (2b), **characterized in** that the device comprises:
- a control unit (8) configured, during a calibration period, to generate control signals to control the switches so that the same
- 25 current is running through the first and second phases,
- a data storage (14) configured to store sensor values (X,Y) from the first and second current sensors during the calibration period,
- a computing unit (16) configured to calculate at least one
- 30 gain compensating parameter (P_G) based on said stored sensor values, and
- 35

a compensating unit (18) configured, during normal operation of the inverter, to compensate for differences in gain between the first and second sensors based on said gain compensating parameter.

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9. The device according to claim 8, wherein the computing unit (16) is configured to calculate the gain compensating parameter (P_G) by dividing one or more sensor values from the first sensor by one or more sensor values from the second sensor.

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10. The device according to any of the claims 8-9, wherein the compensating unit (18) is configured compensate for differences in gain between the first and second sensors (2a-b) by performing a mathematical operation between sensor values from at least one of the sensors and said gain compensating parameter.

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11. The device according to claim 10, wherein said mathematical operation is multiplication.

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12. The device according to any of the claims 8-11, wherein the device is configured to compensate for gain errors in a drive unit of an industrial robot including said three-phase inverter.

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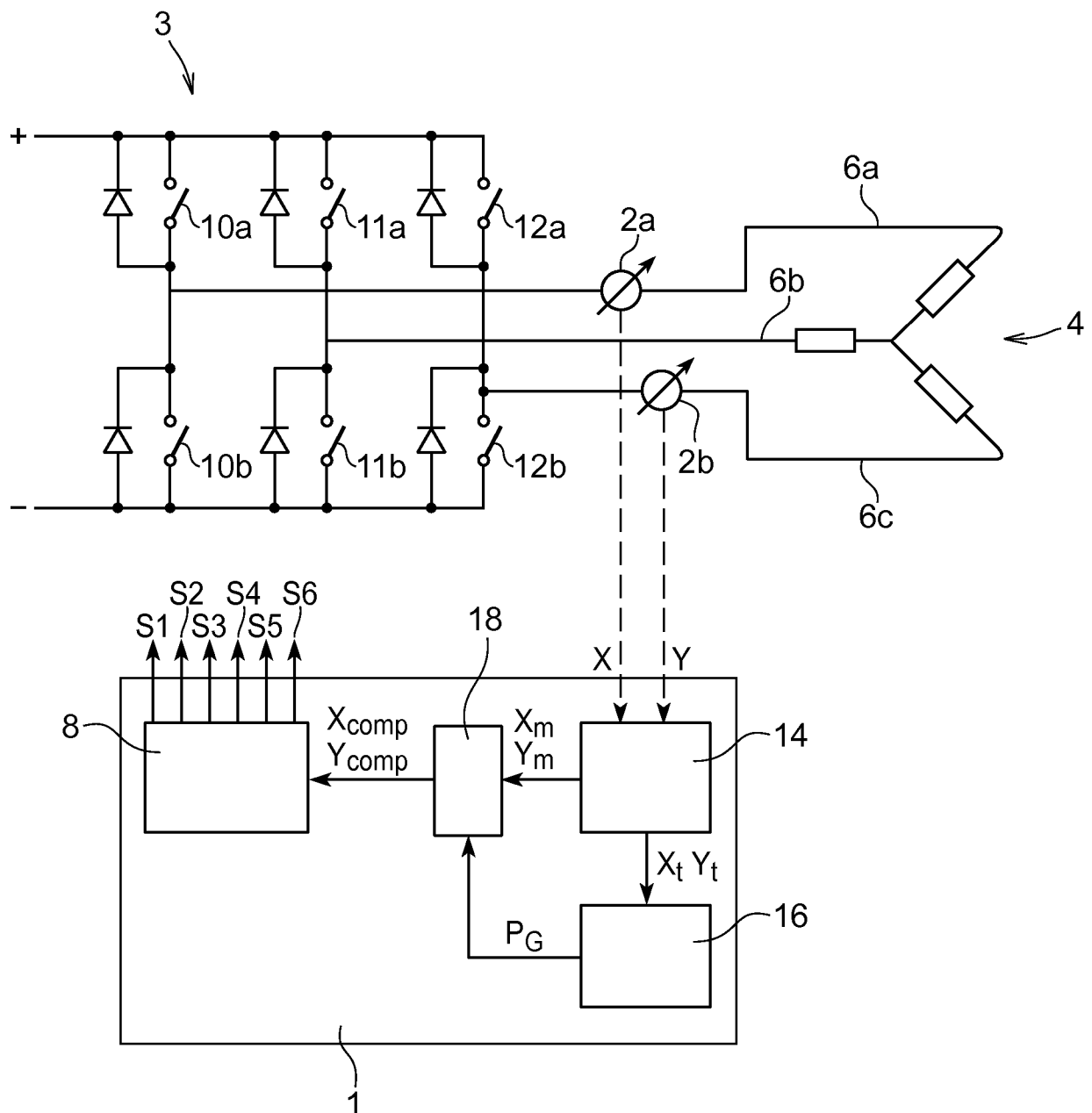


Fig. 1

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2008/064176

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01R35/00

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)
G01R H02M

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 practical, search terms used)

EPO-Internal, WPI Data, INSPEC, COMPENDEX

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	JP 02 219499 A (TOKYO SHIBAURA ELECTRIC CO) 3 September 1990 (1990-09-03) the whole document	1,8
A	JP 2001 119957 A (YAMAHA MOTOR CO LTD) 27 April 2001 (2001-04-27) abstract; figure 1	7,12
T	US 2008/265819 A1 (CHEN CHINGCHI [US] ET AL) 30 October 2008 (2008-10-30) the whole document	



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

9 July 2009

Date of mailing of the international search report

17/07/2009

Name and mailing address of the ISA/

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2008/064176

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
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