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(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, 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,

[Continued on next page]

(54) Title: REVERSE CURRENT PROTECTION CONTROL FOR A MOTOR

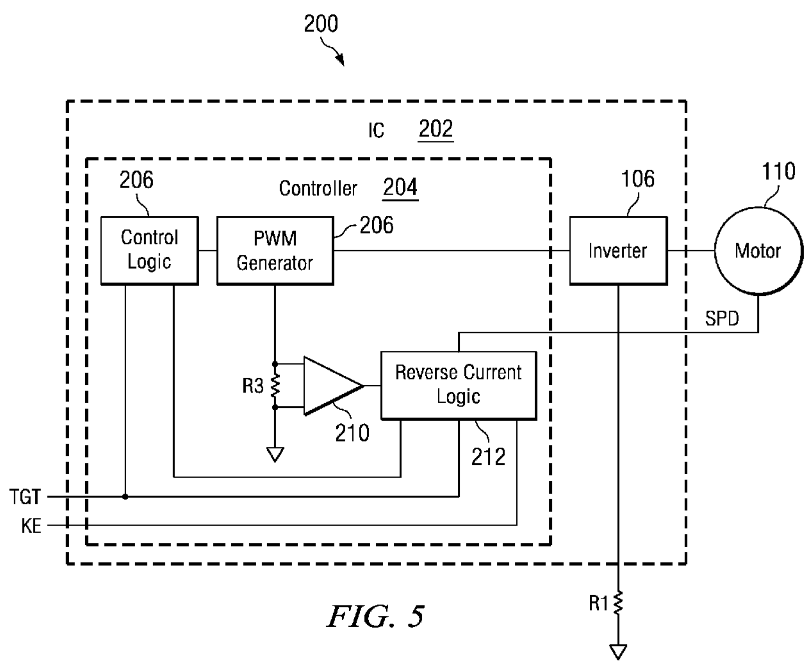

FIG. 5

(57) Abstract: In a motor control system (200), command to correspond to a target speed of a motor (110) is received. A rotational speed (SPD) of the motor is measured, and a brake-to-off ratio for a braking interval is calculated by a control logic (212) based at least in part on the rotation speed (SPD), the target speed (TGT), a braking parameter (KE). An off-state for an inverter (106) that is coupled to motor (110) is induced during an off portion of the braking interval, and a brake signal is applied to the inverter during a braking portion of the braking interval.

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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, ML, MR, NE, SN, TD, TG).

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— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

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REVERSE CURRENT PROTECTION CONTROL FOR A MOTOR

[0001] This relates generally to motor control and, more particularly, to control of a brushless direct current (DC) motor.

BACKGROUND

[0002] Brushless DC motors are employed in a wide variety of applications, and one application, for example, for brushless DC motors is as a spindle motor for a hard disk drive (HDD) or optical disk drive (i.e., digital versatile disk or DVD player). For some of these applications (like DVD players), speed control of the motor can be very important, as the motors will frequently change speed. This means that there are transient periods of braking and acceleration.

[0003] For braking, in particular, the motor should slow quickly to generally ensure that proper functionality is preserved, and, in FIG. 1, an example of a system 100-1 employs a braking scheme that can be seen. In this example, the motor 110 is a three-phase brushless DC motor, where each phase PHA to PHC is respectively coupled to transistor pairs Q1/Q2, Q3/Q4, and Q5/Q6 (which as shown are NMOS transistors) of inverter 106. The controller 104-1 applies pulse width modulation (PWM) signals PWM1 to PWM6 to the inverter 106 to control the phases PHA to PHC of the motor 110 (i.e., drive the motor 110). During braking, though, the motor 110 generates a reverse current or negative current through pins U, V, and W of integrated circuit (IC) or motor driver 102-1 to the supply pin VDD. When this occurs, the controller 104-1 closes switch S of discharge circuit 108 so as to activate the current mirror Q7 and Q8 (which, as shown, are PMOS transistors) by coupling the drain of transistor Q8 to the supply pin GND. This allows the reverse current or negative current to be discharged through resistor R2. One problem with this arrangement, however, is that transistors Q7 and Q8 can occupy a large portion of the area of IC 102-1 in order to be sufficiently large enough to carry the reverse current, so as an alternative (shown in FIG. 2), the discharge circuit 108 can be removed and several different types of braking schemes be employed (as shown in FIGS. 3 and 4).

[0004] For one scheme (which is shown in FIG. 3), controller 104-2 can inactivate or "turn off" transistors Q1 to Q6, placing the inverter 106 in a high impedance or HIZ mode. Mechanical friction (i.e., from bearings) can be used to slow the rotational speed of the motor 110. Usually, to allow this to occur, the speed command issued to the controller 104-2 changes from code L1 (which corresponds to a target rotational speed ω1) to code L3 (which corresponds to a target rotational speed that is not shown) at time T1 so as to allow a negative or reverse current to be generated. At this point, the inverter 106 is placed in a HIZ (off) state or mode, but the losses due to friction are usually so low that the motor 110 does not reach the desired target speed ω2 (which is associated with code L2) within the desired deceleration period (i.e., between times T1 and T2). Instead, the motor 110 reaches a much higher speed ω3 at time T2.

[0005] For another scheme (which is shown in FIG. 4), a short braking period can be employed. During the period between times T3 and T4, the speed command issued to controller 104-2 is set to code L3 (which corresponds to a target rotational speed that is not shown). As a result, the controller 104-2 places inverter 106 in a braking mode or state. In this braking state, transistors Q1, Q3, and Q5 are inactivated or "turned off," while transistors Q2, Q4, and Q6 are activated or "turned on." This allows a reverse or negative current to flow back through the pin COMM so as to be dissipated by resistor R1. This use of this short braking period is effective in slowing motor 110 to the desired or target speed within the desired deceleration period (i.e., between times T3 and T4), but the speed is not stable. There is some "ringing" that does occur.

[0006] Therefore, there is a need for an improved method and/or apparatus of braking with a brushless DC motor.

[0007] Some examples of conventional systems are: U.S. Patent No. 6,528,968; U.S. Patent No. 7,309,967; U.S. Patent No. 8,098,031 U.S. Patent Pre-Grant Publ. No. 2009/0218972.

SUMMARY

[0008] An example apparatus embodiment comprises an inverter that is configured to be coupled to a motor; and a controller having: a pulse width modulation (PWM) generator that is coupled to the inverter; a reverse current detector that is coupled to the PWM; control logic that is coupled to the PWM generator and that is configured to receive a target speed signal; and reverse current logic that is coupled to the reverse current detector and the control logic, wherein the reverse current logic is configured to receive the target speed signal, a braking parameter, and a rotational speed parameter, and wherein, when a reverse current is detected, the reverse current logic is configured to calculate a brake-to-off ratio based for a brake interval that is based at least in part on the target speed signal, the braking parameter, and the rotational speed parameter.

[0009] In one form, the reverse current logic is configured to provide a control signal to the controller so as to apply the brake-to-off ratio to the inverter.

[0010] In one form, the reverse current is configured to iteratively calculate a plurality of brake-to-off ratios for a plurality of brake intervals to achieve a target speed indicated by the target speed signal.

[0011] In one form, the reverse current logic further comprises a finite state machine.

[0012] In one form, the reverse current detector further comprises: a resistor that is coupled to the PWM generator; and a comparator that is coupled to the resistor.

[0013] In one form, the rotational parameter is configured to be a rotational speed of the motor.

[0014] In example method embodiment comprises receiving a command to correspond to a target speed of a motor; measuring a rotational speed of the motor; calculating a brake-to-off ratio for a braking interval based at least in part on the rotation speed, the target speed, a braking parameter; inducing an off state for an inverter that is coupled to motor during an off portion of the braking interval; and applying a brake signal to the inverter during a braking portion of the braking interval.

[0015] In one form, the rotational speed further comprises a first rotational speed, and wherein the braking interval further comprises a first braking interval, and wherein the method further comprises: measuring a second rotational speed of the motor after the first braking interval; and if a calculated back electromotive force (back-emf) for the second rotational speed is greater than a calculated back-emf for the target speed, repeating the steps of calculating, inducing, and applying for a second braking interval.

[0016] In one form, the braking signal further comprises a plurality of PWM signals that correspond to braking.

[0017] In one form, the method further comprises detecting a reverse current.

[0018] In one form, the motor is a three-phase brushless direct current (DC) motor.

[0019] In a modifed example apparatus embodiment, comprises a motor; a motor driver having: an inverter that is coupled to the motor; and a controller having: a PWM generator that is coupled to the inverter; a reverse current detector that is coupled to the PWM; control logic that is coupled to the PWM generator and that is configured to receive a target speed signal; and reverse current logic that is coupled to the reverse current detector and the control logic, wherein the reverse current logic is configured to receive the target speed signal, a braking parameter, and a rotational speed parameter, and wherein, when a reverse current is detected, the reverse current logic is configured to calculate a brake-to-off ratio based for a brake interval that is based at least in part on the target speed signal, the braking parameter, and the rotational speed parameter.

[0020] In one form, the reverse current logic is coupled to the motor so as to receive the rotational speed.

[0021] In one form, the motor is a three-phase brushless DC motor.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] FIGS. 1 and 2 are diagrams of examples of conventional systems;

[0023] FIGS. 3 and 4 are diagrams depicting conventional braking schemes for the system of FIG. 2;

[0024] FIG. 5 is a diagram of an example of a system in accordance with the present invention;

[0025] FIG. 6 is a diagram depicting an example of a braking scheme for the system of FIG. 5; and

[0026] FIG. 7 is an example state diagram for the reverse current logic of FIG. 5.

DETAILED DESCRIPTION OF EXAMPLE EMBODIMENTS

[0027] FIG. 5 illustrates an example of a system 200 embodying principles of the invention. System 200 is similar in construction to that of systems 100-1 and 100-2, except that in IC or motor driver 202 there is a controller 204 that performs an adaptive braking scheme. In operation, a target speed signal TGT is provided to the control logic 206 and the reverse current logic 212 (which can, for example, be a finite state machine or FSM). Based on this target signal TGT, the control logic 206 can provide PWM signals PWM1 to PWM6 to inverter 106 (similar to systems 100-1 and 100-2) to drive the motor 110. When a reverse current is detected by the reverse current detector (which generally comprises resistor R2 and comparator 210), the reverse current logic 212 controls the control logic 206 so as to apply adaptively braking the motor 110. Alternatively, another current measurement or resistive element (like a transistor) may be used as the part of the reverse current detector.

[0028] The adaptive braking scheme (which is shown in FIGS. 5 and 6) is able to slow or decelerate the motor 110 to a desired rotational speed within a target deceleration time. As shown, the target deceleration time is the period between times T5 and T6. Similar to systems 100-1 and 100-2, the target signals TGT changes from code L1 to code L3 at time T5 and from code L3 to code L2 at time T6. Between times T5 and T6, the reverse current detector detects the reverse or negative current (as shown with state 302). The reverse current logic 212 then calculates (in state 304) a brake-to-off or brake-to-HIZ ratio for a braking interval I. The braking interval I is generally a predetermined or preset interval having a generally fixed length that can be programmably changed, and the brake-to-off ratio is the relative portions of the braking interval I that controller 204 places the inverter 106 in a HIZ (off) mode or state (i.e., transistors Q1 to Q6 being deactivated) and a braking mode or state (i.e., transistors Q1, Q3, and Q5 are inactivated and transistors Q2, Q4, and Q6 are activated). Typically, the brake-to-off ratio is calculated from the target speed signal TGT, the braking parameter KE, and the rotational speed parameter SPD (i.e., measured rotational speed from motor 110). For example, the brake-to-off ratio may be calculated by:

(1) $$\frac{HIZ}{HIZ + Brake} = \frac{I - Brake}{I} = \frac{TGT \cdot Gain}{KE \cdot SPD}$$

Once the braking interval has been completed, a determination is made in state 306 as to whether additional braking should be performed using a comparison of calculated back electromotive forces (back-emfs) of the measured rotational speed (from signal SPD) and target speed (from signal TGT); namely:

(2) $$\left(1 - \frac{KE \cdot SPD}{TGT \cdot Gain}\right) > 0 \rightarrow \text{additional braking}$$

(3) $$\left(1 - \frac{KE \cdot SPD}{TGT \cdot Gain}\right) \leq 0 \rightarrow \text{PWM}$$

Usually, as shown in FIG. 6, the brake-to-off ratio becomes smaller (i.e., duration for the braking mode decreases while the duration for the HIZ mode increase) over successive braking intervals

I. This allows the motor 110 to be decelerated within a desired deceleration interval without use of a bulky discharge circuit (i.e., discharge circuit 108) and without ringing.

[0029] Those skilled in the art to which the subject matter hereof pertains will appreciate that modifications may be made to the described embodiments, and also that many other embodiments are possible, within the scope of the claimed invention.

CLAIMS

What is claimed is:

1. An apparatus comprising:

an inverter that is configured to be coupled to a motor; and

a controller having:

a pulse width modulation (PWM) generator that is coupled to the inverter;

a reverse current detector that is coupled to the PWM;

control logic that is coupled to the PWM generator and that is configured to receive a target speed signal; and

reverse current logic that is coupled to the reverse current detector and the control logic, wherein the reverse current logic is configured to receive the target speed signal, a braking parameter, and a rotational speed parameter, and wherein, when a reverse current is detected, the reverse current logic is configured to calculate a brake-to-off ratio based for a brake interval that is based at least in part on the target speed signal, the braking parameter, and the rotational speed parameter.

2. The apparatus of Claim 1, wherein the reverse current logic is configured to provide a control signal to the controller so as to apply the brake-to-off ratio to the inverter.

3. The apparatus of Claim 2, wherein the reverse current is configured to iteratively calculate a plurality of brake-to-off ratios for a plurality of brake intervals to achieve a target speed indicated by the target speed signal.

4. The apparatus of Claim 3, wherein the reverse current logic further comprises a finite state machine.

5. The apparatus of Claim 4, wherein the reverse current detector further comprises a resistor that is coupled to the PWM generator; and a comparator that is coupled to the resistor.

6. The apparatus of Claim 5, wherein the rotational parameter is configured to be a rotational speed of the motor.

7. A method comprising:

receiving a command to corresponding to a target speed of a motor;

measuring a rotational speed of the motor;

calculating a brake-to-off ratio for a braking interval based at least in part on the rotation speed, the target speed, a braking parameter;

inducing an off state for an inverter that is coupled to motor during an off portion of the braking interval; and

applying a brake signal to the inverter during a braking portion of the braking interval.

8. The method of Claim 7, wherein the rotational speed further comprises a first rotational speed, and wherein the braking interval further comprises a first braking interval, and wherein the method further comprises:

measuring a second rotational speed of the motor after the first braking interval; and

if a calculated back electromotive force (back-emf) for the second rotational speed is greater than a calculated back-emf for the target speed, repeating the steps of calculating, inducing, and applying for a second braking interval.

9. The method of Claim 8, wherein the braking signal further comprises a plurality of PWM signals that correspond to braking.

10. The method of Claim 9, wherein the method further comprises detecting a reverse current.

11. The method of Claim 10, wherein the motor is a three-phase brushless direct current (DC) motor.

12. An apparatus comprising:

a motor;

a motor driver having:

an inverter that is coupled to the motor; and

a controller having:

a PWM generator that is coupled to the inverter;

a reverse current detector that is coupled to the PWM;

control logic that is coupled to the PWM generator and that is configured to receive a target speed signal; and

reverse current logic that is coupled to the reverse current detector and the control logic, wherein the reverse current logic is configured to receive the target speed signal, a braking parameter, and a rotational speed parameter, and wherein, when a reverse current is detected, the reverse current logic is configured to calculate a brake-to-off ratio based for a brake interval that is based at least in part on the target speed signal, the braking parameter, and the rotational speed parameter.

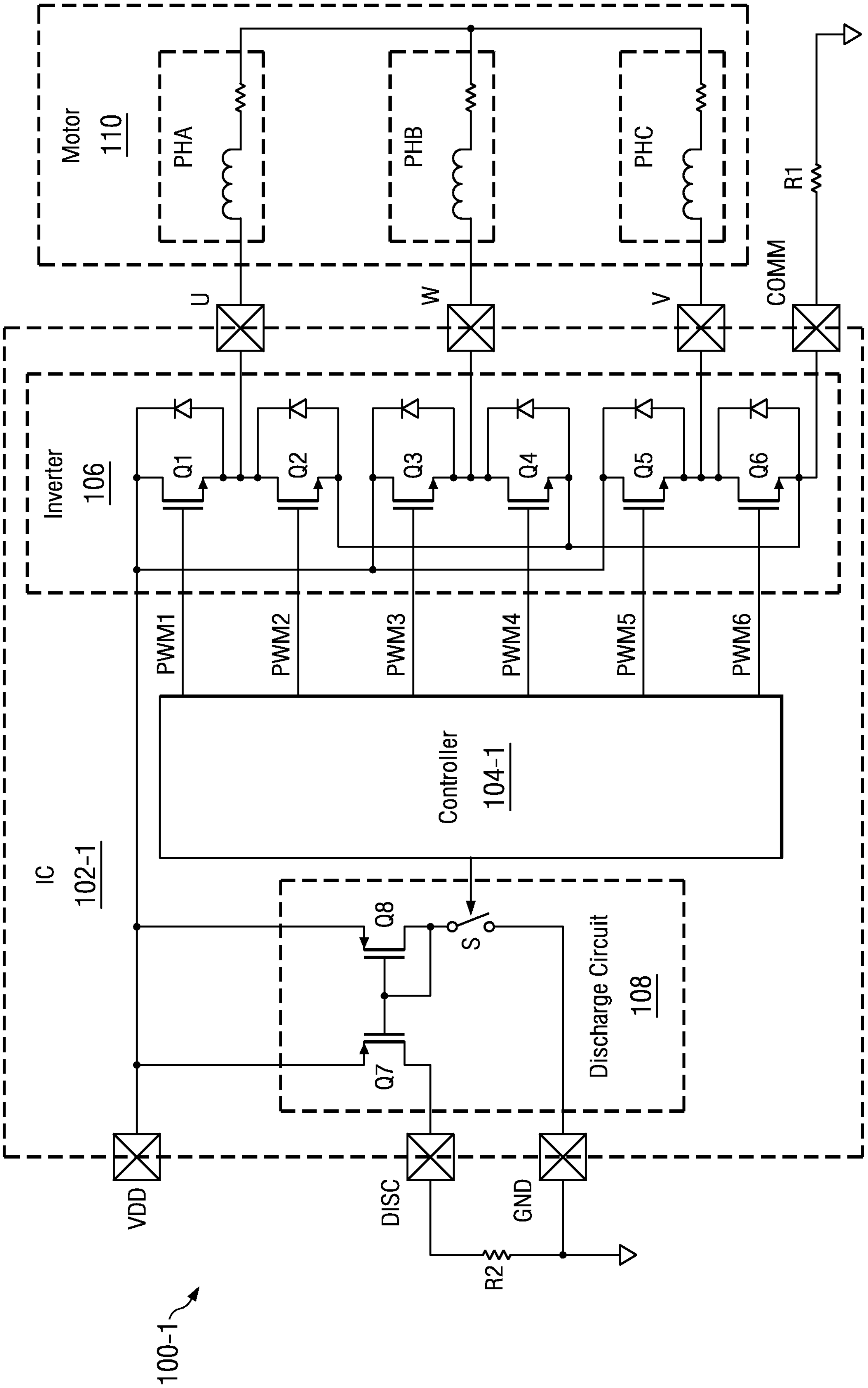

FIG. 1
(PRIOR ART)

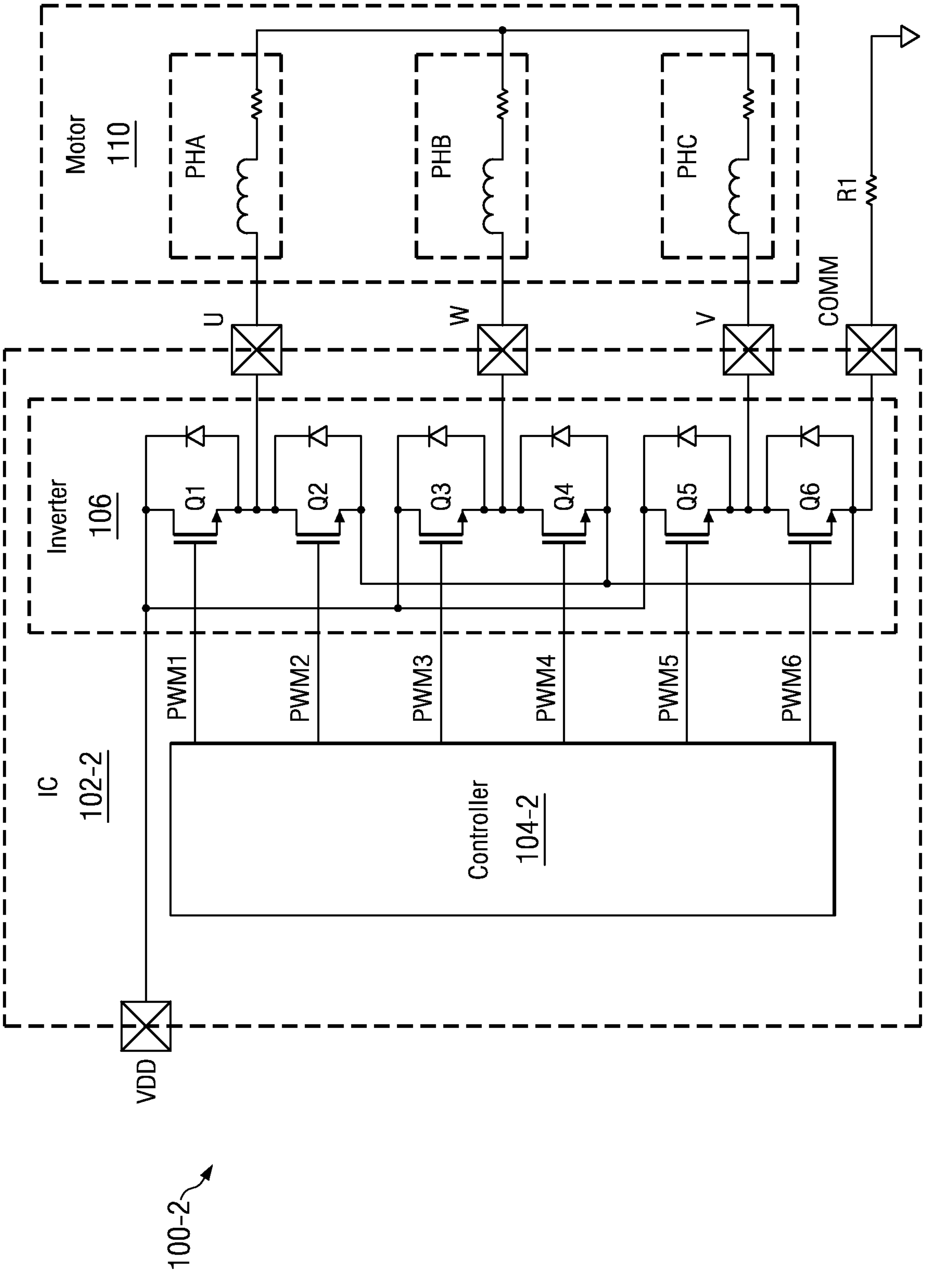

FIG. 2
(PRIOR ART)

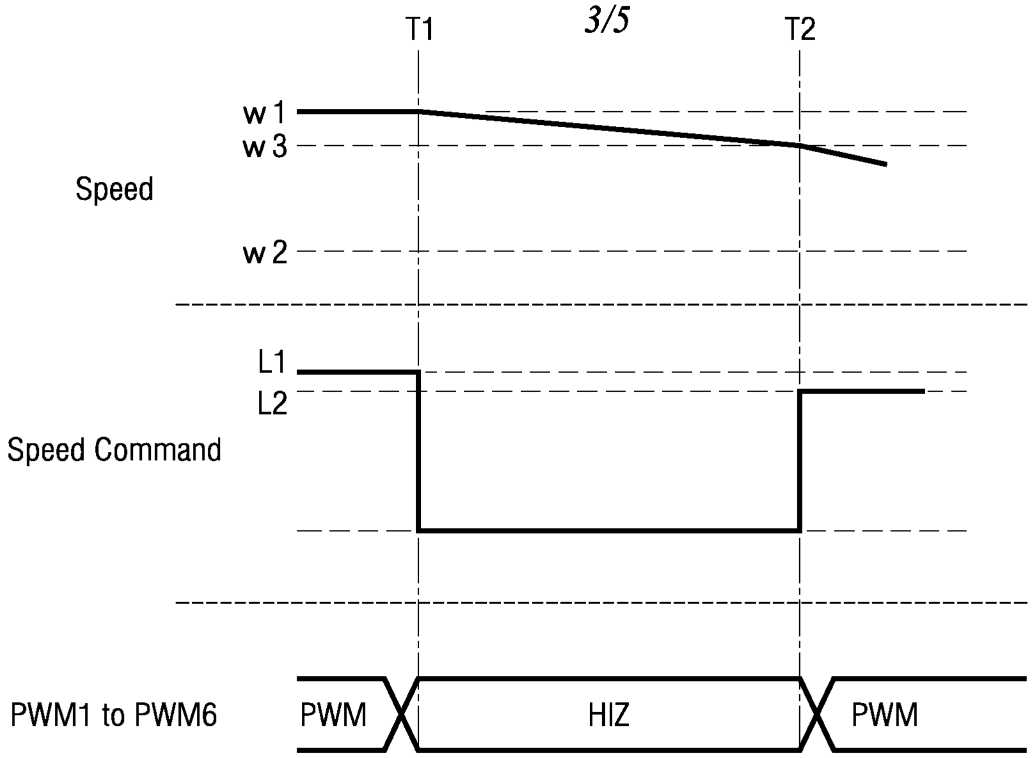

FIG. 3
(PRIOR ART)

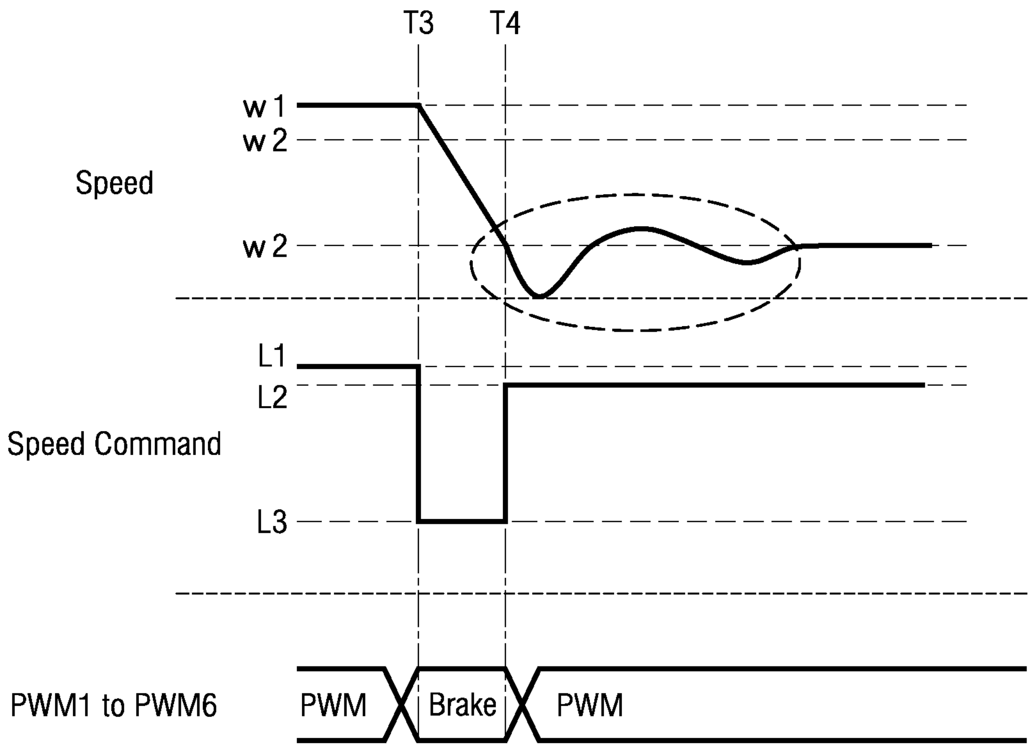

FIG. 4
(PRIOR ART)

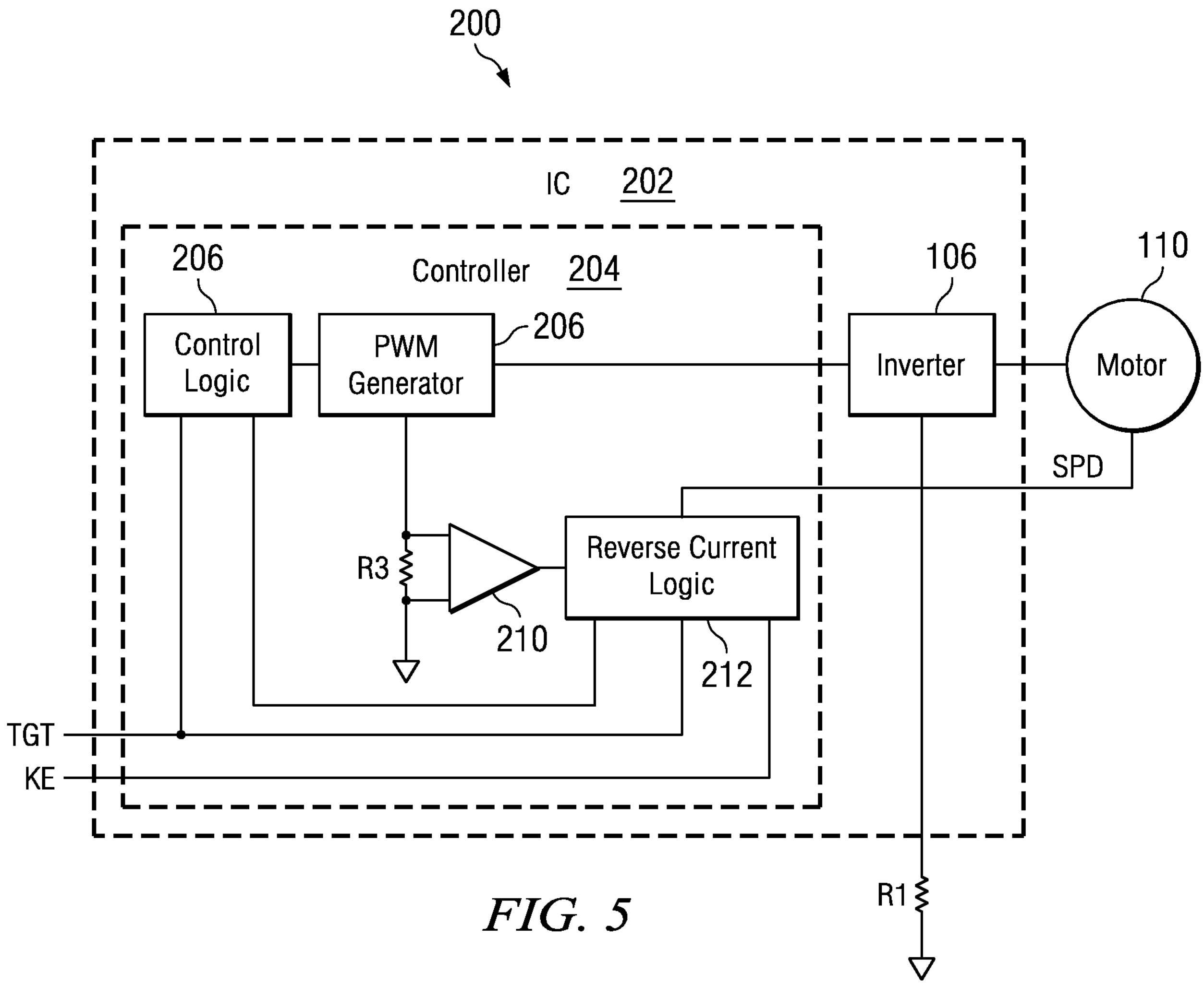
200
IC 202
Controller 204
206
Control Logic
PWM Generator
206
106
Inverter
110
Motor
SPD
R3
210
Reverse Current Logic
212
TGT
KE
R1

FIG. 5

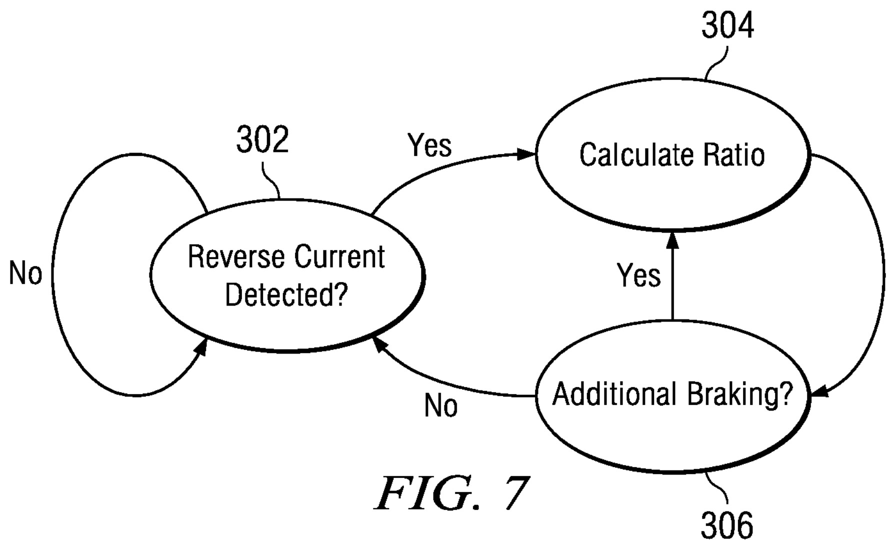
304
302
Yes
Calculate Ratio
No
Reverse Current Detected?
Yes
No
Additional Braking?
306

FIG. 7

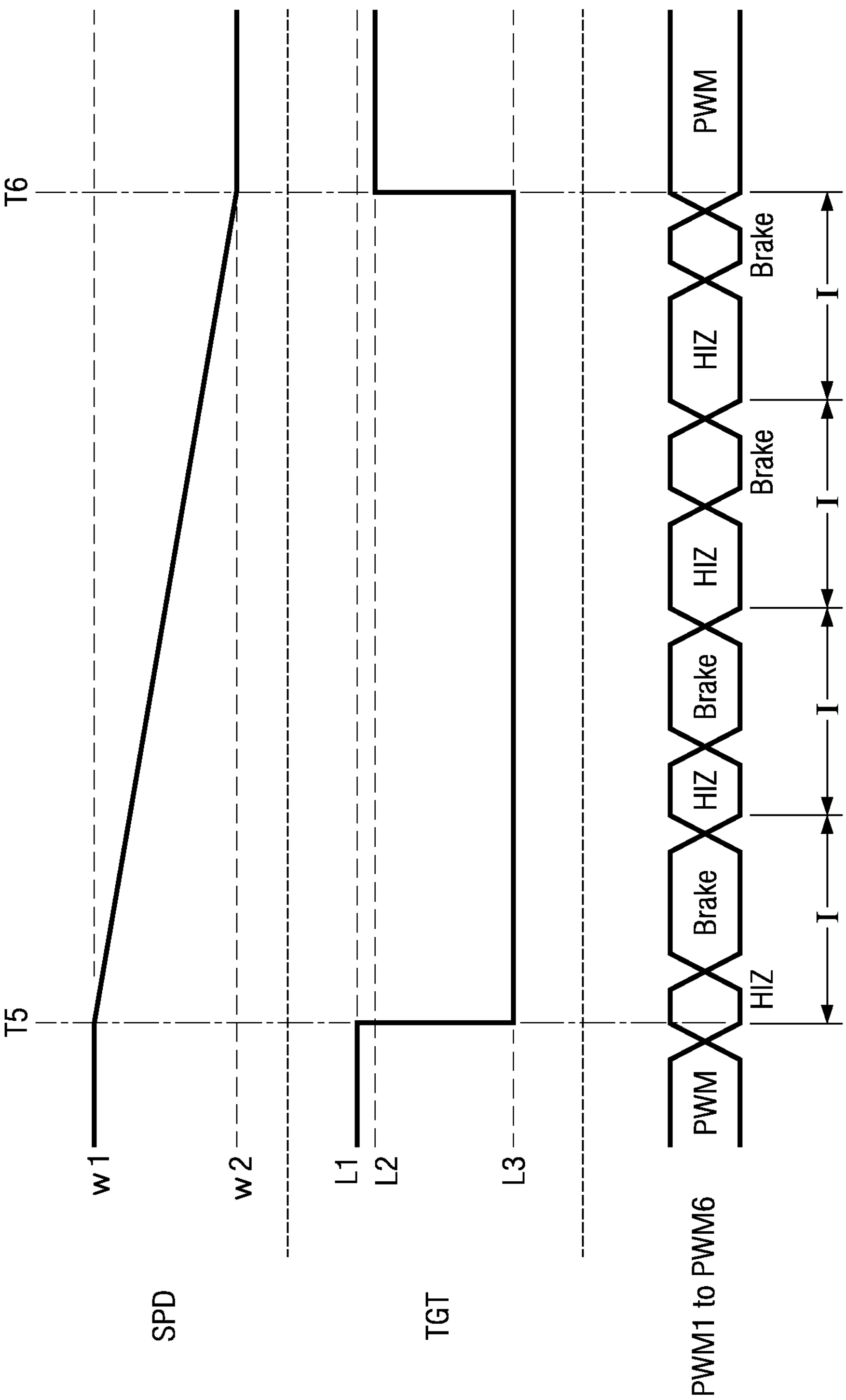
SPD
TGT
PWM1 to PWM6
w 1
w 2
L1
L2
L3
T5
T6
PWM
HIZ
Brake
HIZ
Brake
HIZ
Brake
HIZ
Brake
PWM
I
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FIG. 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2013/026154

A. CLASSIFICATION OF SUBJECT MATTER

H02P 3/08(2006.01)i, H02P 6/06(2006.01)i

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 3/08; H02P 6/24; H02P 3/18; H02P 1/18; H02M 7/12; H02P 6/18; G11B 19/22; H02P 3/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: motor, inverter, driver, brake, deacceleration, PWM, interval, change

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 08-223975 A (SONY CORP.) 30 August 1996 See paragraphs [0035], [0040]-[0042], [0109], [0119], [0142]-[0150], [0160]-[0169] and figures 1-5, 13-16, 18, 23.	1-4,7,12
A		5-6,8-11
A	JP 3615127 B2 (LG ELECTRONICS INC.) 26 January 2005 See abstract, paragraphs [0041]-[0060] and figures 1-2, 8-12.	1-12
A	JP 2007-252058 A (FUJITSU LTD.) 27 September 2007 See paragraphs [0029]-[0045] and figures 1-3, 6-8.	1-12
A	US 06153989 A (JOHN KARDASH et al.) 28 November 2000 See abstract, column 6, line 5-column 11, line 29 and figures 2-5, 7.	1-12
A	US 2003-0102833 A1 (MAKI MURAKAMI) 05 June 2003 See abstract, paragraphs [0041]-[0058] and figures 1-4.	1-12

☐ 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
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"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
25 June 2013 (25.06.2013)	**27 June 2013 (27.06.2013)**

Name and mailing address of the ISA/KR
Korean Intellectual Property Office
189 Cheongsa-ro, Seo-gu, Daejeon Metropolitan City, 302-701, Republic of Korea
Facsimile No. 82-42-472-7140

Authorized officer
PARK, Hye Lyun
Telephone No. 82-42-481-3463

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