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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
23 July 2020 (23.07.2020)

(10) International Publication Number
WO 2020/148173 A1

(51) International Patent Classification:
G01R 19/00 (2006.01) *H02P 27/06* (2006.01)

(21) International Application Number:
PCT/EP2020/050495

(22) International Filing Date:
10 January 2020 (10.01.2020)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
19382023.0 15 January 2019 (15.01.2019) EP

(71) Applicant: **MAHLE INTERNATIONAL GMBH** [DE/DE]; Pragstraße 26-46, 70376 Stuttgart (DE).

(72) Inventors: **CARRIÓN GONZÁLEZ, Juan**; C/Almassera 14-9, 46120 Alboraya (Valencia) (ES). **DOMINGO MÀS, Carlos**; Fuente Hotola, 115, 46340 Requena (Valencia) (ES). **PARDO PERIS, Juan Francisco**; Calle Gregorio Molina 23, 5°, Puerta10, 46800 Xàtiva (ES). **SEVILLA PAVON, Carlos**; Pasaje Doctror Barual Moret 10, 46010 Valencia (ES). **VERNICH GIMENO, Carlos**; Ciudad de Bolonia 1,2, 46015 Valencia (ES).

(74) Agent: **BRP RENAUD UND PARTNER MBB**; Königstraße 28, 70173 Stuttgart (DE).

(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, JO, 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, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(54) **Title:** POWER SUPPLY CONTROL CIRCUITS FOR BRUSHLESS DC (BLDC) MOTORS

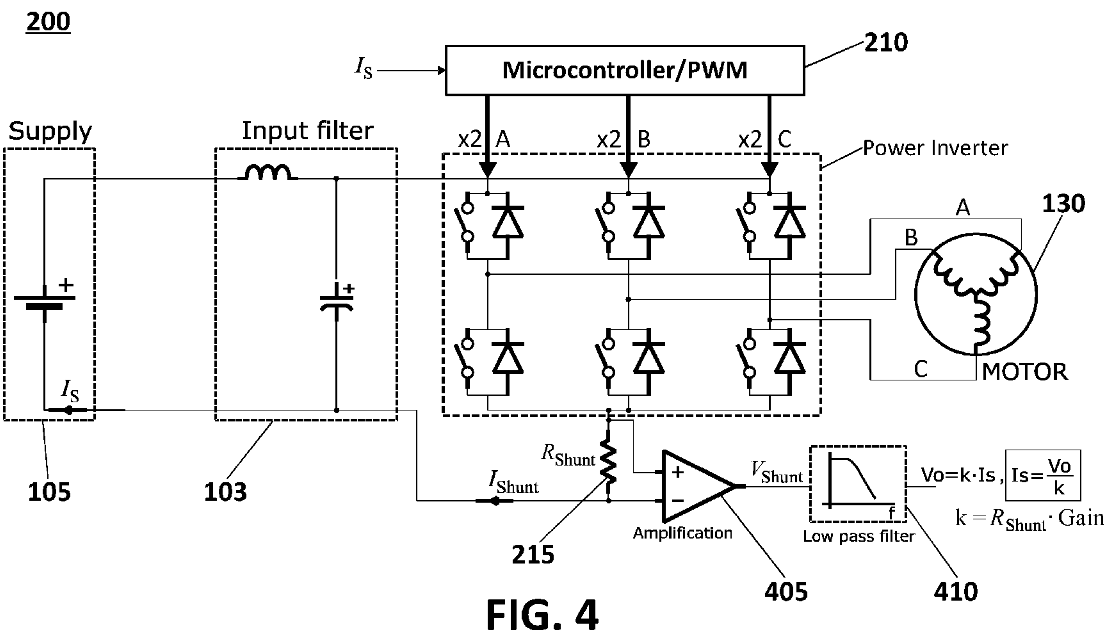


FIG. 4

(57) **Abstract:** A power supply control circuit (200) of a three-phase brushless DC (BLDC) motor (130), characterized in that the control circuit (200) comprises means for calculating the DC current consumption I_s based on a phase current signal I_{shunt} of the BLDC motor (130), the means comprising a shunt resistor (215) R_{shunt}, an amplifier (405) and a low pass filter (410). The amplifier (405) is configured to amplify a measured voltage V_{shunt} that corresponds to the current I_{shunt} across the resistor (215) R_{shunt} and perform an offset correction. The low pass filter (410) is configured to provide a filtered voltage V_0 of the voltage V_{shunt}. The DC current I_s is calculated based on the voltage V_0.

WO 2020/148173 A1

[Continued on next page]

(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))*

POWER SUPPLY CONTROL CIRCUITS FOR BRUSHLESS DC (BLDC) MOTORS

DESCRIPTION

The present invention refers to power supply control circuits for BLDC motors having means to calculate a DC current consumption of the BLDC motor based on the processing of a phase current signal of the BLDC motor.

Background of the invention

The BLDC motor is becoming increasingly popular in sectors such as automotive (particularly electric vehicles (EV)), heating, ventilation, and air conditioning *(*HVAC*),* in white goods and industrial goods because it does away with the mechanical brush used in traditional motors. This characteristic makes the BLDC motors more reliable and increases its service life.

Another advantage of a BLDC motor is that it can be made smaller and lighter than a brush type motor with the same power output, making the BLDC motors suitable for applications where space is tight.

The microcontroller of the control circuit of the BLDC motor may be configured to energize the stator coils of the BLDC at the correct moment by implementing a control algorithm. Precise timing allows for accurate speed and torque control, as well as ensuring the BLDC motor runs at peak efficiency. In this respect, the microcontroller may receive system current values as inputs and signals from position sensors (as e.g. hall sensors that indicate the position of the motor rotor) to implement the control algorithm.

Current values can be measured and used as input for the control algorithm implemented by the microcontroller: Precise motor control performed by the control circuit of the BLDC represents a very significant condition for the correct performance of the BLDC motor. Whether for electronic power steering, electronic stability control, automatic braking systems, or for the self-driving vehicle, precise motor control may be required to ensure safe and efficient operation. Hence, currents can be measured to collect information primarily on the motor torque as the current measurements can be directly proportional to the motor torque.

Current measurements can also be used to determine the speed at which the motor is turning. Such speed information can be calculated by understanding how the control algorithm affects the current level applied in the BLDC motor. In this respect, the measurement of phase motor currents may be required as an input variable for the control algorithm implemented by the microcontroller. Therefore, the precise measurement of the phase motor currents can improve the motor control solution.

Furthermore, currents can be measured for fault protection: Current measurements may be used to detect when an overcurrent condition occurs allowing the system to take action to prevent a potential damage in the BLDC motor.

Current brushless DC motor control circuits may include 1 to 3 shunt resistors to measure the phase current that can be used as input for the control algorithm implemented by the microcontroller. Some algorithms may require the measurement of the DC current consumption I_S. In order to measure the current I_S, an additional shunt (101, 102) can be included either in the positive battery input (A) or in the battery return (B) (i.e. in the DC link) as shown in figure 1 that represents a conventional power supply control circuit (100) of a BLDC motor. However, the type of shunt resistors (101, 102) imply additional unwanted power consumption and heat dissipation in the system.

Furthermore, the power supply control circuit (100) of figure 1 can comprise a DC source (105), an input AC filter (103), in particular a LC filter, a microcontroller/PWM block (110) that represents a pulse width modulation (PWM) generator that generates a PWM signal to a three-phase inverter (120) and a microcontroller implementing a control algorithm that controls the input current in the brushless DC motor (130). The three-phase inverter (120) comprises six switches for high-power switching to feed current to the DC motor (130). Hence, the output from the block (110) comprises pulse width modulated (PWM) signals that determine the average voltage and average current applied to the three coils of the BLDC motor having a "Y" formation as shown in figure 1 in order to control motor speed and motor torque. Furthermore, the BLDC motor (130) may use three hall-effect sensors not shown in the figure to indicate rotor position. The rotor itself uses several pairs of permanent magnets to generate the magnetic flux.

Hence, a power supply control circuit for a BLDC that uses a procedure for measuring the input DC current consumption I_S for the control algorithm other than using shunt resistors in the DC link and thus avoids additional power consumption and heat dissipation and maximizes the performance of the motor-control system is desired.

Description of the invention

The present invention proposes BLDC power supply control circuit that can measure the DC current consumption of the motor I_S without the requirement of establishing shunt resistors (101, 102) in the DC link of the power supply in contrast to current implementations. In this respect, a measured phase current signal can be adequately processed in order to obtain the desired DC current consumption that can be used as input for a control algorithm implemented by a microcontroller of the power supply control circuit. Therefore, the proposed control circuit avoids additional power consumption ($\Delta P_{diss} = I_S^2 \cdot R_{shunt}$), heat dissipation and PCB occupation related to shunt resistors located in the DC link and maximizes the performance of the motor-control system. Furthermore, by getting rid of shunt resistors, in particular, shunt resistor (101) the addition of complex circuitry to measure a differential voltage value can also be avoided. Moreover, getting rid of the shunt resistors (101, 102) may permit to ease the routing of conductive traces on a PCB supporting the control circuit.

Hence, in a main aspect of the present invention, it is proposed a power supply control circuit for a three-phase brushless DC (BLDC) comprising means for calculating a DC current consumption I_S based on a phase current signal I_{shunt} of the BLDC motor. The calculated DC current consumption I_S may be used by a control algorithm for controlling the BLDC motor control or reported to a master controller for performing additional actions as e.g. overcurrent protection.

Hence, the means for calculating a DC current consumption I_S in the power supply control circuit comprises a shunt resistor R_{shunt} for phase current sensing having a voltage V_{shunt} that corresponds to a total phase current signal I_{shunt} of the three phase BLDC motor across the shunt resistor R_{shunt}. In particular, the shunt resistor R_{shunt} can be used to perform low-side phase current sensing as shown in figures 2 and 3. In this regard, low-side phase sensing allows for easier determination of the motor phase currents, but it is not an exact equivalent, an error is potentially introduced relative to the true phase current. Low-side phase sensing also introduces a ground variation of the motor relative to system ground.

Furthermore, the means for calculating a DC current consumption I_S in the power supply control circuit comprises an amplifier to amplify the input voltage V_{shunt} and perform an offset correction of the input voltage V_{shunt} .The power supply control circuit also comprises a low pass filter to filter the amplified voltage signal V_{shunt} to obtain a filtered output voltage V_O. The filtered output voltage V_O. may be fed into an analogue to digital converter (ADC) (which may or may not be included into the microcontroller itself) to calculate the input DC current consumption I_S from the voltage V_O. value.

Hence, the DC current consumption of the BLDC motor I_S can be obtained according to the following equation:

$$\text{Equation 1: } I_S = \frac{V_O}{K}$$

$$K = R_{shunt} * Gain$$

Where $Gain$ is the amplification factor of the amplifier to amplify the input voltage V_{shunt}.

Thus, shunt resistors (101, 102) used to measure the DC current consumption of the BLDC motor I_S as shown in figure 1 are avoided.

In another aspect of the present invention, it is proposed a further example of a power supply control circuit for a BLDC comprising means for calculating a DC current consumption I_S according to the present disclosure. The power supply control circuit uses means for performing phase current sensing. The means comprises three shunt resistors, e.g. R_{Sh1} , R_{Sh2} and R_{Sh3}. The means of the power supply control circuit also comprises means for shunt signal amplification and offset correction, means for summation of the three shunt signals and low-pass signal filter.

Hence, it is proposed an alternative BLDC motor power supply control circuit comprising means for calculating the DC current consumption I_S based on three phase current signals I_{Sh1} I_{Sh2} and I_{Sh3} of the BLDC motor.

Hence, the means of the power supply control circuit according to the second aspect of the present invention comprises three shunt resistors R_{Sh1} , R_{Sh2} and R_{Sh3} for the three phases of the BLDC motor. Furthermore, the means of the power supply control circuit comprises three amplifiers to amplify three measured voltage signals V_{Sh1}, V_{Sh2} and V_{Sh3} corresponding to the phase current signals I_{Sh1}, I_{Sh2} and I_{Sh3} of the BLDC motor across the shunt resistors R_{Sh1} , R_{Sh2} and R_{Sh3}, respectively and perform an offset correction of the voltages V_{Sh1} V_{Sh2} and V_{Sh3}. The total phase current signal can be calculated as $I_{ShT} = I_{sh1} + I_{sh2} + I_{sh3}$.

The means of the power supply control circuit further comprises a summing amplifier to sum the three voltage signals V_{Sh1} V_{Sh2} and V_{Sh3} and a low pass filter that filters V_{ShT} and obtains an output voltage V_O. Therefore $V_{ShT} = V_{Sh1} + V_{Sh2} + V_{Sh3}$.

Hence, the DC current consumption of the BLDC motor I_S can be obtained according to the following equation:

$$\text{Equation 2: } I_S = \frac{V_O}{K}$$

$$K = R_{Total} * Gain_{Total}$$

The $Gain_{Total}$ represents the total amplification factor of the three amplifiers to amplify three measured voltage signals V_{Sh1}, V_{Sh2} and V_{Sh3} .
The R_{Total} is the equivalent resistance of R_{Sh1} , R_{Sh2} and R_{Sh3}:

$$R_{Total} = \frac{1}{\frac{1}{R_{Sh1}} + \frac{1}{R_{Sh2}} + \frac{1}{R_{Sh3}}}$$

In some examples, the power supply control circuit comprises an AC filter comprising a capacitor and an inductance as shown in the figures.

In another aspect, it is proposed a method for calculating a DC current consumption I_S of a three phase brushless DC (BLDC) motor, the method performed by the motor microcontroller of the power supply control circuit. The method comprises a step for amplifying a voltage signal V_{shunt} corresponding to a total phase current signal I_{shunt} of the BLDC motor across a shunt resistor R_{shunt}. The shunt resistor R_{shunt} can measure low-side phase current. The method comprises a step for performing an offset correction of the voltage signal V_{shunt}. The method further comprises a step for obtaining an output voltage V_O by low-pass filtering the amplified voltage signal V_{shunt} . Finally, the method comprises a step for obtaining the DC current consumption I_S based on the output voltage V_O and according to equation 1. In an example, the motor microcontroller can be configured to implement a control algorithm for controlling the BLDC motor based at least on the calculated I_S. In another example, a master controller may use the calculated I_S for performing e.g. overcurrent protection.

In another aspect, it is proposed a second method for calculating a DC current consumption I_S of a three phase brushless DC (BLDC) motor, the method is also performed by the motor microcontroller of the power supply control circuit. The method comprises a step for amplifying three voltage signals V_{Sh1} V_{Sh2} and V_{Sh3} corresponding to three phase current signals I_{Sh1} I_{Sh2} I_{Sh3} of the BLDC motor across shunt resistors R_{Sh1} , R_{Sh2} and R_{Sh3}, respectively. In particular, the shunt resistors can measure low-side phase currents. The method comprises a step for performing offset correction of the three voltage signals V_{Sh1} V_{Sh2} and V_{Sh3}. The method comprises obtaining a total tension V_{ShT} by summing the three voltage signals V_{Sh1} V_{Sh2} and V_{Sh3} and obtaining a filtered voltage V_O by low-pass filtering the total tension V_{ShT}. Finally the DC current consumption I_S is obtained based on the output voltage V_O and according to the equation 2.

Brief description of the drawings

For a better understanding the above explanation and for the sole purpose of providing an example, some non-limiting drawings are included that schematically depict a practical embodiment.

Figure 1 shows a conventional BLDC power supply control circuit.
Figure 2 shows a first example of a BLDC power supply control circuit according to the present disclosure.
Figure 3 shows a second example of a BLDC power supply control circuit according to the present disclosure.
Figure 4 shows the first example of a BLDC power supply control circuit according to the present disclosure.
Figures 5 shows the second example of a BLDC power supply control circuit according to the present disclosure.

Description of a preferred embodiment

Figure 2 shows a power supply control circuit (200) for a BLDC (130) having a “Y” formation. In another example, the BLDC (130) can have a “Delta” formation. The advantages of the configuration of the power supply control circuit (200) are cost reduction, the PCB area for placement of the control circuit is smaller compared to other configurations. Furthermore, one single ADC converters is needed. The control circuit (200) comprises a microcontroller/PWM control block (210) that generates a PWM signal for a power inverter (120) which produces an AC electric current that feeds the BLDC motor (130). The microcontroller/PWM block (210) controls current in the brushless DC motor (130) based on a control algorithm implemented by the microcontroller. The control circuit (200) comprises means for calculating a DC current consumption I_S based on a phase current signal I_{shunt} of the BLDC motor, the means comprises a R_{shunt} (215) for measuring low-side current sensing and an input AC filter (103). In order to obtain the DC current consumption I_S, the voltage V_{shunt} corresponding to the current I_{Shunt} across R_{shunt}

(215) is measured, amplified, offset corrected and filtered as shown in figure 4. The DC current consumption I_S is calculated according to equation 1.

Figure 3 shows a power supply control circuit (300) for the BLDC (130). The advantages of the configuration of the power supply control circuit (300) are that this configuration can obtain more precise phase currents readings and involve less acoustic noise and less total harmonic distortion (THD). Hence, the control algorithm can be improved when calculated DC current consumption I_S is used to implement the control algorithm. The control circuit (300) comprises a microcontroller/PWM generator control block (310) that generates six PWM signals for the power inverter (120) that feeds the DC motor (130). The microcontroller/PWM generator block (310) controls current in the brushless DC motor (130) based on the control algorithm. In some examples, the DC current consumption I_S of the BLDC motor (130) can be used as input to the control algorithm. The control circuit (300) comprises means for calculating the DC current consumption I_S based on a phase current signal $I_{ShT}\mathrm{I_{shunt}}$, the means comprises a three shunt resistors R_{Sh1}, R_{Sh2} and R_{Sh3} for measuring each phase current and an input AC filter (103). In order to obtain the DC current consumption I_S, three voltages V_{Sh1} V_{Sh2} and V_{Sh3} are measured that correspond to the currents I_{Sh1}, $I_{Sh2}$and I_{Sh3} across the three shunt resistors R_{Sh1} , R_{Sh2} and R_{Sh3}, respectively. The total phase current signal can be calculated as $I_{ShT} = I_{sh1} + I_{sh2} + I_{sh3}$. Furthermore, the three voltages V_{Sh1} V_{Sh2} and V_{Sh3} are amplified, offset corrected, summed and filtered as shown in figure 5. The DC current consumption I_S is calculated according to equation 2.

Figure 4 shows the control circuit (200) previously shown in figure 2 comprising means for calculating a DC current consumption I_S , the means comprises signal processing elements to obtain the DC current consumption I_S of the BLDC motor (130). In this example, the DC current consumption I_S can be used as input for the microcontroller/PWM block (210) as shown in the figure. These signal processing elements comprise an amplifier (405) to amplify the voltage V_{shunt} and perform an offset correction and a low pass filter (410) to filter the voltage signal V_{shunt} from the amplifier (405). Hence, an output voltage V_O is obtained from the low pass filter (410) and the DC current consumption of the BLDC motor I_S is obtained based on said voltage V_O and according to the equation 1.

Figure 5 shows the control circuit (300) previously shown in figure 3 further comprising means for calculating a DC current consumption I_S , the means comprises signal processing elements to obtain the DC current consumption I_S of the BLDC motor (130). In this example, the DC current consumption I_S can also be used as input for the microcontroller/PWM block (310) as in figure 4. As previously mentioned, the means for calculating a DC current consumption I_S comprises three shunt resistors R_{Sh1}, R_{Sh2} and R_{Sh3}. The signal processing elements comprise three amplifiers (505, 510, 515) to amplify three measured voltage levels V_{Sh1} V_{Sh2} and V_{Sh3} corresponding to the shunts resistors R_{Sh1} , R_{Sh2} and R_{Sh3}, respectively and to perform an offset correction of the voltage levels. Furthermore, the signal processing elementscomprise a summation module as e.g. a summing amplifier (not drawn in the figure) but represented by reference (520) to obtain a total voltage $V_{ShT} = V_{Sh1} + V_{Sh2} + V_{Sh3}$. A low pass filter is also included as part of the control circuit (300) to filter the total voltage V_{ShT} in order to obtain an output voltage V_O. Finally, the DC current consumption of the BLDC motor I_S is obtained based on said voltage V_O and according to the equation 2.

Even though reference has been made to a specific embodiment of the invention, it is obvious for a person skilled in the art that the BLDC power supply control circuit architectures described herein are susceptible to numerous variations and modifications, and that all the details mentioned can be substituted for other technically equivalent ones without departing from the scope of protection defined by the attached claims.

CLAIMS

1. A power supply control circuit (200) of a three-phase brushless DC (BLDC) motor (130), **characterized in that** the control circuit (200) comprises means for calculating the DC current consumption I_S based on a phase current signal I_{shunt} of the BLDC motor (130), the means comprising:

a shunt resistor (215) R_{shunt};
an amplifier (405); and
a low pass filter (410),
wherein the amplifier (405) is configured to amplify and perform an offset correction of a voltage V_{shunt} that corresponds to the current I_{shunt} across the resistor (215) R_{shunt};
wherein the low pass filter (410) is configured to provide a filtered voltage V_O of the voltage V_{shunt}, and
wherein the DC current I_S is calculated according to the following equation:

$$I_S = \frac{V_O}{K}$$

wherein $K = R_{shunt} * Gain$ and $Gain$ is the amplification factor of the amplifier (405).

2. A power supply control circuit (300) of a three-phase brushless DC (BLDC) motor (130) **characterized in that** the control circuit (300) comprises means for calculating the DC current consumption I_S based on three phase current signals I_{Sh1} I_{Sh2} and I_{Sh3} of the BLDC motor (130), the means comprising:

three shunt resistors (315, 320, 325) R_{Sh1} , R_{Sh2} and R_{Sh3} ;
three amplifiers (505, 510, 515);
a summing amplifier (520); and

a low pass filter (525)

wherein the three amplifiers (505, 510, 515) are configured to amplify and perform an offset correction of voltages V_{Sh1}, V_{Sh2} and V_{Sh3} that correspond to the currents I_{Sh1} I_{Sh2} and I_{Sh3} across the three shunt resistors (315, 320, 325) R_{Sh1} , R_{Sh2} and R_{Sh3};
wherein the summing amplifier (520) is configured to provide a summed voltage V_{ShT};
wherein the low pass filter (525) is configured to provide a filtered voltage V_O of the voltage V_{ShT}, and
wherein the DC current consumption of the BLDC motor I_S is calculated according to the following equation:

$$I_S = \frac{V_O}{K}$$

wherein $K = R_{Total} * Gain_{Total}$, R_{Total} is the equivalent resistance of resistors R_{Sh1}, R_{Sh2} and R_{Sh3} and $Gain_{Total}$ is the total amplification factor of the three amplifiers (505, 510, 515).

3. The power supply control circuit according to any of the preceding claims further comprising an AC filter.

4. A method for calculating a DC current consumption I_S of a three phase brushless DC (BLDC), the method performed by a microcontroller of a power supply control circuit of the BLDC motor, the method comprising:

amplifying a voltage signal V_{shunt} corresponding to a phase current signal I_{shunt} of the BLDC motor across a shunt resistor R_{shunt} for phase current sensing;
performing offset correction of the voltage signal V_{shunt};
obtaining an output voltage V_O by low-pass filtering the amplified voltage signal V_{shunt} ; and
calculating the DC current consumption I_S according to the following equation:

$$I_S = \frac{V_O}{K}$$

wherein $K = R_{shunt} * Gain$ and $Gain$ is the amplification factor of the amplifier (405).

5. The method according to claim 4, further comprising implementing a control algorithm for controlling the BLDC motor based at least on the calculated I_S.

6. A method for calculating a DC current consumption I_S of a three phase brushless DC (BLDC) motor, the method performed by a microcontroller of a power supply control circuit of the BLDC motor, the method comprising:

amplifying three voltage signals V_{Sh1}, V_{Sh2} and V_{Sh3} corresponding to three phase current signals I_{Sh1}, I_{Sh2} and I_{Sh3} of the BLDC motor across three shunt resistors R_{Sh1}, R_{Sh2} and R_{Sh3} for phase current sensing, respectively;
performing an offset correction of the three voltage signals V_{Sh1}, V_{Sh2} and V_{Sh3};
obtaining a total tension V_{ShT} by summing the three voltage signals V_{Sh1}, V_{Sh2} and V_{Sh3};
obtaining a filtered voltage V_O by low-pass filtering the total tension V_{ShT} ; and calculating the DC current consumption I_S according to the following equation:

$$I_S = \frac{V_O}{K}$$

wherein $K = R_{Total} * Gain_{Total}$,
wherein R_{Total} is the equivalent resistance of R_{Sh1} , R_{Sh2} and R_{Sh3} and $Gain_{Total}$ is the total amplification factor of the three amplifiers (505, 510, 515).

7. The method according to claim 6, further comprising implementing a control algorithm for controlling the BLDC motor based at least on the calculated I_S.

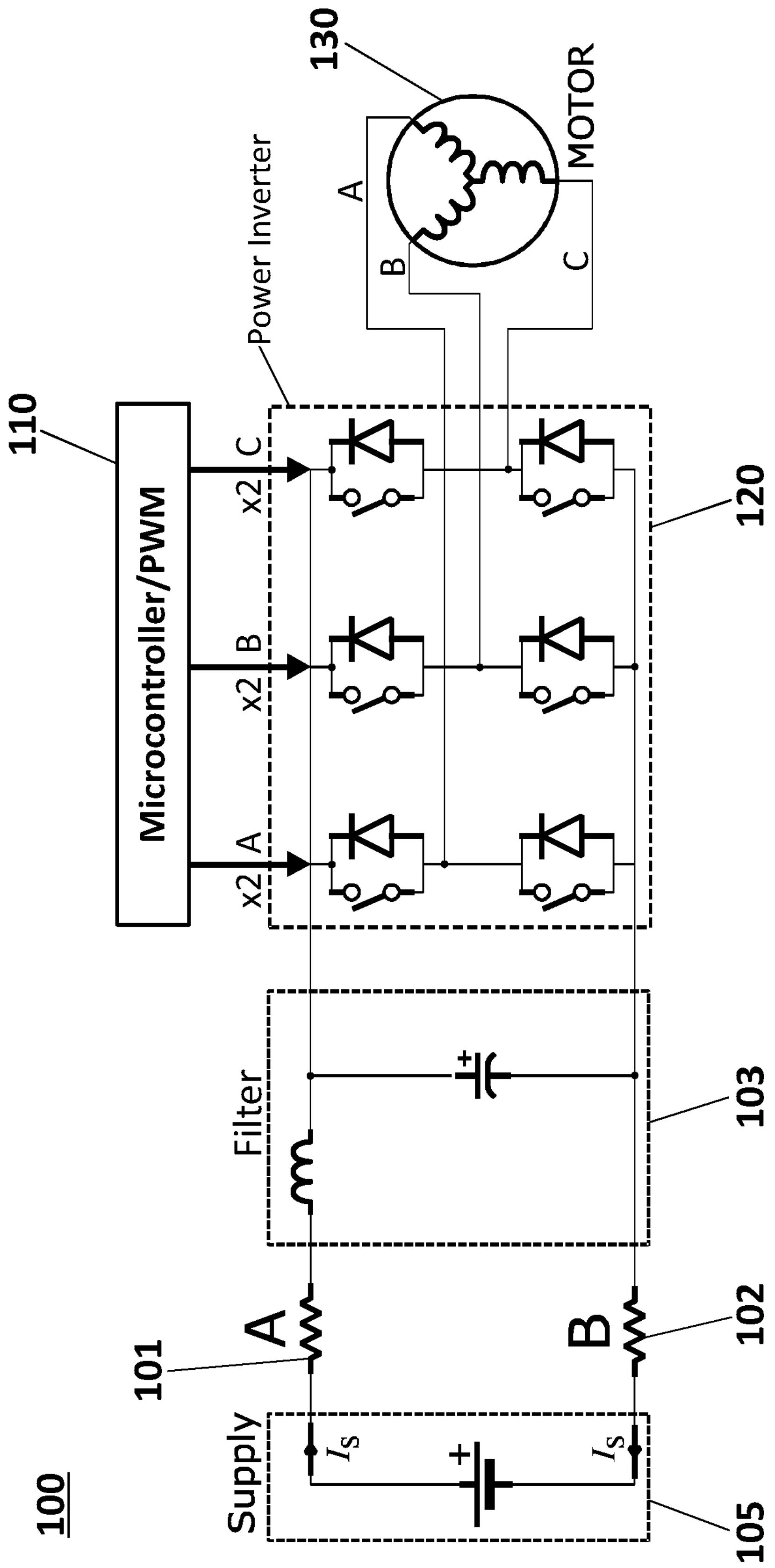

100
Supply
105
101
A
B
102
Filter
103
Microcontroller/PWM
110
x2 A
x2 B
x2 C
Power Inverter
120
A
B
C
MOTOR
130

FIG. 1

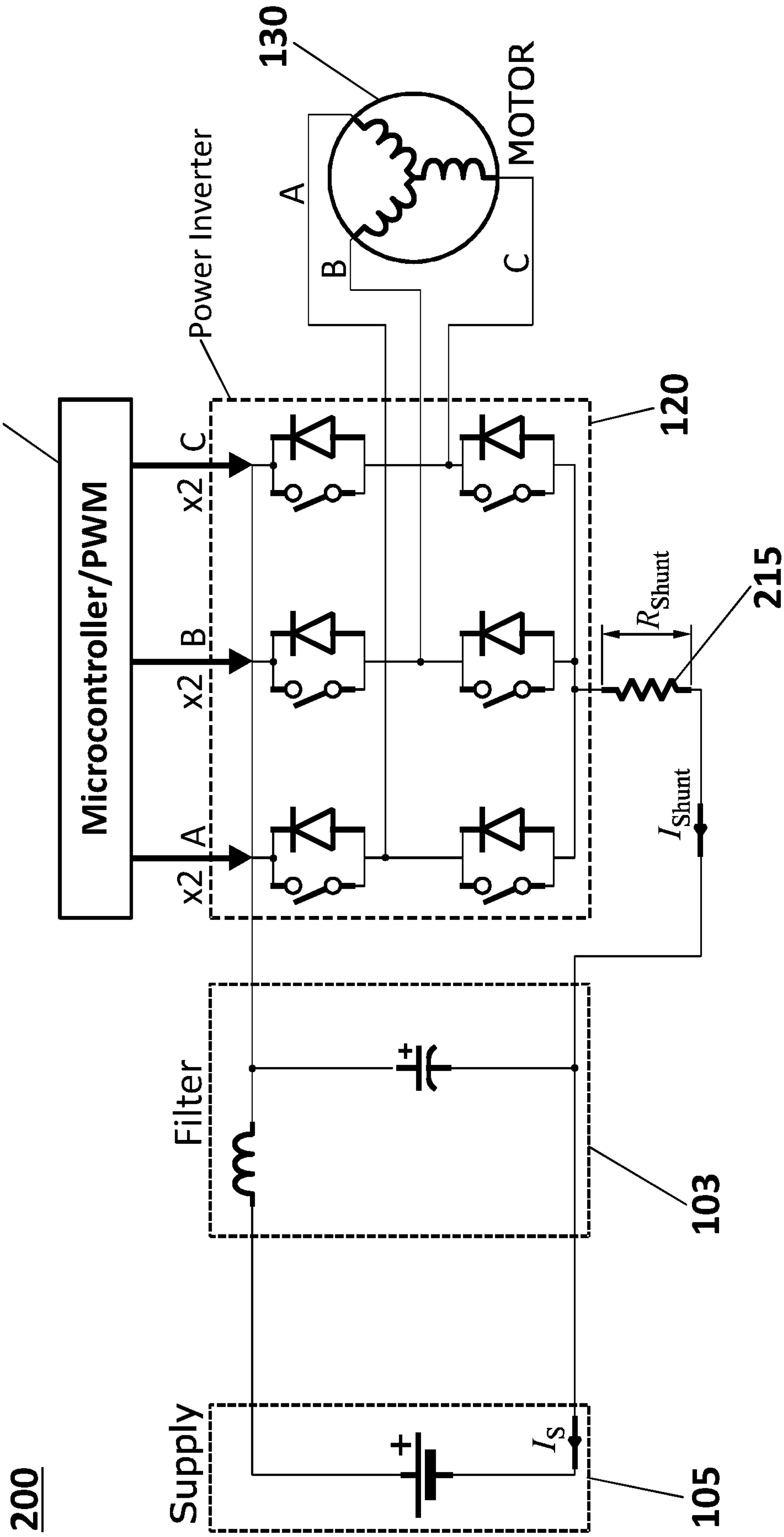

200
Supply
105
Filter
103
Power Inverter
120
Microcontroller/PWM
210
x2 A
x2 B
x2 C
MOTOR
130
A
B
C
R_{Shunt}
215
I_{Shunt}
I_S

FIG. 2

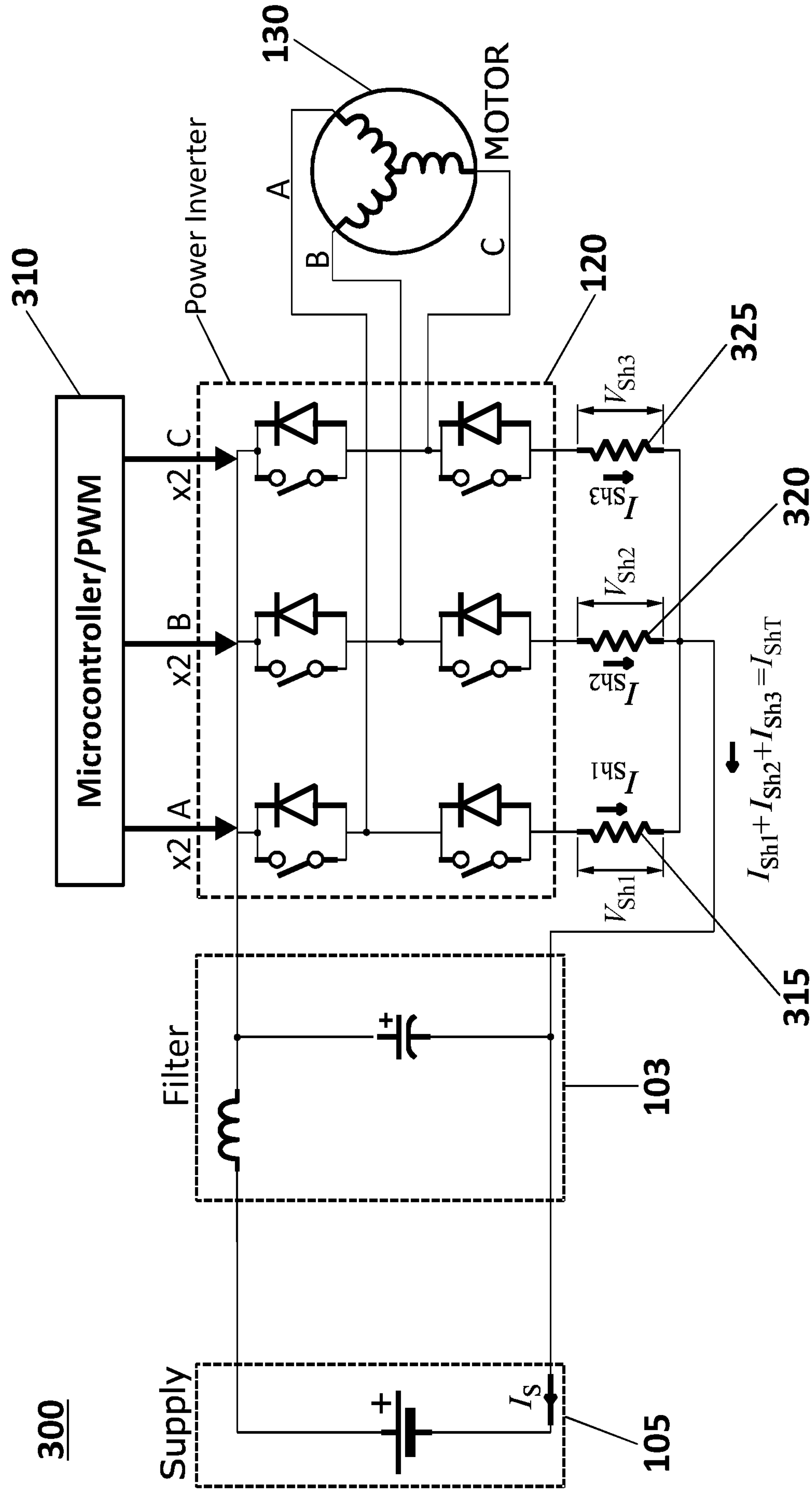

300
Supply
105
Filter
103
Power Inverter
120
Microcontroller/PWM
310
x2 A
x2 B
x2 C
MOTOR
130
A
B
C
V_{Sh1}
V_{Sh2}
V_{Sh3}
I_{Sh1}
I_{Sh2}
I_{Sh3}
I_S
315
320
325
$I_{Sh1}+I_{Sh2}+I_{Sh3}=I_{ShT}$

FIG. 3

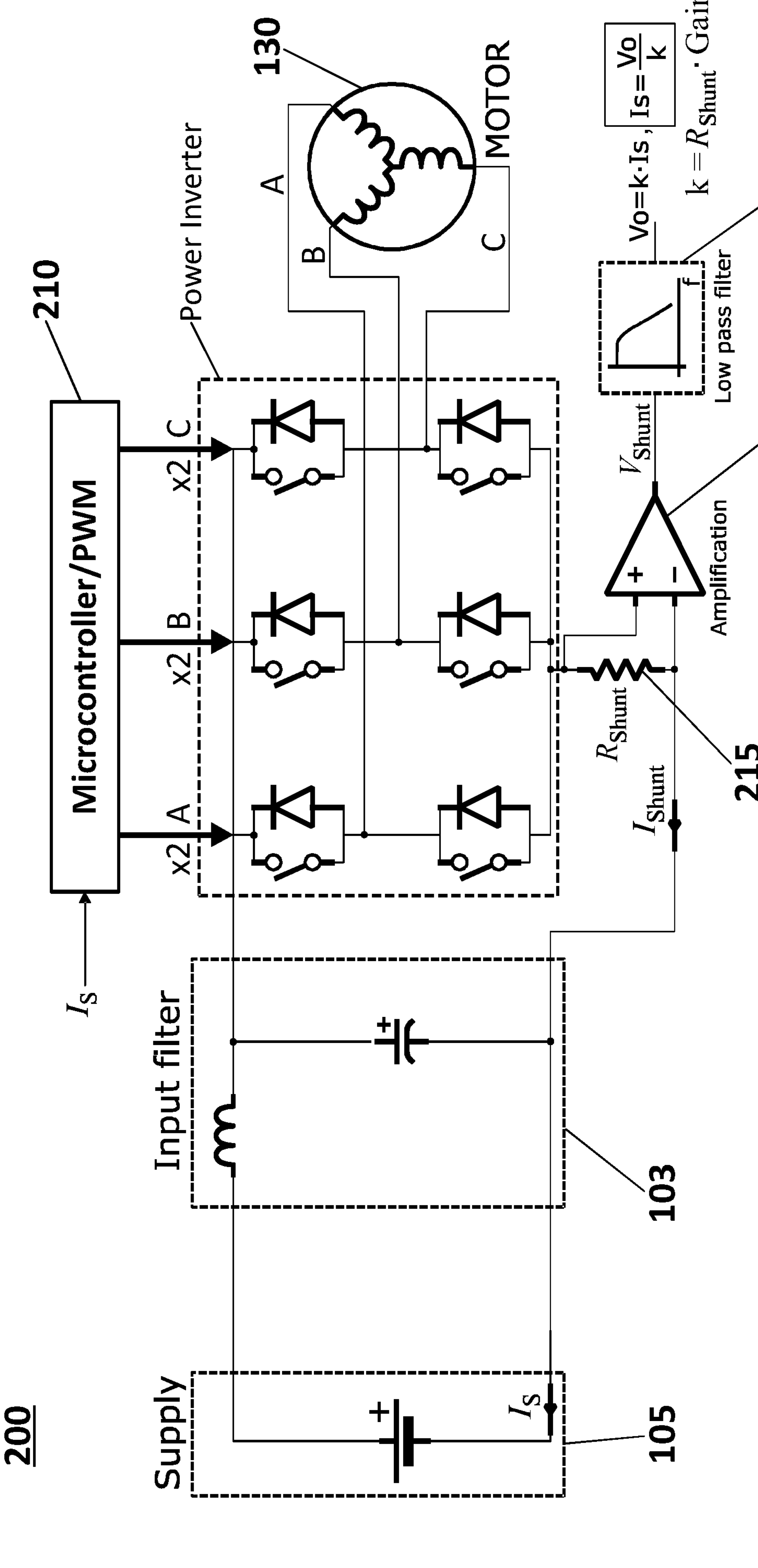
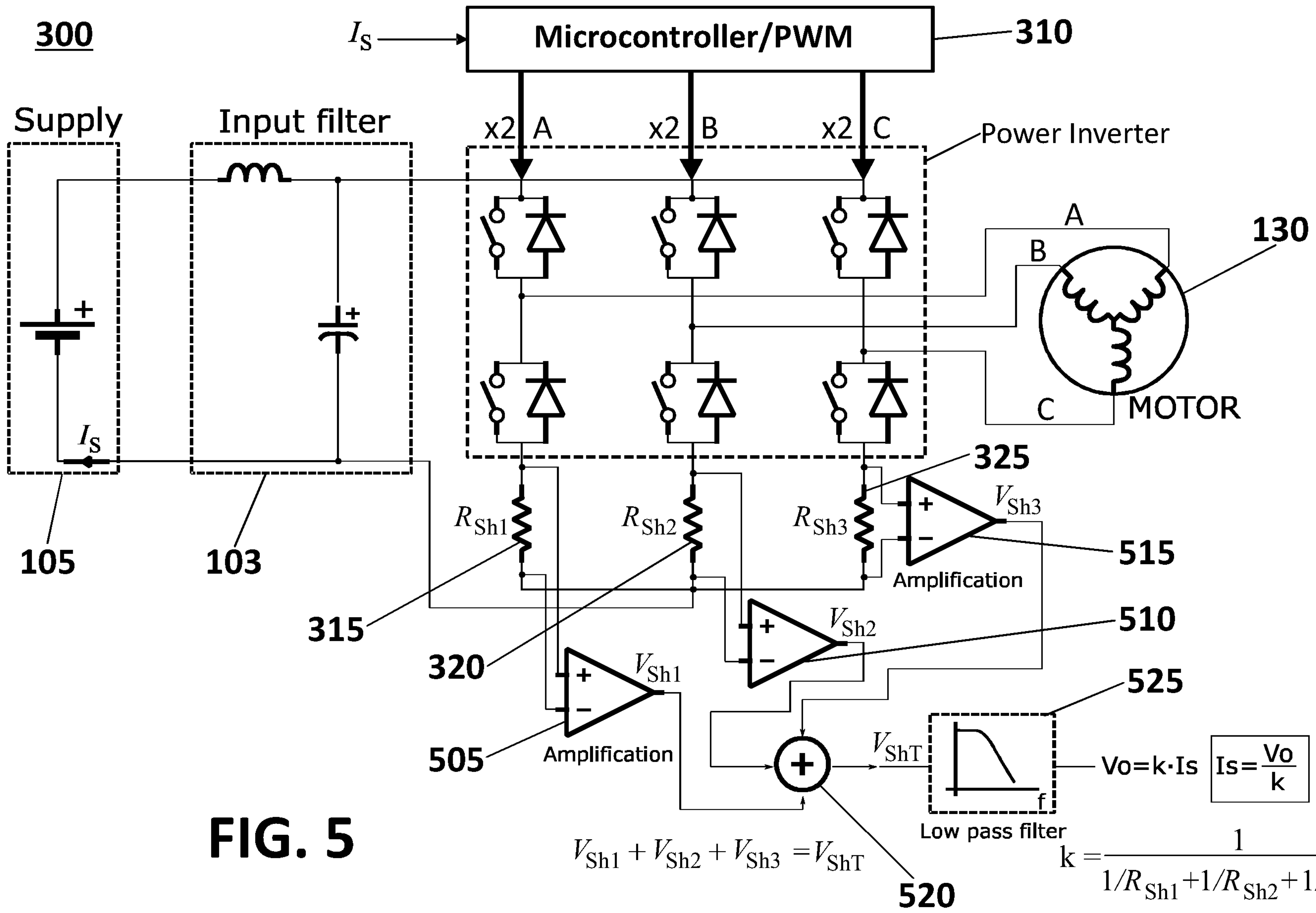

200
Supply
105
Input filter
103
I_S
Microcontroller/PWM
210
x2 A
x2 B
x2 C
Power Inverter
A
B
C
MOTOR
130
I_{Shunt}
R_{Shunt}
215
Amplification
405
V_{Shunt}
Low pass filter
f
410
Vo=k·Is , Is= Vo/k
$k = R_{Shunt}$ · Gain

FIG. 4



$$V_{Sh1} + V_{Sh2} + V_{Sh3} = V_{ShT}$$

$$k = \frac{1}{1/R_{Sh1} + 1/R_{Sh2} + 1/R_{Sh3}} \cdot \mathrm{Gain}_T$$

FIG. 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2020/050495

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01R19/00 H02P27/06
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)
G01R 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	EP 2 420 850 A1 (DAIKIN IND LTD [JP]) 22 February 2012 (2012-02-22)	1,3-5
Y	paragraph [0013] - paragraph [0027]; figures 2,3	2,3,6,7
Y	US 2012/163046 A1 (HIBINO HIROSHI [JP]) 28 June 2012 (2012-06-28) paragraph [0068] - paragraph [0076]; figure 6	2,3,6,7

☐ 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
10 March 2020	19/03/2020

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	Kruip, Stephan

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2020/050495

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
EP 2420850	A1	22-02-2012	AU	2010238132	A1	10-11-2011
			CN	102395890	A	28-03-2012
			EP	2420850	A1	22-02-2012
			ES	2659443	T3	15-03-2018
			JP	4557085	B1	06-10-2010
			JP	2010249751	A	04-11-2010
			KR	20120004505	A	12-01-2012
			US	2012048520	A1	01-03-2012
			WO	2010119619	A1	21-10-2010
US 2012163046	A1	28-06-2012	AU	2010299394	A1	15-03-2012
			CN	102577070	A	11-07-2012
			EP	2485381	A1	08-08-2012
			JP	4671000	B1	13-04-2011
			JP	2011091992	A	06-05-2011
			KR	20120043120	A	03-05-2012
			US	2012163046	A1	28-06-2012
			WO	2011036896	A1	31-03-2011