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SUZUKI

(54) **MOTOR CONTROL DEVICE**

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H02P 21/22	(2016.01)
H02P 21/30	(2016.01)

(52) **U.S. Cl.**

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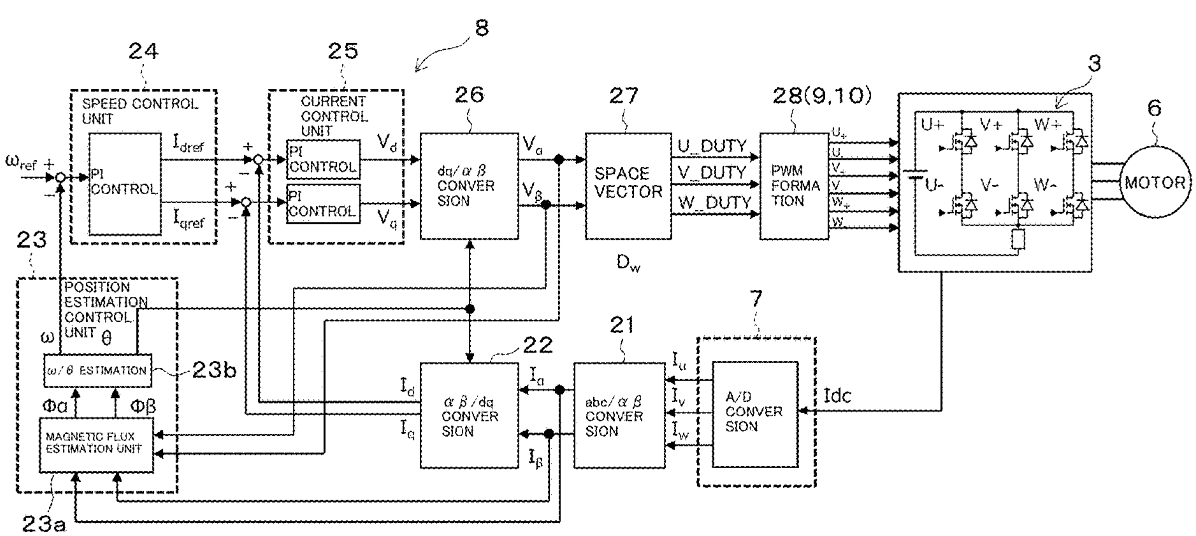
(57) **ABSTRACT**

Embodiments provide a motor control device configured to perform on/off control on a plurality of switching elements connected to each other in a three-phase bridge according to a PWM signal and to drive a motor via an inverter circuit that converts a direct current (DC) into a three-phase alternating current (AC), the motor control device including: a current detection element connected to a DC side of the inverter circuit to generate a signal corresponding to a current value; a PWM signal generation unit configured to determine a rotor position based on at least a phase current of the motor and to generate a PWM signal to follow the rotor position; and a current detection unit configured to detect the phase current of the motor based on the signal generated by the current detection element and the PWM signal; the PWM signal generation unit being capable of executing a first output method of outputting a phase-shifted PWM signal with three phases and causing the current detection unit to detect a current at fixed timing, a second output method of outputting a phase-shifted PWM signal with two phases and causing the current detection unit to detect a current at fixed timing, and a third output method of outputting a symmetrical PWM signal with three phases or two phases and causing the current detection unit to detect a current at fixed or variable timing, such that the current detection unit is capable of detecting two-phase currents at two timing points within a carrier wave cycle of the PWM signal, the motor control device further including: a magnetic flux estimation unit configured to estimate a magnetic flux interlinkage of an armature coil of the motor based on the phase current of the motor and an output voltage command; a signal switching output unit configured to estimate a rotating magnetic field angle and a speed of the motor based on the magnetic flux interlinkage, and to output a switching command such that the PWM signal generation unit executes the first output method when a modulation rate of a motor applied voltage is less than a first threshold value, executes the second output method when the modulation rate is the first threshold value or greater or less than a second threshold value, and executes the third output method when the modulation rate is the second threshold value or greater; and an angle compensation unit configured to use a speed estimated in a previous control cycle and to generate an angle computed based on the speed estimated in the previous control cycle when the motor current is not detectable in one cycle of an electrical angle.



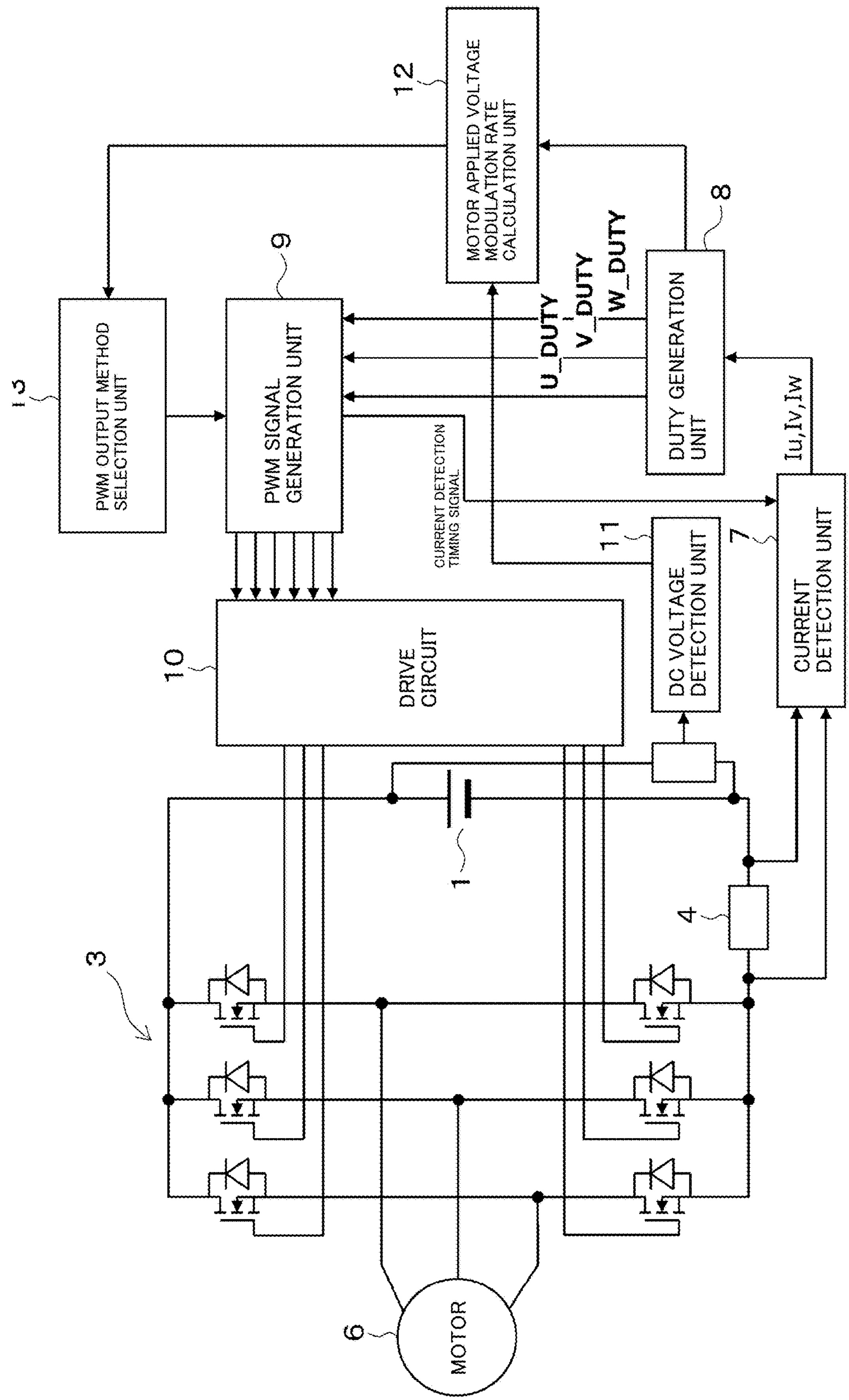

MOTOR APPLIED VOLTAGE MODULATION RATE CALCULATION UNIT
12
PWM OUTPUT METHOD SELECTION UNIT
13
PWM SIGNAL GENERATION UNIT
9
U_DUTY
V_DUTY
W_DUTY
DUTY GENERATION UNIT
8
Iu,Iv,Iw
CURRENT DETECTION TIMING SIGNAL
DC VOLTAGE DETECTION UNIT
11
CURRENT DETECTION UNIT
7
DRIVE CIRCUIT
10
1
4
3
MOTOR
6

FIG.1

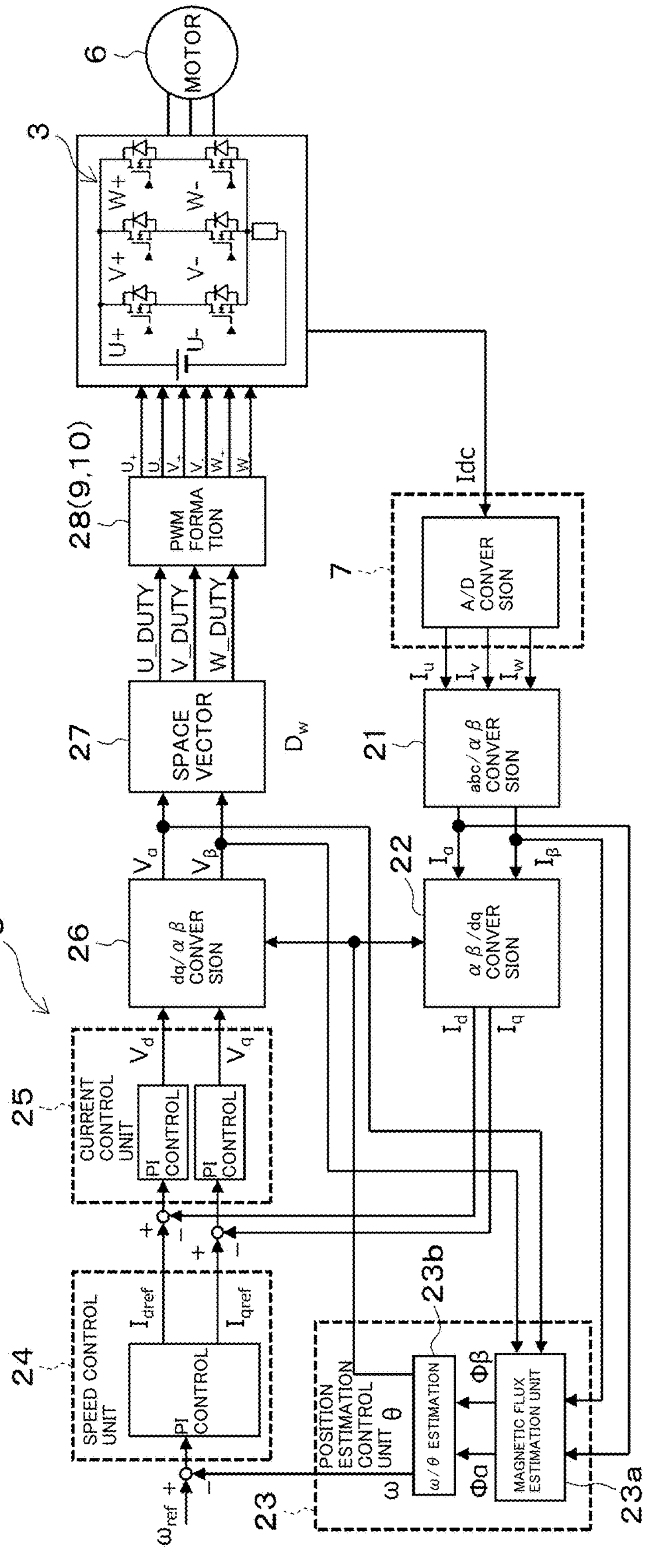

6
MOTOR
3
U+
V+
W+
U-
V-
W-
28(9,10)
PWM FORMATION
U+
U-
V+
V-
W+
W-
Idc
7
A/D CONVERSION
27
SPACE VECTOR
U_DUTY
V_DUTY
W_DUTY
D_w
21
abc/αβ CONVERSION
I_u
I_v
I_w
22
αβ/dq CONVERSION
$I_α$
$I_β$
I_d
I_q
26
dq/αβ CONVERSION
$V_α$
$V_β$
8
25
CURRENT CONTROL UNIT
PI CONTROL
PI CONTROL
V_d
V_q
24
SPEED CONTROL UNIT
PI CONTROL
I_{dref}
I_{qref}
$ω_{ref}$
23
POSITION ESTIMATION CONTROL UNIT
θ
ω
23b
ω/θ ESTIMATION
Φβ
Φα
MAGNETIC FLUX ESTIMATION UNIT
23a

FIG.2

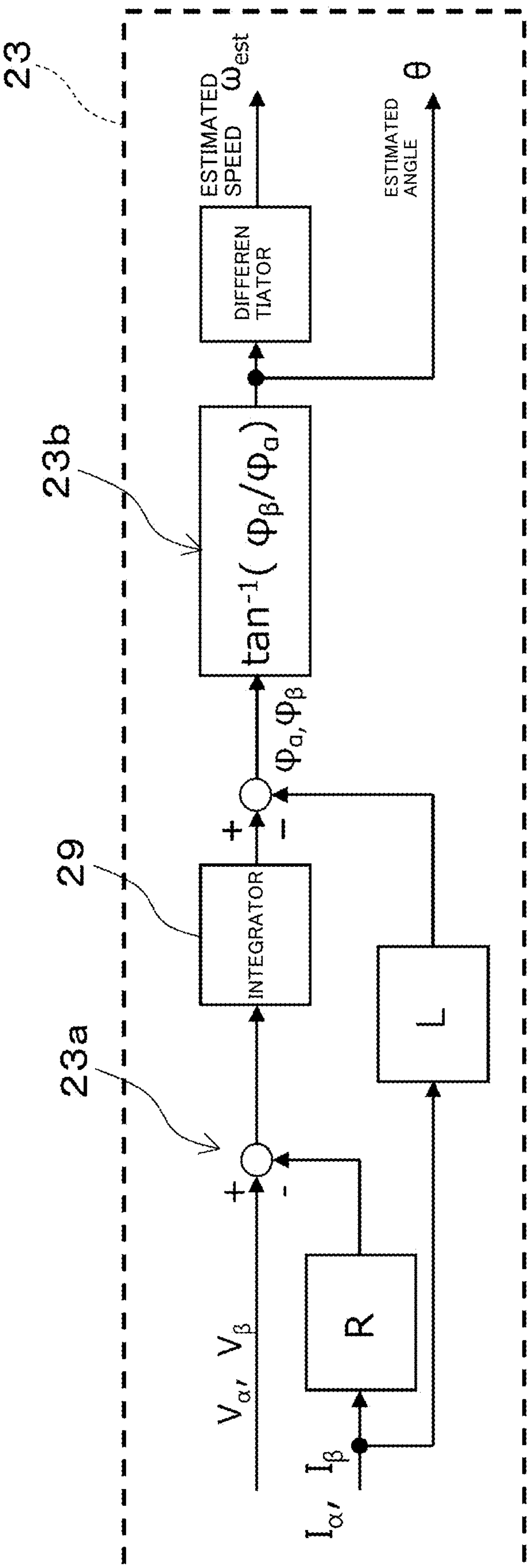

23
23a
23b
29
V_α, V_β
I_α, I_β
R
L
INTEGRATOR
Φ_α, Φ_β
$\tan^{-1}(\Phi_\beta/\Phi_\alpha)$
DIFFEREN TIATOR
ESTIMATED SPEED
ω_{est}
ESTIMATED ANGLE
θ

FIG.3

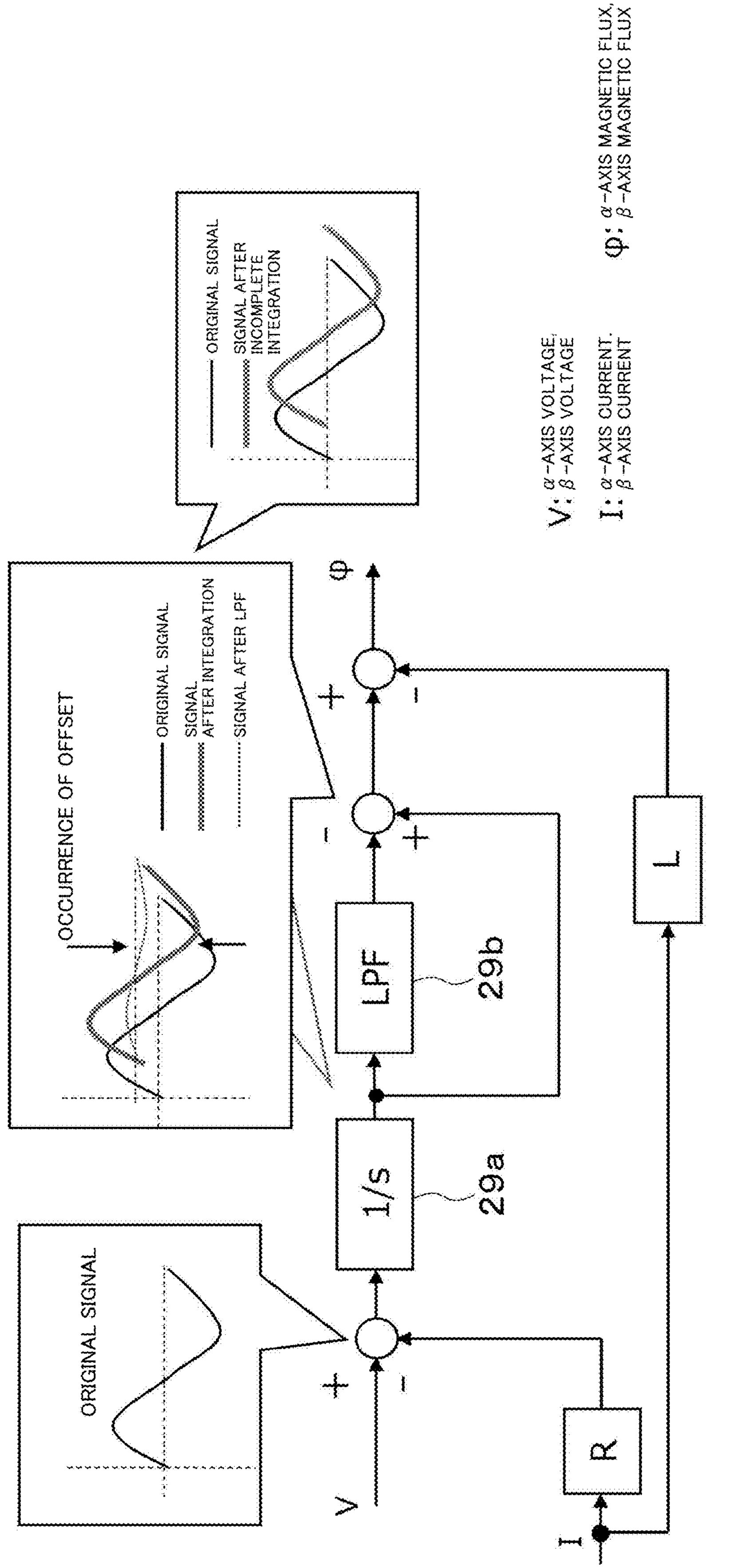

ORIGINAL SIGNAL
OCCURRENCE OF OFFSET
ORIGINAL SIGNAL
SIGNAL AFTER INTEGRATION
SIGNAL AFTER LPF
ORIGINAL SIGNAL
SIGNAL AFTER INCOMPLETE INTEGRATION
V
I
R
1/s
29a
LPF
29b
L
Φ
+
-
V: α-AXIS VOLTAGE, β-AXIS VOLTAGE
I: α-AXIS CURRENT, β-AXIS CURRENT
Φ: α-AXIS MAGNETIC FLUX, β-AXIS MAGNETIC FLUX

FIG.4

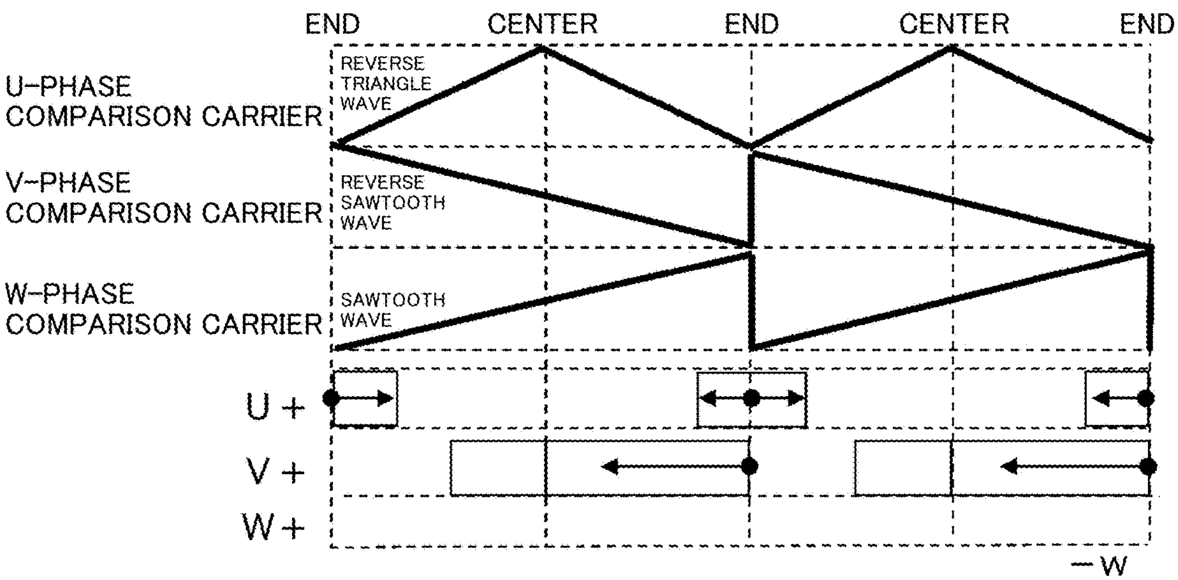

END
CENTER
END
CENTER
END
U-PHASE
COMPARISON CARRIER
REVERSE
TRIANGLE
WAVE
V-PHASE
COMPARISON CARRIER
REVERSE
SAWTOOTH
WAVE
W-PHASE
COMPARISON CARRIER
SAWTOOTH
WAVE
U +
V +
W +
— W

FIG.5

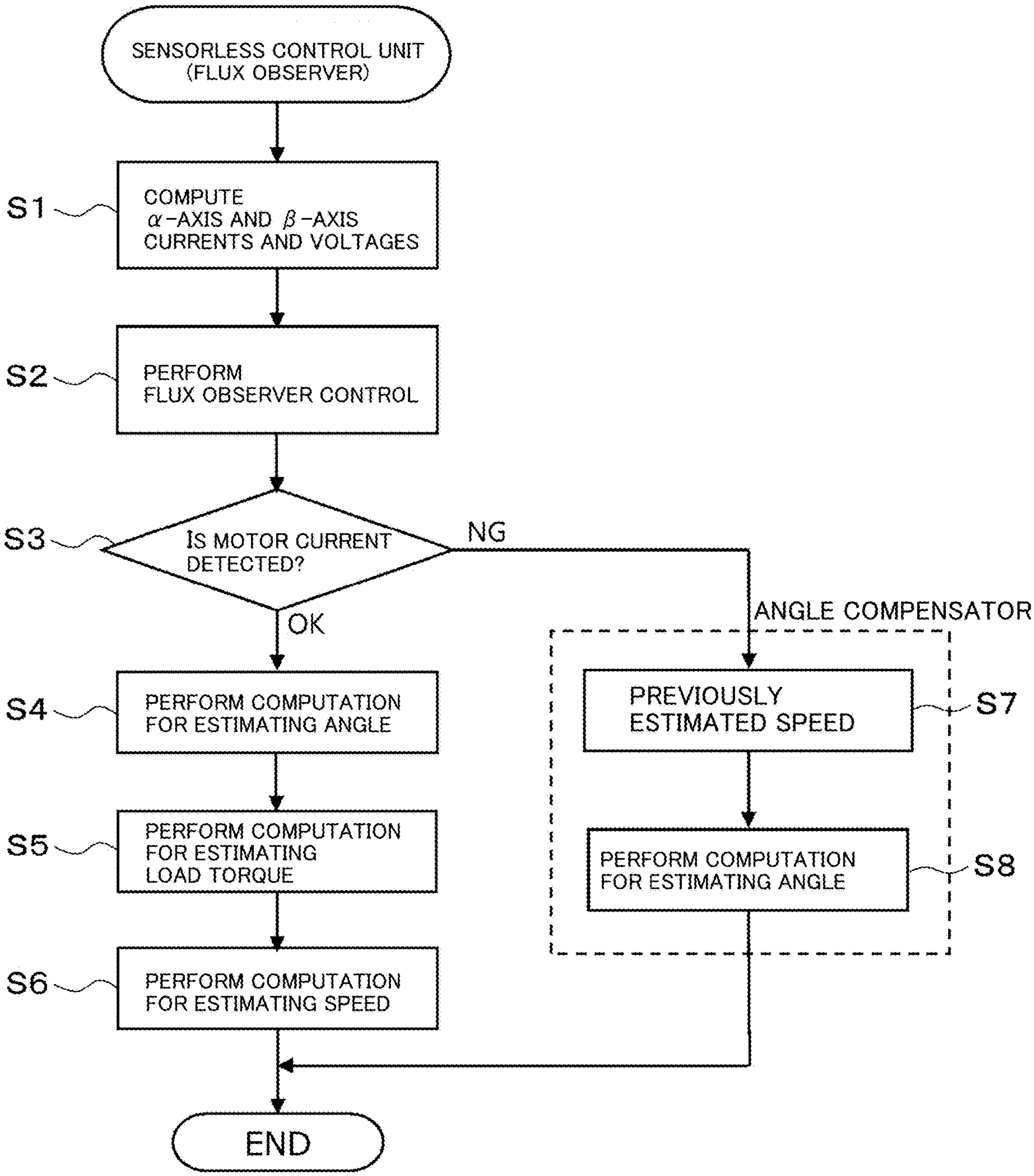

SENSORLESS CONTROL UNIT (FLUX OBSERVER)
S1
COMPUTE α-AXIS AND β-AXIS CURRENTS AND VOLTAGES
S2
PERFORM FLUX OBSERVER CONTROL
S3
IS MOTOR CURRENT DETECTED?
NG
OK
ANGLE COMPENSATOR
S4
PERFORM COMPUTATION FOR ESTIMATING ANGLE
S5
PERFORM COMPUTATION FOR ESTIMATING LOAD TORQUE
S6
PERFORM COMPUTATION FOR ESTIMATING SPEED
S7
PREVIOUSLY ESTIMATED SPEED
S8
PERFORM COMPUTATION FOR ESTIMATING ANGLE
END

FIG.6

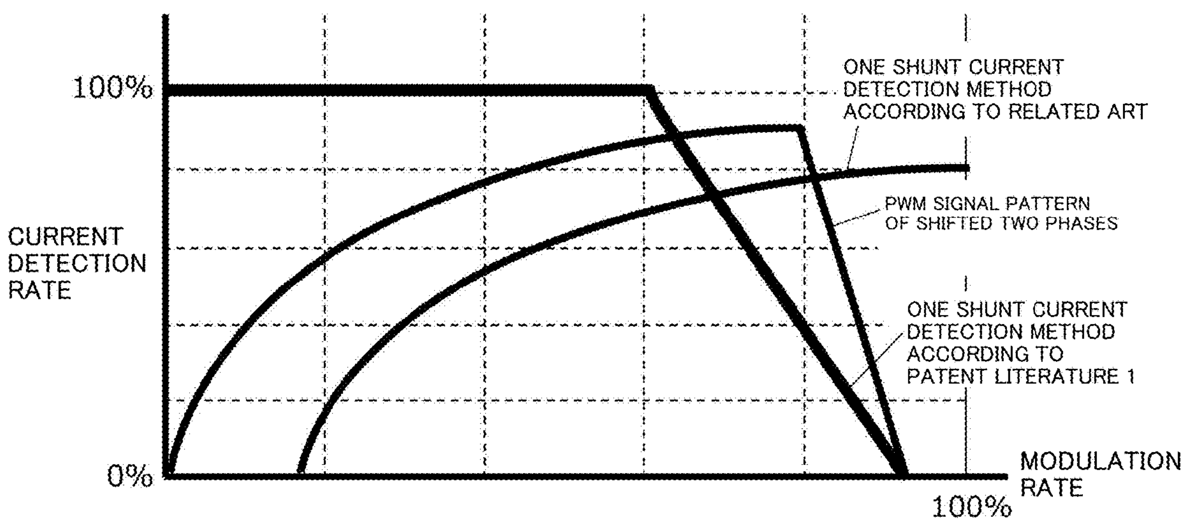

100%
0%
CURRENT
DETECTION
RATE
MODULATION
RATE
100%
ONE SHUNT CURRENT
DETECTION METHOD
ACCORDING TO RELATED ART
PWM SIGNAL PATTERN
OF SHIFTED TWO PHASES
ONE SHUNT CURRENT
DETECTION METHOD
ACCORDING TO
PATENT LITERATURE 1

FIG.7

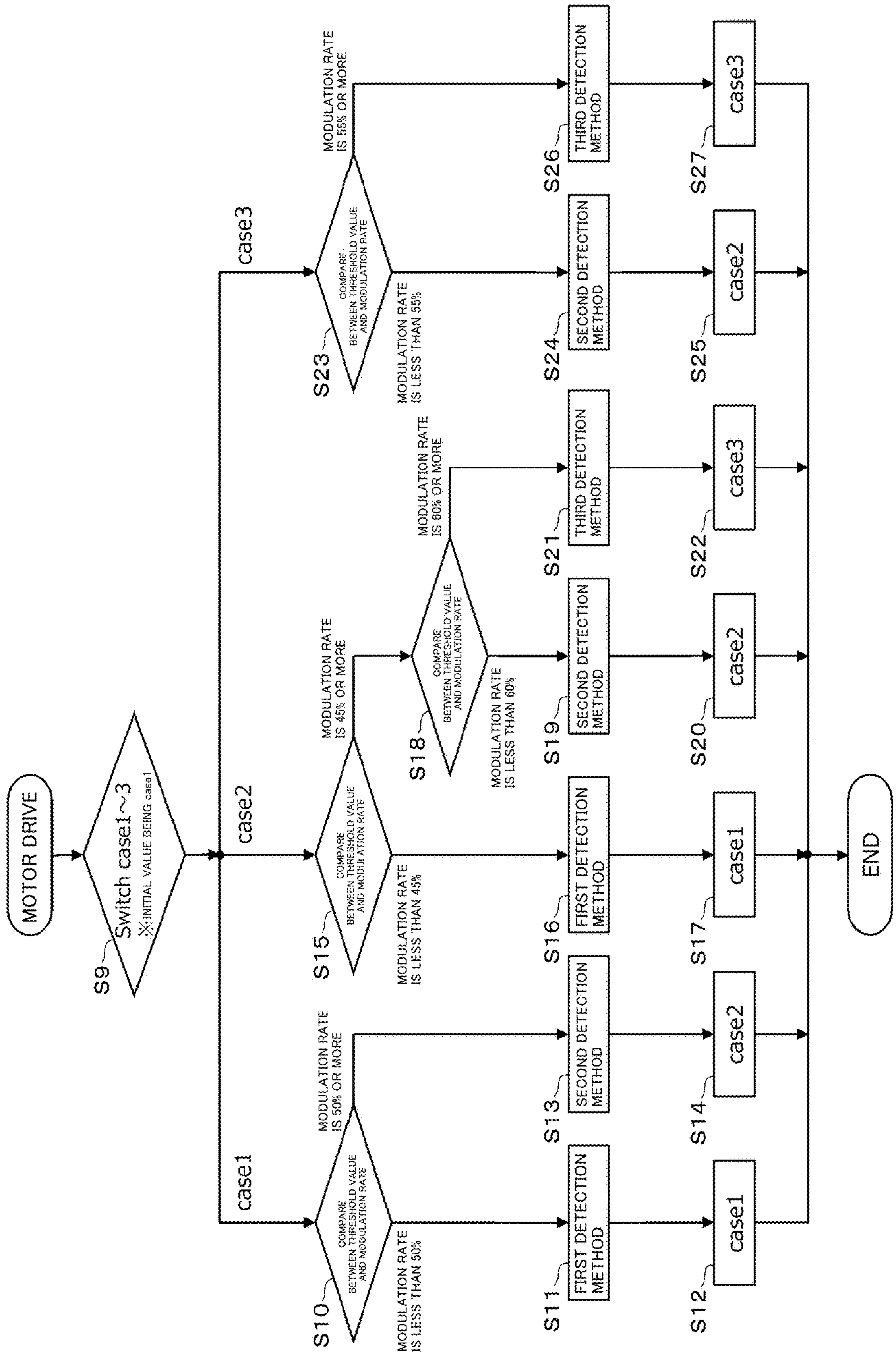

MOTOR DRIVE
S9
Switch case1~3
※INITIAL VALUE BEING case1
case1
case2
case3
S10
COMPARE BETWEEN THRESHOLD VALUE AND MODULATION RATE
MODULATION RATE IS LESS THAN 50%
MODULATION RATE IS 50% OR MORE
S11
FIRST DETECTION METHOD
S12
case1
S13
SECOND DETECTION METHOD
S14
case2
S15
COMPARE BETWEEN THRESHOLD VALUE AND MODULATION RATE
MODULATION RATE IS LESS THAN 45%
MODULATION RATE IS 45% OR MORE
S16
FIRST DETECTION METHOD
S17
case1
S18
COMPARE BETWEEN THRESHOLD VALUE AND MODULATION RATE
MODULATION RATE IS LESS THAN 60%
MODULATION RATE IS 60% OR MORE
S19
SECOND DETECTION METHOD
S20
case2
S21
THIRD DETECTION METHOD
S22
case3
S23
COMPARE BETWEEN THRESHOLD VALUE AND MODULATION RATE
MODULATION RATE IS LESS THAN 55%
MODULATION RATE IS 55% OR MORE
S24
SECOND DETECTION METHOD
S25
case2
S26
THIRD DETECTION METHOD
S27
case3
END

FIG.8

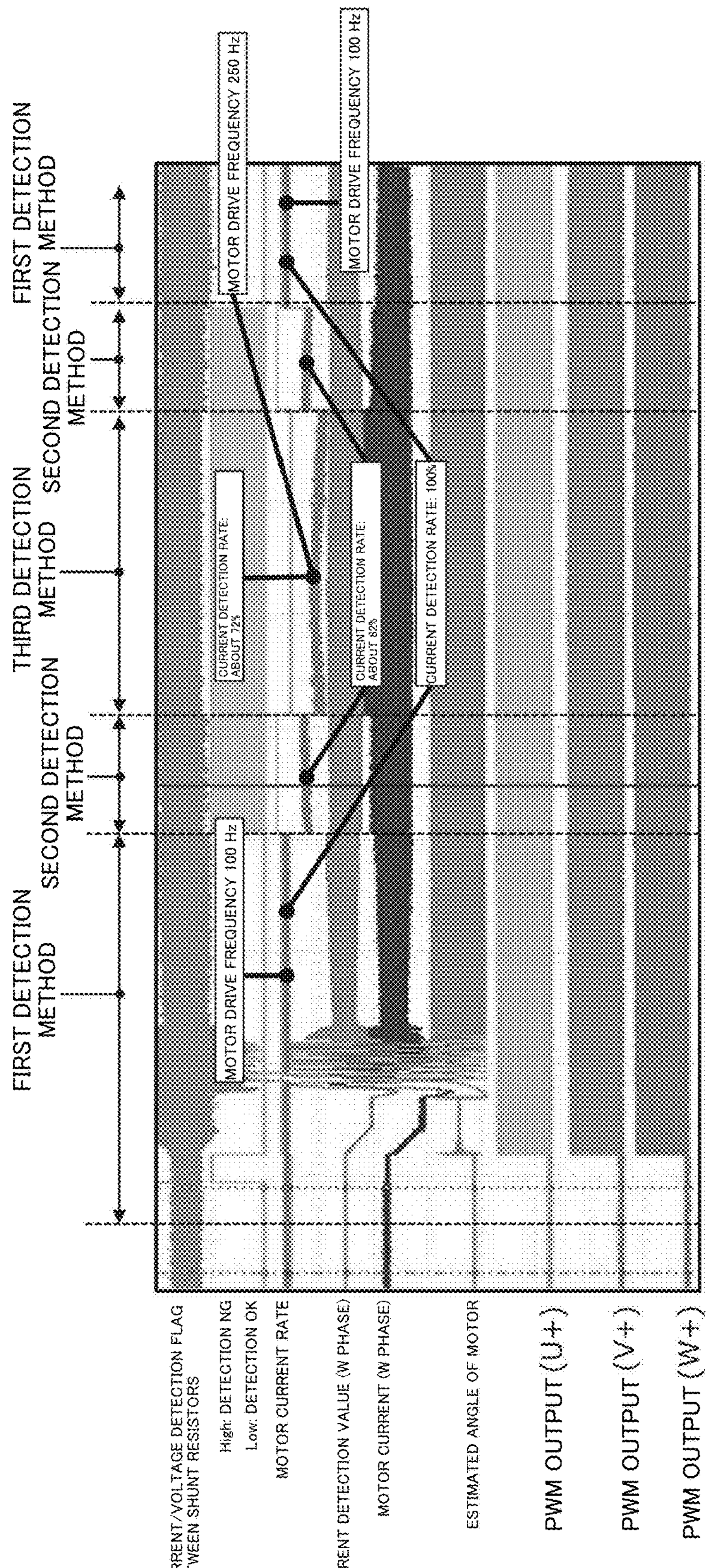

FIRST DETECTION METHOD
SECOND DETECTION METHOD
THIRD DETECTION METHOD
SECOND DETECTION METHOD
FIRST DETECTION METHOD
MOTOR DRIVE FREQUENCY 100 Hz
MOTOR DRIVE FREQUENCY 250 Hz
MOTOR DRIVE FREQUENCY 100 Hz
CURRENT DETECTION RATE: ABOUT 72%
CURRENT DETECTION RATE: ABOUT 82%
CURRENT DETECTION RATE: 100%
CURRENT/VOLTAGE DETECTION FLAG BETWEEN SHUNT RESISTORS
High: DETECTION NG
Low: DETECTION OK
MOTOR CURRENT RATE
MOTOR CURRENT DETECTION VALUE (W PHASE)
MOTOR CURRENT (W PHASE)
ESTIMATED ANGLE OF MOTOR
PWM OUTPUT (U+)
PWM OUTPUT (V+)
PWM OUTPUT (W+)

FIG.9

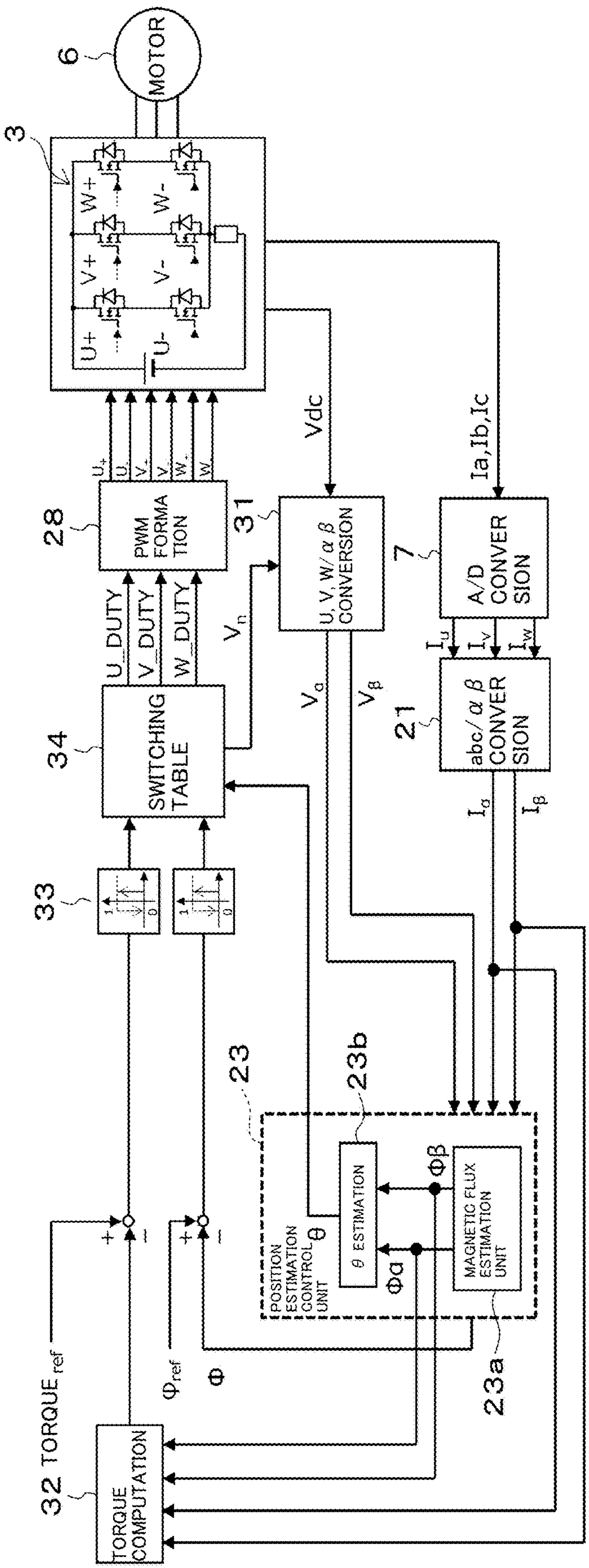

6
MOTOR
3
U+
V+
W+
U-
V-
W-
Vdc
Ia,Ib,Ic
28
PWM FORMATION
31
U, V, W/ α β CONVERSION
7
A/D CONVERSION
34
SWITCHING TABLE
U_DUTY
V_DUTY
W_DUTY
Vn
Vα
Vβ
Iu
Iv
Iw
21
abc/ α β CONVERSION
Iα
Iβ
33
23
23b
θ ESTIMATION
Φβ
Φα
θ
POSITION ESTIMATION CONTROL UNIT
MAGNETIC FLUX ESTIMATION UNIT
23a
TORQUE ref
Φref
Φ
+
-
32 TORQUE
TORQUE COMPUTATION

FIG.10

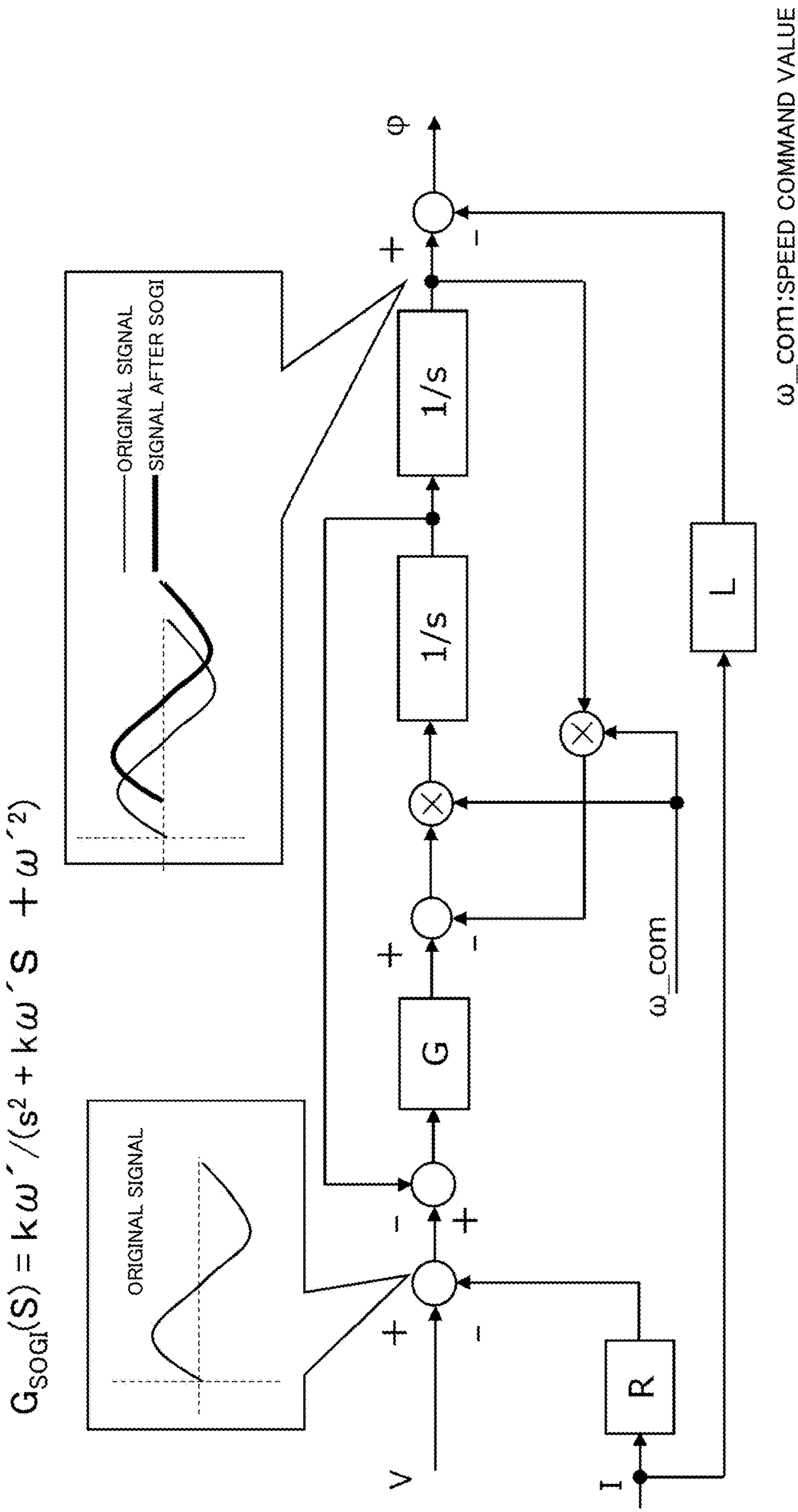

$G_{SOGI}(S) = k\omega' / (s^2 + k\omega' S + \omega'^2)$
ORIGINAL SIGNAL
ORIGINAL SIGNAL
SIGNAL AFTER SOGI
V
I
R
G
1/s
1/s
L
φ
ω_com
ω_com:SPEED COMMAND VALUE

FIG.11

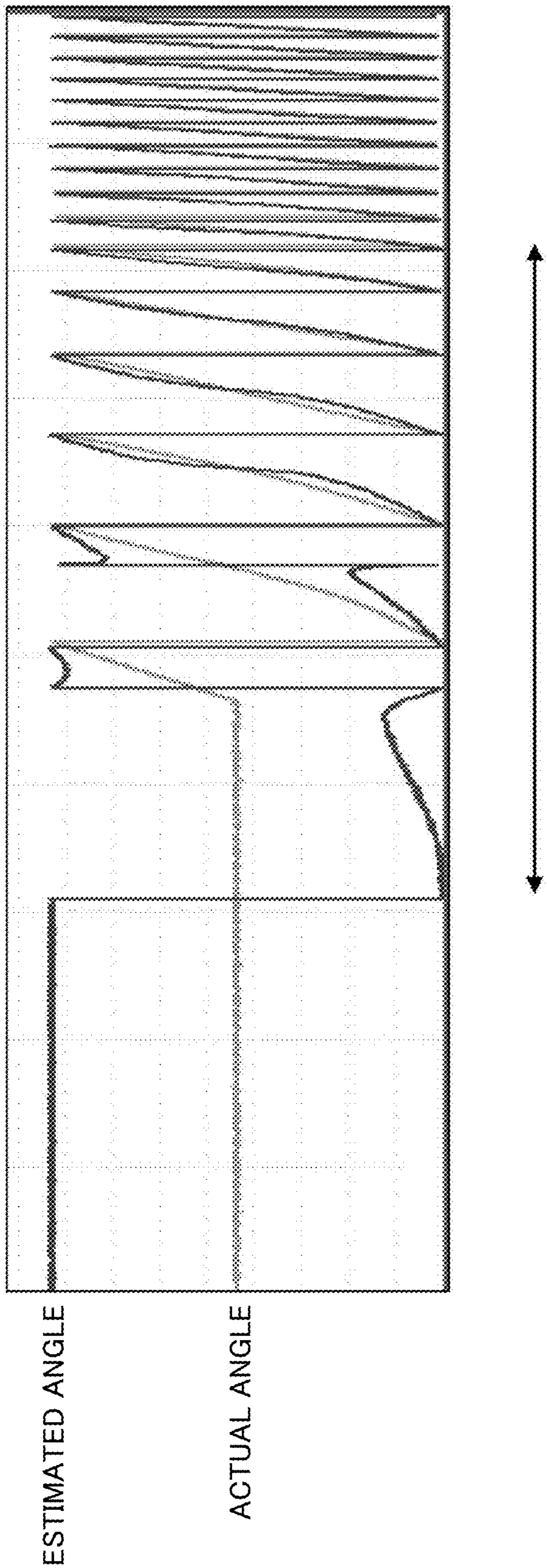


FIG.12

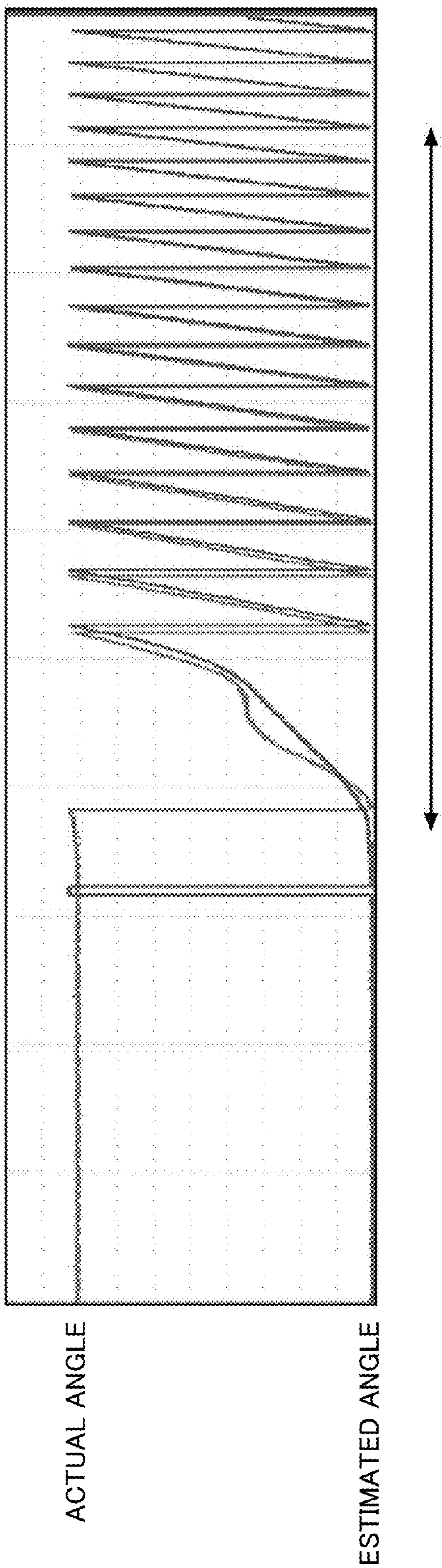


FIG.13

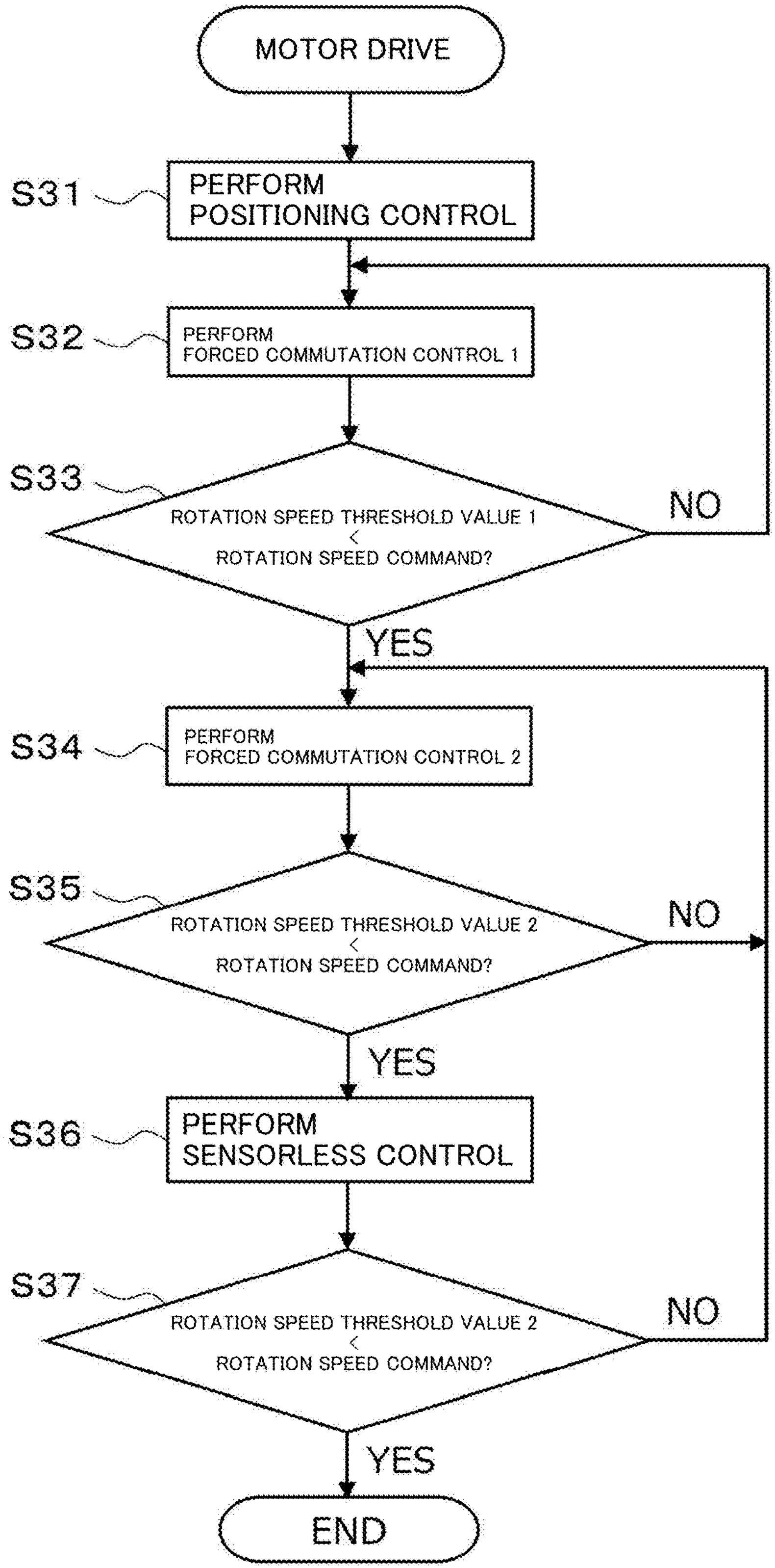

MOTOR DRIVE
S31
PERFORM
POSITIONING CONTROL
S32
PERFORM
FORCED COMMUTATION CONTROL 1
S33
ROTATION SPEED THRESHOLD VALUE 1
<
ROTATION SPEED COMMAND?
NO
YES
S34
PERFORM
FORCED COMMUTATION CONTROL 2
S35
ROTATION SPEED THRESHOLD VALUE 2
<
ROTATION SPEED COMMAND?
NO
YES
S36
PERFORM
SENSORLESS CONTROL
S37
ROTATION SPEED THRESHOLD VALUE 2
<
ROTATION SPEED COMMAND?
NO
YES
END

FIG.14

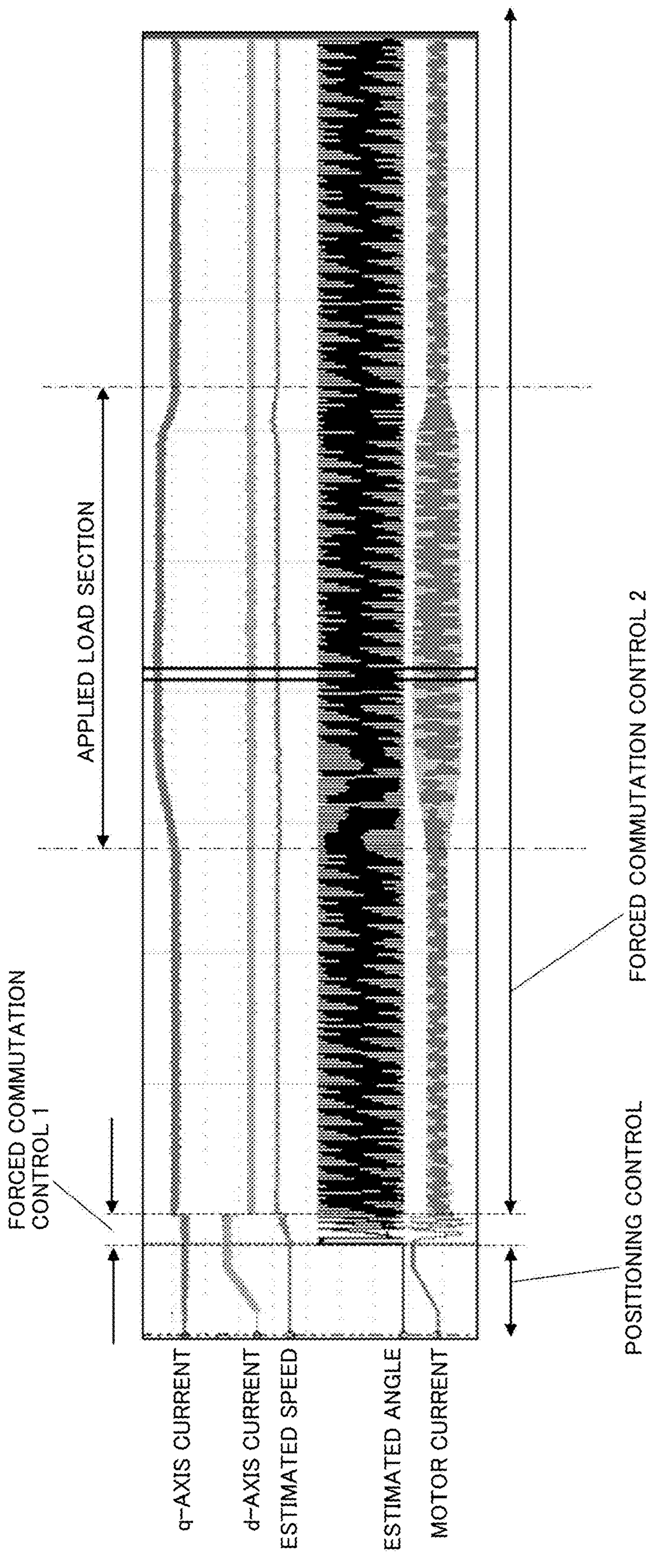

FORCED COMMUTATION CONTROL 1
APPLIED LOAD SECTION
FORCED COMMUTATION CONTROL 2
POSITIONING CONTROL
q-AXIS CURRENT
d-AXIS CURRENT
ESTIMATED SPEED
ESTIMATED ANGLE
MOTOR CURRENT

FIG.15

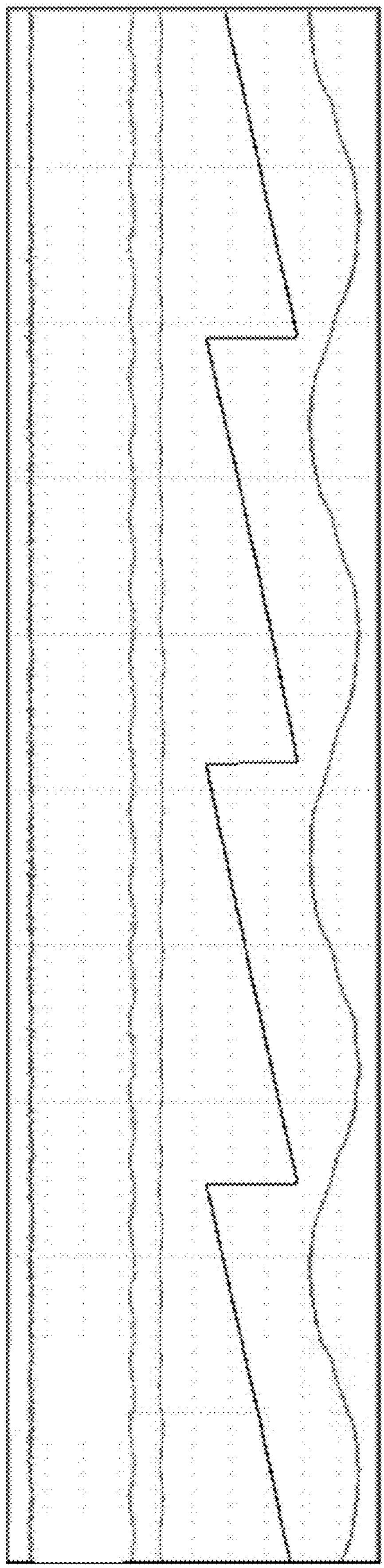


FIG.16

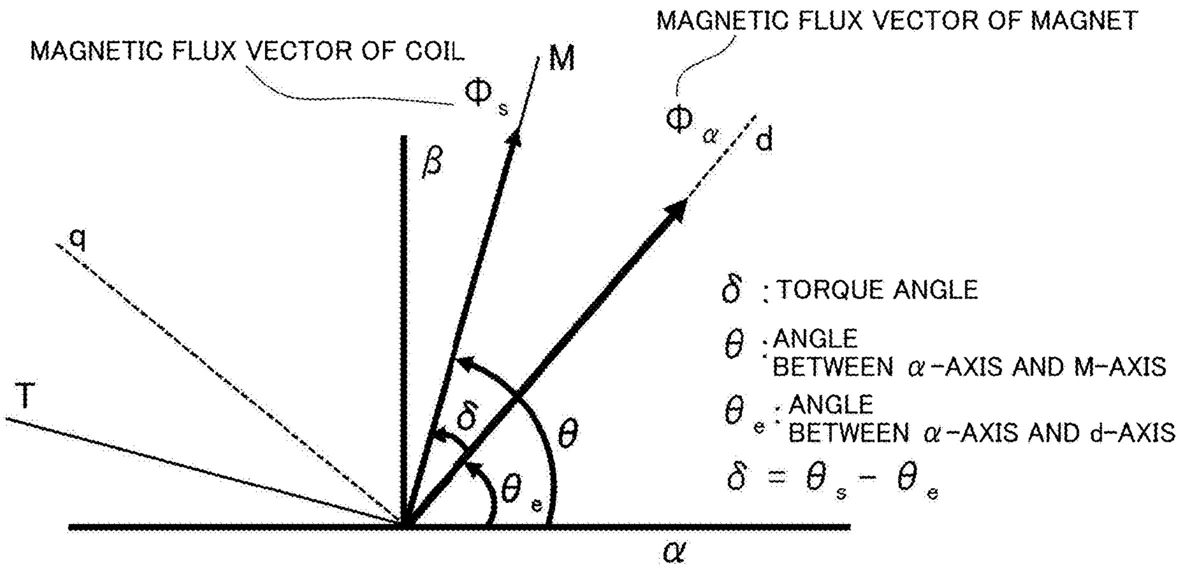
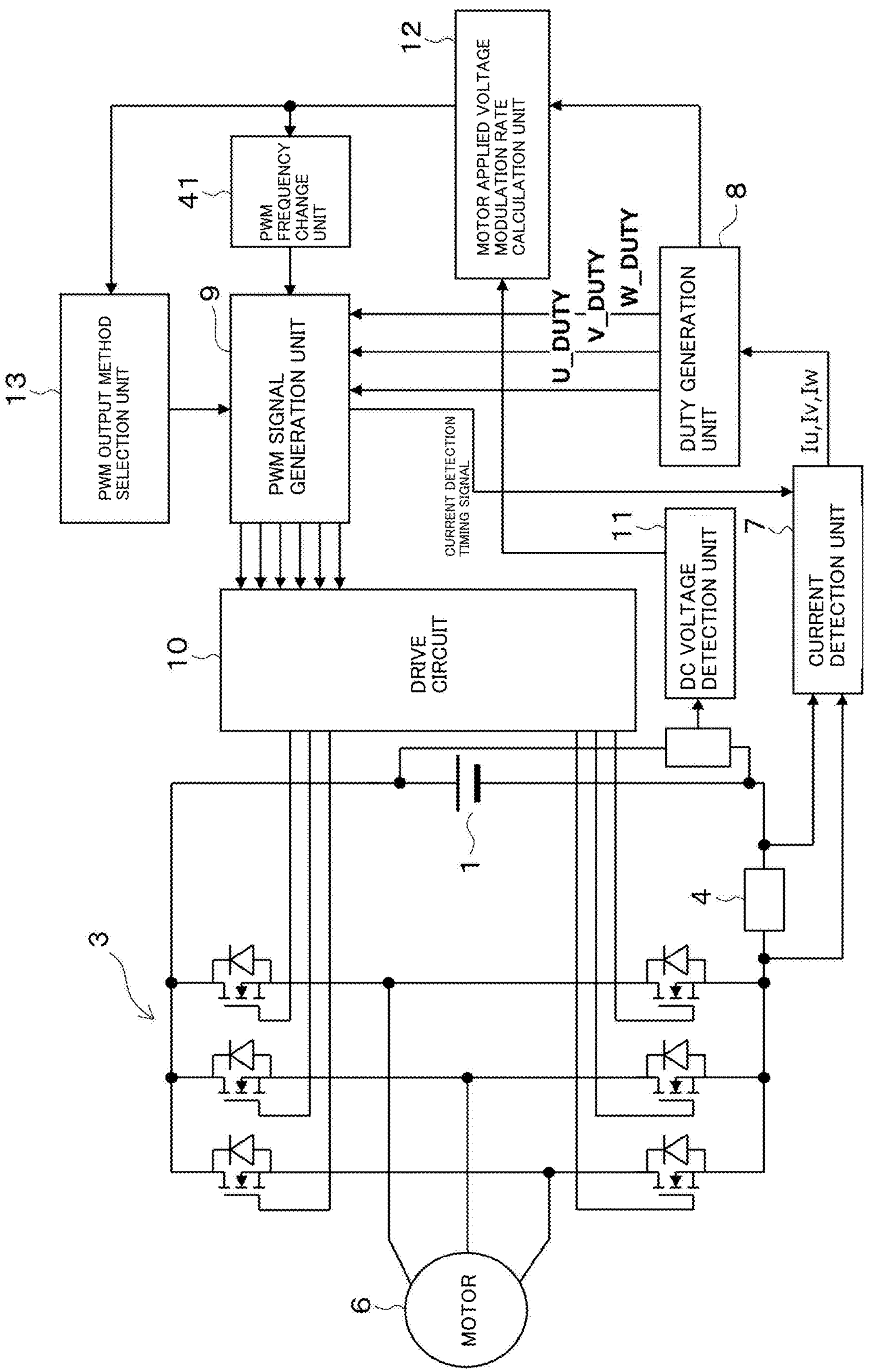

MAGNETIC FLUX VECTOR OF COIL
MAGNETIC FLUX VECTOR OF MAGNET
M
Φ_s
Φ_α
d
β
q
T
δ
θ
θ_e
α
δ : TORQUE ANGLE
θ : ANGLE BETWEEN α-AXIS AND M-AXIS
θ_e : ANGLE BETWEEN α-AXIS AND d-AXIS
$\delta = \theta_s - \theta_e$

FIG.17



12
MOTOR APPLIED VOLTAGE MODULATION RATE CALCULATION UNIT
41
PWM FREQUENCY CHANGE UNIT
13
PWM OUTPUT METHOD SELECTION UNIT
9
PWM SIGNAL GENERATION UNIT
U_DUTY
V_DUTY
W_DUTY
8
DUTY GENERATION UNIT
Iu,Iv,Iw
CURRENT DETECTION TIMING SIGNAL
11
DC VOLTAGE DETECTION UNIT
7
CURRENT DETECTION UNIT
10
DRIVE CIRCUIT
1
4
3
6
MOTOR

FIG.18

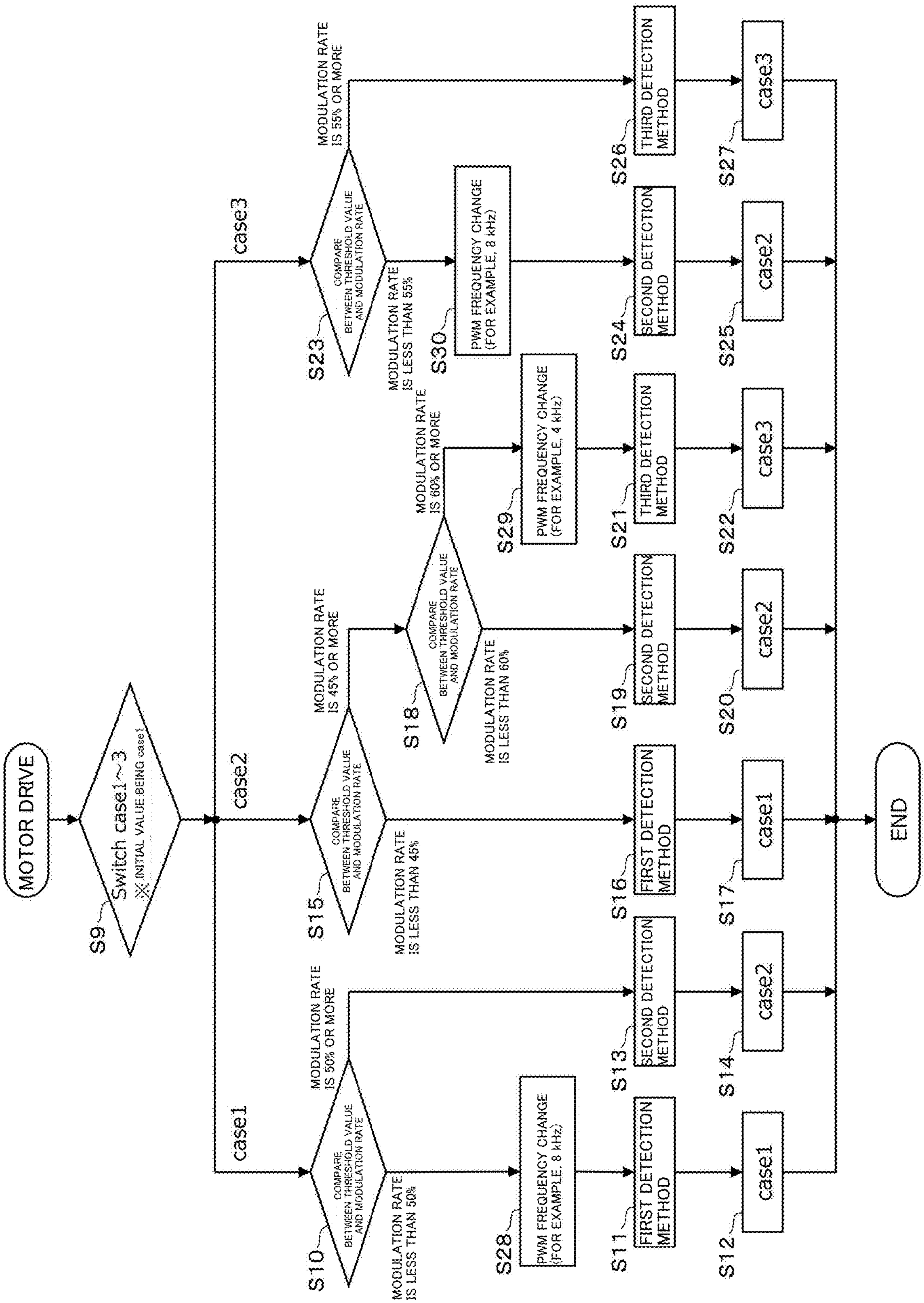

MOTOR DRIVE
S9
Switch case1~3
※ INITIAL VALUE BEING case1
case1
case2
case3
S10
COMPARE BETWEEN THRESHOLD VALUE AND MODULATION RATE
MODULATION RATE IS LESS THAN 50%
MODULATON RATE IS 50% OR MORE
S28
PWM FREQUENCY CHANGE (FOR EXAMPLE, 8 kHz)
S11
FIRST DETECTION METHOD
S12
case1
S13
SECOND DETECTION METHOD
S14
case2
S15
COMPARE BETWEEN THRESHOLD VALUE AND MODULATION RATE
MODULATION RATE IS LESS THAN 45%
MODULATION RATE IS 45% OR MORE
S16
FIRST DETECTION METHOD
S17
case1
S18
COMPARE BETWEEN THRESHOLD VALUE AND MODULATION RATE
MODULATION RATE IS LESS THAN 60%
MODULATION RATE IS 60% OR MORE
S19
SECOND DETECTION METHOD
S20
case2
S29
PWM FREQUENCY CHANGE (FOR EXAMPLE, 4 kHz)
S21
THIRD DETECTION METHOD
S22
case3
S23
COMPARE BETWEEN THRESHOLD VALUE AND MODULATION RATE
MODULATION RATE IS LESS THAN 55%
MODULATION RATE IS 55% OR MORE
S30
PWM FREQUENCY CHANGE (FOR EXAMPLE, 8 kHz)
S24
SECOND DETECTION METHOD
S25
case2
S26
THIRD DETECTION METHOD
S27
case3
END

FIG.19

MOTOR CONTROL DEVICE

FIELD OF THE INVENTION

[0001] Embodiments of the present invention relate to a control device that perform PWM control on a plurality of switching elements connected to each other in a three-phase bridge to control a motor via an inverter circuit.

DESCRIPTION OF THE RELATED ART

[0002] There is a technique of detecting a current using a single shunt resistor inserted into a DC section of an inverter circuit in a case of detecting U-phase, V-phase, and W-phase currents to control a motor. In order to detect all three phase currents with such a method, a three-phase PWM signal needs to be generated such that two or more phase currents can be detected within one cycle of a pulse width modulation (PWM) carrier (a carrier wave).

[0003] For this reason, a technique is disclosed in Patent Literature 1 (Japanese Patent No. 5178799) that can always detect two or more phase currents without increasing noise even in a region where a modulation rate of a motor applied voltage is low by shifting a phase of a PWM signal within one cycle. On the other hand, as a method of estimating a motor speed and a motor angle from an estimated magnetic flux, a flux observer has been proposed in Non-Patent Literature 1. In the flux observer method, an α-axis component $\psi\alpha$ and a β-axis component $\psi\beta$ of a magnetic flux interlinkage of a motor coil are estimated based on, for example, tow-phase currents $I\alpha$ and $I\beta$ obtained from a current sensor, two-phase voltages $V\alpha$ and $V\beta$, and a motor coil resistor R, and a rotating magnetic field angle of the motor, and a phase angle and a generated torque T of a rotor are estimated.

[0004] In addition, the applicant has proposed, in Japanese Patent Application No. 2022-130097, a technique for preventing an error in estimation of a magnetic flux interlinkage that can occur in a low-speed region from a startup when a flux observer method of estimating a phase angle and a speed of a rotating magnetic field of a motor from an estimated magnetic flux interlinkage and a one-shunt current output method are combined.

[0005] In a flux observer disclosed in Non-Patent Literature 1 (Inoue and five others, "Experimental Verification of Flux Estimation Method Expanding Operation Region for Direct Torque Control in PMSM", Papers for National Conference of the Institute of Electrical Engineers of Japan in 2021, Institute of Electrical Engineers of Japan, Mar. 1, 2021, 5-095), it is assumed that a current sensor such as a CT or a three-shunt current output method is applied for detecting the current used to estimate the magnetic flux. However, a one-shunt current output method is often applied in order to reduce costs of inverters or the like in home appliances. When the one-shunt current output method is applied, there is a possibility in a case where a modulation rate of a motor applied voltage is low at a low speed from a startup that the current cannot be detected and an error will occur in the estimation of the magnetic flux. Particularly, when a previous value is used during non-detection of the current in a case where an α-axis current and a β-axis current, which change in a sine wave, are used for computation of magnetic estimation, there is a problem that an error in estimation of the magnetic flux interlinkage increases.

[0006] Further, the above application provides a motor control device that uses a three-phase modulation method to shift a phase of a PWM signal within one cycle, prevents an error in estimation of a magnetic flux interlinkage that can occur in a low-speed region from a startup, and enables a stable motor drive when a flux observer method of estimating a phase angle and a speed of a rotating magnetic field of a motor from an estimated magnetic flux interlinkage and a one-shunt current output method are combined. However, when the phase of the PWM signal is shifted in the three-phase modulation method in a middle-speed region, a current detection rate drops sharply, resulting in a problem that an error in estimation of the magnetic flux interlinkage increases.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. **1** is a functional block diagram showing a configuration of a motor control device according to a first embodiment;

[0008] FIG. **2** is a diagram showing a vector control block using a flux observer;

[0009] FIG. **3** is a functional block diagram showing a detail configuration of a position estimation control unit;

[0010] FIG. **4** is a functional block diagram showing a configuration of an integrator used in a magnetic flux estimation unit;

[0011] FIG. **5** is a diagram showing a two-phase PWM signal with shifted phases;

[0012] FIG. **6** is a flowchart showing angle compensation processing in a one-shunt current detection method;

[0013] FIG. **7** is a diagram showing an example of a current detection rate according to each current detection method;

[0014] FIG. **8** is a flowchart showing processing of switching a current detection method according to a level of a modulation rate;

[0015] FIG. **9** is a diagram showing a switching example of a current detection method;

[0016] FIG. **10** is a functional block diagram showing a configuration of a motor control device according to a second embodiment;

[0017] FIG. **11** is a functional block diagram showing a configuration of an integrator used in a magnetic flux estimation unit according to a third embodiment;

[0018] FIG. **12** is a diagram showing a relationship between an actual angle and an estimated angle in a low speed region according to the first embodiment;

[0019] FIG. **13** is a diagram showing a relationship between an actual angle and an estimated angle in a low speed region according to the third embodiment;

[0020] FIG. **14** is a flowchart showing processing at the start of a motor according to a fourth embodiment;

[0021] FIG. **15** is a diagram showing signal waveforms;

[0022] FIG. **16** is an enlarged view of a portion in FIG. **15**;

[0023] FIG. **17** is a diagram showing a principle of compensating a phase θ of a rotating magnetic field according to a fifth example;

[0024] FIG. **18** is a functional block diagram showing a configuration of a motor control device according to a sixth example; and

[0025] FIG. **19** is a flowchart showing processing for switching a carrier wave frequency and a current detection method for PWM control according to a level of a modulation rate.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0026] Therefore, embodiments of the present invention provide a motor control device that prevents an error in estimation of the magnetic flux interlinkage over the entire motor driving range from a startup to a high-speed region in a flux observer method, thereby enabling a stable motor drive.

[0027] Embodiments provides a motor control device configured to perform on/off control on a plurality of switching elements connected to each other in a three-phase bridge according to a PWM signal and to drive a motor via an inverter circuit that converts a direct current (DC) into a three-phase alternating current (AC), the motor control device including:

- **[0028]** a current detection element connected to a DC side of the inverter circuit to generate a signal corresponding to a current value;
- **[0029]** a PWM signal generation unit configured to determine a rotor position based on at least a phase current of the motor and to generate a PWM signal to follow the rotor position; and a current detection unit configured to detect the phase current of the motor based on the signal generated by the current detection element and the PWM signal;
- **[0030]** the PWM signal generation unit being capable of executing:
- **[0031]** a first output method of outputting a phase-shifted PWM signal with three phases and causing the current detection unit to detect a current at fixed timing;
- **[0032]** a second output method of outputting a phase-shifted PWM signal with two phases and causing the current detection unit to detect a current at fixed timing; and
- **[0033]** a third output method of outputting a symmetrical PWM signal with three phases or two phases and causing the current detection unit to detect a current at fixed or variable timing,
- **[0034]** such that the current detection unit is capable of detecting two-phase currents at two timing points within a carrier wave cycle of the PWM signal,
- **[0035]** the motor control device further including: a magnetic flux estimation unit configured to estimate a magnetic flux interlinkage of an armature coil of the motor based on the phase current of the motor and an output voltage command;
- **[0036]** a signal switching output unit configured to estimate a rotating magnetic field angle and a speed of the motor based on the magnetic flux interlinkage, and to output a switching command such that the PWM signal generation unit:
- **[0037]** executes the first output method when a modulation rate of a motor applied voltage is less than a first threshold value,
- **[0038]** executes the second output method when the modulation rate is the first threshold value or greater or less than a second threshold value, and
- **[0039]** executes the third output method when the modulation rate is the second threshold value or greater; and
- **[0040]** an angle compensation unit configured to use a speed estimated in a previous control cycle and to generate an angle computed based on the speed estimated in the previous control cycle when the motor current is not detectable in one cycle of an electrical angle.

[0041] A "symmetric PWM signal" refers to having a pulse width of the PWM signal increasing and decreasing in the same direction for each phase based on an arbitrary phase of a carrier wave frequency. In addition, a "phase-shifted PWM signal" refers to having a pulse width of the PWM signal increasing and decreasing in different directions for each phase based on an arbitrary phase of a carrier wave frequency.

First Embodiment

[0042] FIG. **1** is a functional block diagram showing a configuration of a motor control device of the present embodiment, which is obtained by adding some functional blocks to FIG. 1 of Patent Literature 1. A DC power source unit **1** is indicated by a symbol of a DC power source, but includes a rectifier circuit, a smoothing capacitor, and the like when a DC power source is generated from a commercial AC power source. An inverter circuit **3** is connected to the DC power source unit **1** via a positive-side bus line **2***a* and a negative-side bus line **2***b*, but a shunt resistor **4** as a current detection element is inserted toward the negative-side bus line. The inverter circuit **3** includes switching elements, which are, for example, N-channel type power MOSFETs **5** (U+, V+, W+, U−, V−, and W−) connected to each other in a three-phase bridge, and an output terminal of each phases is connected to each of phase coils of a motor **6**, which is, for example, a brushless DC motor.

[0043] A terminal voltage of the shunt resistor **4** is detected by a current detection unit **7**. The current detection unit **7** detects currents Iu, Iv, and Iw of phases U, V, and W, respectively, based on the terminal voltage and three-phase PWM signals output to the inverter circuit **3**. When each of the phase currents detected by the current detection unit **7** is given to a DUTY generation unit **8** and is subjected to A/D conversion to be read, a computation is performed based on control conditions of the motor **6**. As a result, duty ratios U_DUTY, V_DUTY, and W_DUTY for generating PWM signals of the phases, respectively, are determined.

[0044] For example, in a case of performing vector control, when a rotation speed command ωref of the motor **6** is given to the DUTY generation unit **8** from a microcomputer or the like that sets the control conditions, a torque current command Iqref is generated based on a difference from an estimated actual rotation speed of the motor **6**. When a rotor position θ of the motor **6** is determined from the phase currents Iu, Iv, and Iw of motor **6**, a torque current Iq and an excitation current Id are calculated by a vector control computation using the rotor position θ. For example, a PI control computation is performed on the difference between the torque current command Iqref and the torque current Iq to generate a voltage command Vq. The same process is performed on the excitation current Id to generate a voltage command Vd, and the voltage commands Vq and Vd are converted into three-phase voltages Vu, Vv, and Vw using the rotor position θ. Then, phase duty ratios U_DUTY, V_DUTY, and W_DUTY are determined based on these three-phase voltages Vu, Vv, and Vw, respectively.

[0045] Each of the phase duty ratios U_DUTY, V_DUTY, and W_DUTY is given to a PWM signal generation unit **9**, and a three-phase PWM signal is generated by comparing a level with a carrier wave. Further, signals on a lower arm side are also generated by inverting the three-phase PWM signals, and the signals are output to the drive circuit **10** after dead time is added as necessary. The drive circuit **10** outputs a gate signal to each of gates of six power MOSFET **5** (U+, V+, W+, U−, V−, and W−) constituting the inverter circuit **3** according to the given PWM signal. For an upper arm side, a potential boosted by a necessary level is output.

[0046] A DC voltage detection unit **11** detects a voltage of the DC power source **1**, and outputs a detection result to a motor applied voltage modulation rate calculation unit **12**. The motor applied voltage modulation rate calculation unit **12** calculate a modulation rate of the voltage applied to the motor **6** via the inverter circuit **3**, based on duty ratio information input or the like from the DUTY generation unit **8**. The calculated modulation rate is output to a PWM output method selection unit **13**. The PWM output method selection unit **13** serving as a signal switching output unit outputs a switching signal for switching an output method of the PWM signal by the PWM signal generation unit **9** according to the modulation rate to be input.

[0047] FIG. **2** shows a vector control block using a flux observer. In FIG. **2**, each of the phase currents detected by the current detection unit **7** is converted into an α-axis component Iα and a β-axis component Iβ of a current of the motor by an abc/αβ conversion unit **21** of the DUTY generation unit **8**. The currents Iα and Iβ obtained by such a conversion are given to a position estimation control unit **23**. The position estimation control unit **23** estimates a magnetic flux based on the currents Iα and Iβ and voltage commands Vα and Vβ input from a dq/αβ conversion unit **26**, which will be described below.

[0048] The position estimation control unit **23** includes a magnetic flux estimation unit **23***a* and a speed/position estimation unit **23***b*. The magnetic flux estimation unit **23***a* estimates an α-axis component pa and a β-axis component φβ of a magnetic flux interlinkage according to Formulas (1) and (2) below. Here, L uses mutual inductance. The mutual inductance may be substituted by Self-inductance, d-axis inductance Ld, and q-axis inductance Lq.

$$\varphi\alpha = \int (V\alpha - R \times I\alpha)\,dt - LI\alpha \tag{1}$$

$$\varphi\beta = \int (V\beta - R \times I\beta)\,dt - LI\beta \tag{2}$$

[0049] Voltages of α-axis and β-axis components used in computations of Formula (1) and (2) may use previous computation values.

[0050] Based on the estimated magnetic fluxes pa and φβ, the speed/position estimation unit **23***b* first estimates a phase θ and a torque T of a rotating magnetic field using an α-axis as a basis, according to Formulas (3) and (4) below.

$$\theta = \mathrm{ATAN}\left(\varphi\beta/\varphi\alpha\right) \tag{3}$$

$$T = 3/2 \times (\text{number of pole pairs}) \times (\varphi\alpha \times I\beta - \varphi\beta \times I\alpha) \tag{4}$$

[0051] An integrator on a right side of each of Formulas (1) and (2) integrates the magnetic flux as shown in FIG. **4**, using an incomplete integration method by an LPF (Low Pass Filter) with a cutoff angular frequency ωc as shown in a transfer function of Formula (5). Here, a symbol "s" indicates a differential operator.

$$G(S) = 1/(s + \omega c) \tag{5}$$

[0052] When a frequency of the magnetic flux is sufficiently larger than the cutoff angular frequency ωc, it is possible to obtain an excellent estimation result. A speed ω is estimated by differentiation of the phase θ estimated by Formula (3). As the LPF, not only a general LPF but also an IIR (Infinite Impulse Response) filter, a FIR (Finite Impulse Response) filter, or the like may be applied.

[0053] FIG. **3** is a functional block diagram showing in more detail an internal configuration of the position estimation control unit **23** corresponding to the above-described computation. An integrator **29** of the magnetic flux estimation unit **23***a* shown in FIG. **3** is actually configured by a combination of an integrator **29***a* and a lowpass filter (LPF) **29***b* as shown in FIG. **4**, and employs a so-called incomplete integration method. An output signal of the integrator **29***a* contains an offset. The offset component is extracted by filtering of the output signal with the LPF **29***b*, and the offset component is canceled by subtraction of the offset component with a subtractor in a subsequent stage. The LPF **29***b* and the subtractor in the subsequent stage may be configured by an HPF (High Pass Filter). Information on a rotator speed of the motor **6** is required for speed control. When the flux observer is used in the configuration of vector control, the fact is used that the rotating magnetic speed of the motor **6** and the rotor speed constantly match.

[0054] FIG. **2** is referred to again. The rotation speed command ωref of the motor **6** is given by a host control device such as a microcomputer for setting control conditions. A speed control unit **24** generates the torque current command Iqref based on the difference between the rotation speed command ωref and the rotation speed ω estimated by the position estimation unit **23**. The αβ/dq conversion unit **22** calculates the torque current Iq and the excitation current Id from the currents Iα and Iβ by the vector control computation using the rotor position θ.

[0055] In a current control unit **25**, for example, a PI control computation is performed on the difference between the torque current command Iqref and the torque current Iq to generate the voltage command Vq. The same process is performed on the excitation current Id to generate the voltage command Vd. A space vector generation unit **27** converts the voltage commands Vq and Vd into three-phase voltages Vu, Vv, and Vw using the rotor position θ. Then, phase duty ratios U_DUTY, V_DUTY, and W_DUTY for generating PWM signals of the phases are determined based on the three-phase voltages Vu, Vv, and Vw, respectively.

[0056] Each of the phase duty ratios U_DUTY, V_DUTY, and W_DUTY is given to a PWM formation unit **28**, and a two-phase or three-phase PWM signal is generated by comparing a level with a carrier wave. In addition, signals on a lower arm side are also generated by inverting the two-phase or three-phase PWM signals, and the signals are output to the drive circuit **10** after dead time is added as necessary. As for the method of generating the three-phase PWM signals with phases shifted by the PWM formation unit **28**, a method of a fourth embodiment disclosed in Patent Literature 1 is used, for example. In the method of generating two-phase PWM signals with phases shifted by the PWM formation unit **28**, as shown in FIG. **5**, for example, an inverted triangular wave is used for an U-phase comparison carrier, an inverted sawtooth wave is used for a V-phase of comparison carrier, and a sawtooth wave is used for a W-phase of comparison carrier, with respect to the duty during two-phase modulation.

[0057] The motor applied voltage modulation rate calculation unit **12** shown in FIG. **1** calculates a modulation rate of a motor applied voltage for each carrier cycle as indicated by Formula (6), based on Vα and Vβ calculated by the DUTY generation unit **8**.

$$\text{(Modulation rate)} = 100 \times Vdc/\left(\sqrt{3} \times \sqrt{\left(Vq^2 + Vd^2\right)}\right) \tag{6}$$

[0058] The calculation result is output to the PWM output method selection unit **13**. The PWM output method selection unit **13** outputs a signal for switching the PWM output signal to the PWM signal generation unit **9** based on such information. Further, a current detection timing signal is output from the PWM signal generation unit **9** to the current detection unit **7**. The modulation rate of the motor applied voltage may be simply substituted by the motor rotation speed or the like.

[0059] Since the currents Iα and Iβ change in a sine wave in time series, when the magnetic flux is estimated using the currents Iα and Iβ estimated in the previous control cycle in a case where the phase current of the motor **6** cannot be detected in one-shunt current output method, estimation accuracy may deteriorate. In addition, since the angle changes in a sawtooth wave, when the angle estimated in the previous control cycle is used in a case where the phase current of the motor **6** cannot be detected, an error occurs in the computation of the vector control system. In the present embodiment, the control cycle is equal to the carrier wave cycle.

[0060] FIG. **6** shows a flowchart of angle compensation processing in a one-shunt current output method using a flux observer. Currents and voltages of α-axis and β-axis are computed (S**1**), and flux observer control is performed (S**2**). When the phase current can be detected (S**3**; OK), normal control is performed, and computations for estimating the angle θ, the load torque T, and the speed ω are sequentially performed (S**4** to S**6**). On the other hand, when the phase current cannot be detected (S**3**; NG), the previously estimated speed ω is used (S**7**), and the angle θ obtained by integration of the speed ω is used (S**8**). The processing is performed in the magnetic flux estimation unit **23***a* which also serves as an angle compensation unit.

[0061] FIG. **7** shows an example of a current detection rate in each current detection method. As the rotation speed of the motor and the load torque increase, the modulation rate of the motor applied voltage approaches 100%. The PWM output method selection unit **13** switches the output method of the PWM signal generated by the PWM signal generation unit **9** according to a level of the modulation rate, and switches the detection method of the phase current detected by the current detection unit **7**. When the modulation rate is in a low region, the PWM signal generation unit **9** is caused to generate a three-phase PWM signal in which an output phase of a PWM signal pulse of each of phases is shifted by the method according to Patent Literature 1, which is different from the method according to the related art. This is called a first output method. When the modulation rate is near 50% to 70% of an intermediate region, a PWM signal is generated in which output phases of two-phase PWM signal pulses are shifted, as shown in FIG. **5**. This is called a second output method. In addition, when the modulation rate is in a high region, for example, as shown in FIG. 7 of Patent Literature 1, a switching command is output so as to generate a two-phase or three-phase PWM signal that is a pulse signal symmetrical with respect to the midpoint of the PWM cycle. This is called a third output method.

[0062] In the following description, a method of causing the current detection unit **7** to detect two-phase currents at fixed timing will be referred to as a first detection method, corresponding to the first output method. Further, a method of causing the current detection unit **7** to detect two-phase currents at fixed timing will be referred to as a second detection method, corresponding to the second output method. Furthermore, a method of causing the current detection unit **7** to detect two-phase currents at fixed or variable timing will be referred to as a third detection method, corresponding to the third output method. When the motor **6** is driven from a startup to a high-speed region, the PWM output method selection unit **13** switches in the order of the first detection method, the second detection method, and the third detection method according to the modulation rate.

[0063] Conversely, when the speed of the motor **6** is changed from the high-speed region to the low-speed region, switching in the order of the third detection method, the second detection method, and the first detection method is performed. In this case, even when the speed of the motor **6** increases or decreases, frequent switching of the current detection method is prevented by providing hysteresis to a threshold value for switching the current detection method.

[0064] FIG. **8** shows a flowchart of switching of the current detection method. After the startup of the motor **6**, the process goes to a branch of case1 (S**9**) and the first or second detection method is selected. Through comparison between the modulation rate and the threshold value of the current detection method switching (S**10**), when the modulation rate is less than, for example, 50%, the first detection method is selected (S**11**), and the flow goes again to the branch of case1 (S**12**). When the modulation rate is 50% or more, the second detection method is selected (S**13**), the process proceeds to case2 (S**14**) and goes to the branch thereof to select one of the first to third detection methods. The modulation rate of 50% corresponds to a first threshold value.

[0065] For example, when the modulation rate is less than 45% (S**15**), the first detection method is selected (S**16**), and the process returns to case1 (S**17**). When the modulation rate is 45% or more (S**18**), the modulation rate is again compared with the threshold value of the current detection method switching, and when the modulation rate is less than, for example, 60% (S**18**), the process continues to the second detection method (S**19**). When the modulation rate is 60% or more (S**18**) the third detection method is selected (S**21**), and the process proceeds case3 (S**22**). The modulation rate of 60% corresponds to a second threshold value. After proceeding to case3, when the modulation rate is, for example, less than 55% (S**23**), the second detection method is selected (S**24**), and the process proceeds to case2 (S**25**). When the modulation rate is 55% or more (S**23**), the third detection method is selected (**S26**), and the process goes again to case3 (**S27**). The modulation rate of 55% corresponds to a third threshold value. The value of the threshold value may be changed appropriately in consideration of a current ripple, an A/D conversion time, and the like.

[0066] FIG. **9** shows an example in which the one-shunt current detection method using the flux observer is switched to the third detection method, the second detection method, and the first detection method to drive the motor **6**. When a drive frequency is increased after the startup of the motor **6**, the detection method is switched in the order of the first detection method, the second detection method, and the third detection method. When the drive frequency is decreased after switching to the third detection method, the detection method is switched in the order of the third detection method, the second detection method, and the first detection method.

[0067] As described above, according to the present embodiment, the PWM signal generation unit **9** determines the rotor position based on at least the phase currents of the motor **6**, and generates the PWM signal to follow the rotor position. The current detection unit **7** detects the phase currents of the motor **6** based on the signal generated in the shunt resistor **4** and the PWM signal. The PWM signal generation unit **9** outputs the PWM signal using the first to third output methods such that the current detection unit **7** can detect two-phase currents at two timing points within the carrier wave cycle according to the first to third detection methods. In the first output methods, one of the three phases increases or decreases the duty ratio in both directions of lagging and leading sides with reference to an arbitrary phase of the carrier wave cycle, another phase increases or decreases the duty ratio in one direction of the lagging and leading sides, and the remaining phase increases or decreases the duty ratio in a direction opposite to the one direction.

[0068] The magnetic flux estimation unit **23***a* estimates the magnetic flux interlinkage of the armature coil of the motor **6** based on the phase currents and the output voltage commands of the motor **6**, and estimates the rotating magnetic field angle and speed of the motor **6** based on the magnetic flux interlinkage. The PWM output method selection unit **13** outputs the switching command to the PWM signal generation unit **9** to execute the first output method when the modulation rate of the motor applied voltage is in the low region, the second output method when the modulation rate of the motor applied voltage is in the intermediate region, and the first output method when the modulation rate of the motor applied voltage is in the high region. Accordingly, the current detection unit **7** is switched to the first to third detection methods. When the motor current cannot be detected, the magnetic flux estimation unit **23***a* uses the previously estimated speed, and generates an angle computed based on the previous speed.

[0069] Here, the condition under which the motor current cannot be detected is that a duration of the PWM signal for which the current is to be detected in one cycle of an electrical angle is shorter than a current detectable time, for example, 5 to 10 usec in consideration of a current ripple and A/D conversion time. Therefore, even when "a PWM signal is generated such that two-phase currents can be detected at two timing points", the detection rate is not always 100%, and the actual detection rate is generally in a range of 70% to 100%. Furthermore, in a region where the modulation rate exceeds approximately 50 to 60%, the detection rate drops sharply, which may cause the motor drive to become unstable depending on the application.

[0070] Therefore, the second detection method is adopted in the region where the modulation rate exceeds approximately 50 to 60%, and thus the current detection rate can be increased compared to the first detection method. With such a configuration, even when the one-shunt current detection method is applied, the three-phase currents Iu, Iv, and Iw can be detected with a high current detection rate from a state in which the modulation rate of the motor applied voltage is low to a state in which the modulation rate is high, and the magnetic flux can be estimated based on the α-axis current and the β-axis current and the voltage command vector. Additionally, even when the phase current of the motor **6** cannot be detected, deterioration of position estimation accuracy can be prevented by using the previously estimated speed value.

Second Embodiment

[0071] Hereinafter, the same components as those in the first embodiment are denoted by the same reference numerals and will not be described, and other components will be described. The first embodiment has described the case where the angle θ and the speed ω of the motor **6** are estimated based on the estimated magnetic flux and applied to the vector control. A second embodiment shows a case where flux observer control is applied to direct torque control.

[0072] As shown in FIG. **10**, the direct torque control using the flux observer uses an UVW/αβ conversion unit **31**, a torque computation unit **32** which is a direct torque control execution unit, a binary level output unit **33**, and a switching table **34** instead of the αβ/dq conversion unit **22**, the speed estimation unit **24**, the current control unit **25**, the dq/αβ conversion unit **26**, and the space vector formation unit **27**. Instead of the rotation speed command ωref, a target torque command Tref and a target flux command φref are input from the host control device. Then, a three-phase PWM signal is generated with reference to the switching table **34**. Since the direct torque control is a well-known technology, detailed descriptions thereof will not be given. As the motor, a synchronous reluctance motor or an induction motor can be applied in addition to a permanent magnet motor.

Third Embodiment

[0073] In the first embodiment, the incomplete integration method is adopted for the integrators on the right sides of Formulas (1) and (2). In the second embodiment, a second-order generalized integration method of a transfer function as shown in FIG. **11** and Formula (7) is used for the integration of magnetic flux in the same case.

$$G(S) = k\omega'/\left(s^2 + K\omega'S + \omega'^2\right) \tag{7}$$

[0074] Where, ω' indicates a natural angular frequency of a second-order filter, and k indicates a coefficient used to determine attenuation.

[0075] In the estimation of the magnetic flux by the incomplete integration method, the magnetic flux can be excellently estimated when the magnetic flux frequency is sufficiently larger than ωc, but since the LPF **29***b* is used, estimation accuracy deteriorates in a low-speed region indicated by a double-headed arrow in FIG. **12**. In contrast, the second-order generalized integration method shown in FIG. **13** improves frequency characteristics in the low-speed region, so that the operable range can be expanded.

[0076] As described above, according to the third embodiment, when the output phase of the PWM signal pulse of each phase is shifted by the method of Patent Literature 1 to generate a three-phase PWM signal and perform sensorless operation in a case where the modulation rate of the motor applied voltage is in a low region, since estimation accuracy in magnetic flux of the motor can be maintained even at low speed by integrating the magnetic flux using the second-order generalized integration method, sensorless control can be performed.

Fourth Embodiment

[0077] According to the third embodiment, the estimation accuracy in magnetic flux of the motor can be maintained even at low speed. However, when the motor **6** starts, the magnetic flux of the motor cannot be estimated with sufficient accuracy. For this reason, it is conceivable to perform forced commutation in which a d-axis current is applied at an angle corresponding to the command speed at the startup and to switch to sensorless operation after increasing the rotation speed of the motor **6**. However, when the load torque of the motor **6** is excessively large, there is a risk of stepping out. When a sufficiently large d-axis current is applied during the forced commutation, it is possible to cope with the load at the startup, but the power at the startup will increase.

[0078] Therefore, according to the fourth embodiment, at the start of the motor **6**, a forced commutation is performed in which a d-axis current is applied according to the estimated angle of the magnetic flux of the motor. In addition, based on the difference between the command rotation speed and the estimated rotation speed of the motor **6**, a torque current command Iqref is also applied. As a result, during the forced commutation at the startup, the d-axis current is applied when the motor load is small, and a q-axis current is applied when the motor load becomes large. Thus, even in the forced commutation at the startup, the motor current can be changed according to the load, and the motor **6** can be started without spending wasteful power.

[0079] In a control sequence at the startup shown in FIG. **14**, first, positioning control is performed (S**31**). Here, an excitation current command Idref is defined as a predetermined value set in advance, the torque current command Iqref is defined as zero, and the angle is defined as a target angle. Subsequently, "forced commutation control **1** is performed (S**32**). The current commands Idref and Iqref and the angle are the same as in step S**31**. Then, the rotation speed command ωref is increased, and when it is determined in step S**33** that the rotation speed command ωref exceeds rotation speed threshold **1** (S**33**; YES), the process proceeds to "forced commutation control **2**" (S**34**).

[0080] In the "forced commutation control **2**", the excitation current command Idref is assumed to be, for example, approximately half the predetermined value in the "forced commutation control **1**". The torque current command Iqref uses the result of speed control in the vector control, and the angle is assumed to be a value estimated by the flux observer. Subsequently, when it is determined in step S35 that the rotation speed command ωref exceeds rotation speed threshold **2** (YES), the process proceeds to sensorless control (S**36**). Here, the excitation current command Idref is assumed to be zero. Then, the same determination is made as in step S**35** (S**37**). When the rotation speed command ωref exceeds rotation speed threshold **2**, the startup processing is completed, and when the rotation speed command is equal to or lower than rotation speed threshold **2**, the process returns to step S**34**.

[0081] FIG. **15** shows operation waveforms of the motor when the forced commutation is performed according to the estimated angle of the magnetic flux of the motor, and FIG. **16** is an enlarged view of a portion enclosed by a rectangle in an applied load section in FIG. **15**. The torque current component Iq increases even when the load increases during the forced commutation. Therefore, it can be seen that the motor output torque can be varied according to the load torque even during the forced commutation.

[0082] As described above, according to the fourth embodiment, at the start of the motor **6**, the forced commutation is performed in which the d-axis current is applied according to the estimated angle of the magnetic flux of the motor, and based on the difference between the command rotation speed and the estimated rotation speed of the motor **6**, and the torque current command Iqref is also applied, whereby the output torque of the motor **6** can be varied according to the load torque even during the forced commutation. Thus, the motor **6** can be started without spending wasteful power.

Fifth Embodiment

[0083] In the first and second embodiments, the phase θ of the rotating magnetic field has been estimated by Formula (3). As the load torque of the motor increases, the error between the phase θ of the rotating magnetic field and the phase of the magnet increases. Therefore, the phase θ of the rotating magnetic field is compensated according to Formula (9) using a torque angle δ calculated by Formula (8) from q-axis inductance Lq, d-axis inductance Ld, q-axis current Iq, d-axis current Id, and magnetic flux of the magnet Φ. FIG. **17** is a diagram showing a principle of compensation.

$$\delta = \tan^{-1}\{(Lq \times Iq)/(Ld \times Id + \Phi)\} \tag{8}$$

$$\theta = \theta s - \delta \tag{9}$$

[0084] According to the fifth embodiment as described above, it is possible to reduce a position estimation error between the phase θ of the rotating magnetic field and the phase of the magnet that occurs when the load torque of the motor **6** increases at the time of startup of the motor **6**. Thereby, even when the load torque of the motor **6** increases, the motor **6** can be driven stably.

Sixth Embodiment

[0085] When the output phase of the PWM signal pulse of each phase is shifted as in the above-described embodiments, noise may become a problem when the frequency of the carrier wave is within an audible range to human, for example, 4 KHz. On the other hand, when the frequency of the carrier wave is increased over the entire range of the motor drive, there is a concern that switching loss of the inverter circuit **3** will increase and the overall efficiency will decrease. In the sixth embodiment, therefore, when the PWM output method selection unit **13** causes the current detection unit **7** to switch between the first and second current detection method and the third current detection method depending on the level of the modulation rate, a carrier wave frequency is changed by a PWM frequency change unit **41** shown in FIG. **18**.

[0086] As shown in FIG. **19**, when the modulation rate is less than 50% in step S**10**, the carrier wave frequency is set to, for example, 8 kHz to 16 kHz or higher (S**27**), and the first detection method is executed (S**11**). Similarly, even when the modulation rate is less than 55% in step S**23**, the carrier wave frequency is set to, for example, 8 kHz to 16 kHz or higher (S**30**), and the second detection method is executed (S**24**).

[0087] On the other hand, when the modulation rate is 60% or more in step S**18**, the carrier wave frequency is set to, for example, to 4 kHz as possible as low (S**29**), and the third detection method is executed (S**21**). In the case of such a detection method, noise due to the carrier wave frequency is smaller compared with a case where the output phase is shifted. Either the current detection method or the change in carrier wave frequency may be performed ahead. Further, the change in frequency of the carrier wave may be performed step by step or at once. In addition, the modulation rate of the motor applied voltage may be simply substituted by the motor rotation speed.

Other Embodiments

[0088] As for a method of expanding the pulse width of the PWM signal for each phase, the first to third embodiments of Patent Literature 1 may be applied.

[0089] Magnetic fluxes φα and φβ may be estimated by computation according to Formulas (10) and (11).

$$\varphi\alpha = \int (V\alpha - R \times I\alpha)\, dt \tag{10}$$

$$\varphi\beta = \int (V\beta - R \times I\beta)\, dt \tag{11}$$

[0090] The control cycle does not necessarily have to coincide with the carrier wave cycle, and may be set to more than twice the carrier wave cycle or ½ the carrier wave cycle.

[0091] While certain embodiments have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the inventions. Indeed, the novel embodiments described herein may be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the embodiments described herein may be made without departing from the spirit of the inventions. The accompanying claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of the inventions.

We claim:

1. A motor control device configured to perform on/off control on a plurality of switching elements connected to each other in a three-phase bridge according to a PWM signal and to drive a motor via an inverter circuit that converts a direct current (DC) into a three-phase alternating current (AC), the motor control device comprising:

a current detection element connected to a DC side of the inverter circuit to generate a signal corresponding to a current value;

a PWM signal generation unit configured to determine a rotor position based on at least a phase current of the motor and to generate a PWM signal to follow the rotor position; and

a current detection unit configured to detect the phase current of the motor based on the signal generated by the current detection element and the PWM signal;

the PWM signal generation unit being capable of executing:

a first output method of outputting a phase-shifted PWM signal with three phases and causing the current detection unit to detect a current at fixed timing;

a second output method of outputting a phase-shifted PWM signal with two phases and causing the current detection unit to detect a current at fixed timing; and

a third output method of outputting a symmetrical PWM signal with three phases or two phases and causing the current detection unit to detect a current at fixed or variable timing,

such that the current detection unit is capable of detecting two-phase currents at two timing points within a carrier wave cycle of the PWM signal,

the motor control device further comprising:

a magnetic flux estimation unit configured to estimate a magnetic flux interlinkage of an armature coil of the motor based on the phase current of the motor and an output voltage command;

a signal switching output unit configured to estimate a rotating magnetic field angle and a speed of the motor based on the magnetic flux interlinkage, and to output a switching command such that the PWM signal generation unit:

executes the first output method when a modulation rate of a motor applied voltage is less than a first threshold value,

executes the second output method when the modulation rate is the first threshold value or greater or less than a second threshold value, and

executes the third output method when the modulation rate is the second threshold value or greater; and

an angle compensation unit configured to use a speed estimated in a previous control cycle and to generate an angle computed based on the speed estimated in the previous control cycle when the current detection unit is unable to detect the phase current in one cycle of an electrical angle.

2. The motor control device according to claim **1**, wherein the signal switching output unit outputs a switching command so as to execute the second output method when the modulation rate falls below a third threshold value set to be the first threshold value or greater or less than the second threshold value, after outputting a switching command so as to execute the third output method.

3. The motor control device according to claim **1**, wherein the PWM signal generation unit generates, in the first output method, the PWM signal in a manner that one phase of the PWM signal with three phases increases or decreases a pulse width in both directions of lagging and leading sides with reference to an arbitrary phase of the carrier wave cycle, another phase increases or decreases the pulse width in one direction of the lagging and leading sides with reference to the arbitrary phase of the carrier wave cycle, and the third phase increases or decreases the pulse width in a direction opposite to the one direction with reference to the arbitrary phase of the carrier wave cycle.

4. The motor control device according to claim **1**, wherein

the magnetic flux estimation unit estimates the magnetic flux interlinkage by performing time integration based on a motor current value obtained by converting the three-phase AC motor current into a two-phase AC motor current, an output voltage command obtained by converting a DC component output voltage command into a two-phase AC component, and a coil resistance value of the motor.

5. The motor control device according to claim **4**, wherein

the magnetic flux estimation unit estimates the magnetic flux interlinkage by performing time integration on a value computed from the output voltage command converted into two phases, the two-phase AC current of the motor, and the coil resistance value of the motor with a double integrator.

6. The motor control device according to any one of claims **1** to **5**, wherein

the magnetic flux estimation unit compensates a position estimation error that increases or decreases due to a load torque generated at a motor angle computed from the estimated magnetic flus, using a torque angle computed from a q-axis inductance Lq, a d-axis inductance Ld, a q-axis current Iq, a d-axis current Id, and a magnetic flux of a magnet Φ.

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