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(54) **ELECTRIC MOTOR**

(71) Applicant: **KABUSHIKI KAISHA TOYOTA JIDOSHOKKI**, Aichi-ken (JP)

(72) Inventors: **Masashi Kubota**, Kariya (JP); **Takuya Naruse**, Kariya (JP); **Takashi Kawashima**, Kariya (JP)

(73) Assignee: **KABUSHIKI KAISHA TOYOTA JIDOSHOKKI**, Aichi-Ken (JP)

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H02P 21/18 (2016.01)

(52) **U.S. Cl.**
CPC ***H02P 21/18*** (2016.02)

(58) **Field of Classification Search**
CPC H02P 21/18
USPC 318/400.02, 400.01, 700
See application file for complete search history.

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Primary Examiner — David Luo
(74) *Attorney, Agent, or Firm* — GREENBLUM & BERNSTEIN, P.L.C.

(57) **ABSTRACT**

An electric motor includes processing circuitry. The processing circuitry estimates the position of a rotor in a mode selected from an induced voltage mode and a harmonic superimposition mode. The induced voltage mode is a mode of estimating the position of the rotor based on an induced voltage that is generated in three-phase coils. The harmonic superimposition mode is a mode of estimating the position of the rotor by superimposing a harmonic on a command value. The processing circuitry estimates the position of the rotor using the induced voltage mode when the output voltage is greater than or equal to a predetermined threshold value and estimates the position of the rotor using the harmonic superimposition mode when the output voltage is less than the threshold value.

3 Claims, 3 Drawing Sheets

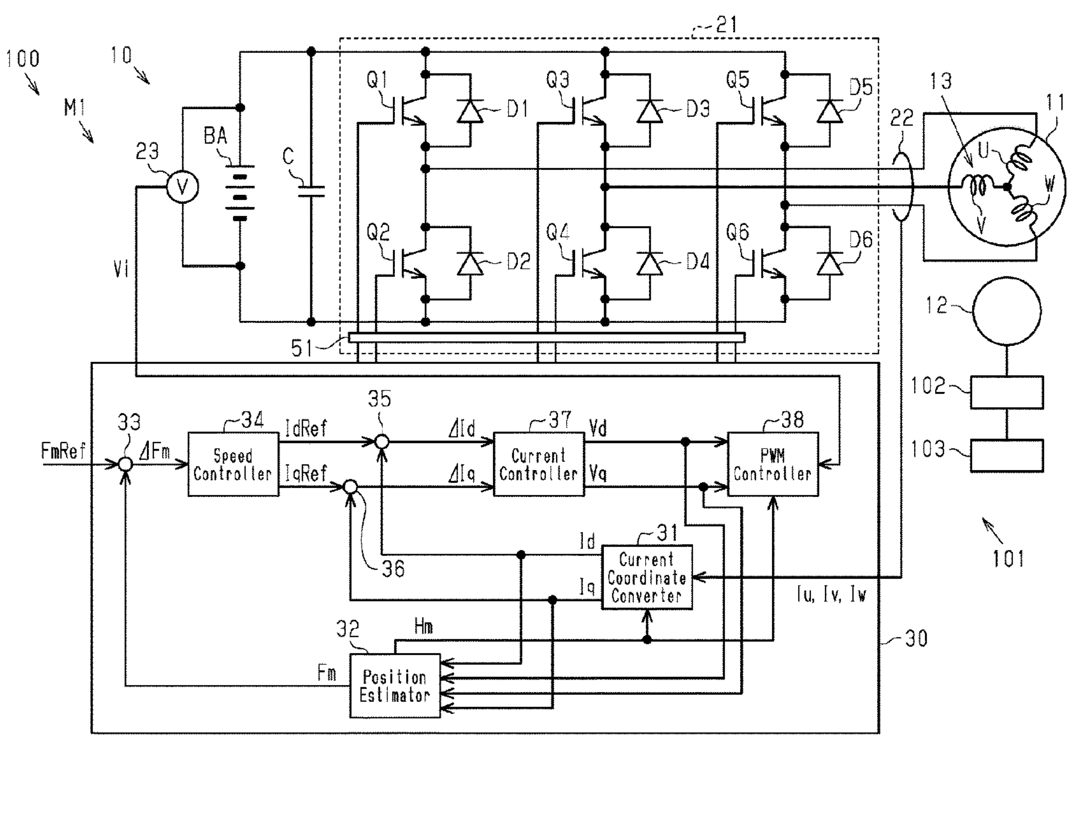


Fig.1

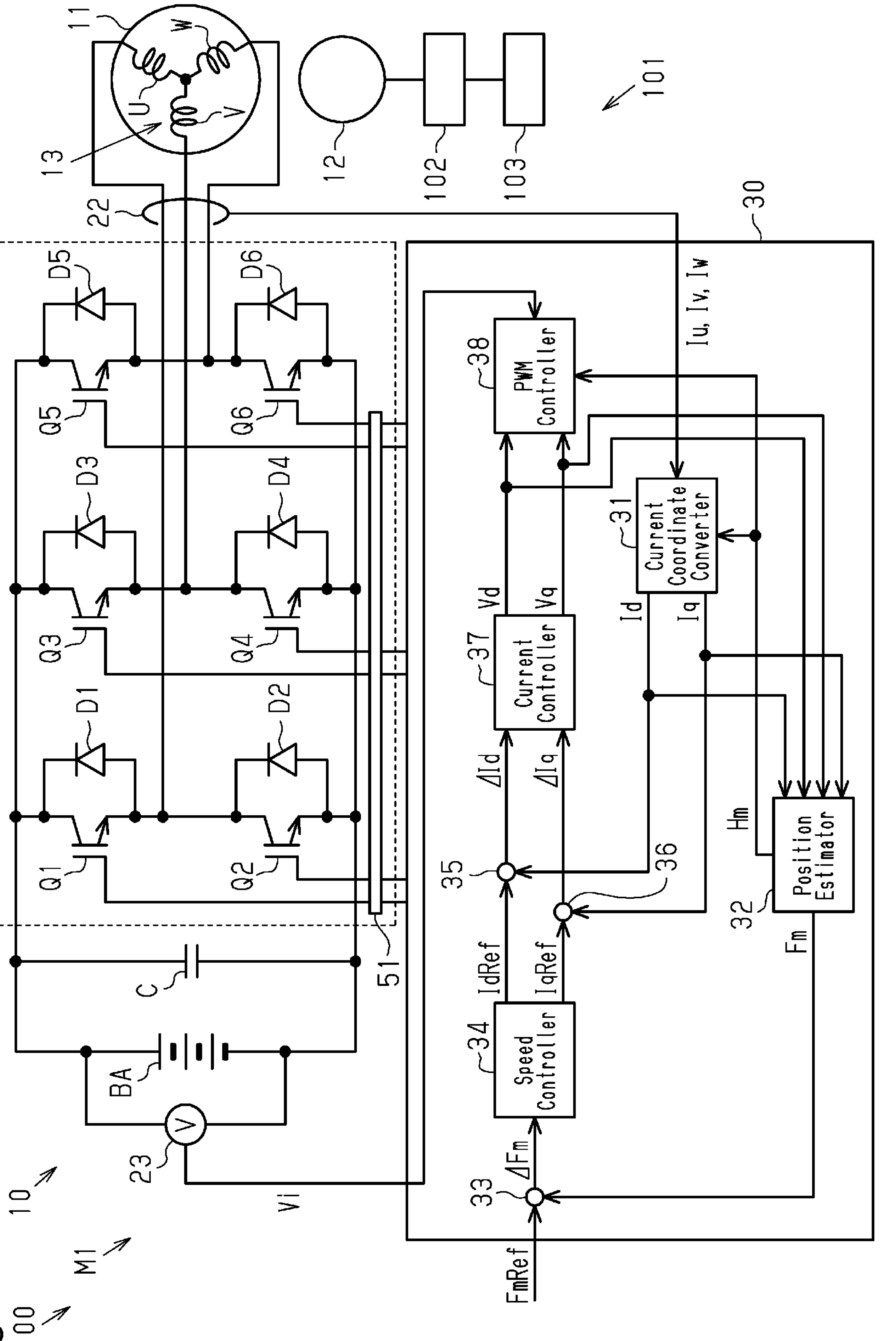

100
M1
10
11
12
13
U
V
W
101
102
103
21
22
23
30
31
Current Coordinate Converter
32
Position Estimator
33
34
Speed Controller
35
36
37
Current Controller
38
PWM Controller
51
Q1
Q2
Q3
Q4
Q5
Q6
D1
D2
D3
D4
D5
D6
C
BA
V
Vi
Iu, Iv, Iw
Id
Iq
Vd
Vq
ΔId
ΔIq
IdRef
IqRef
ΔFm
FmRef
Fm
Hm

Fig.2

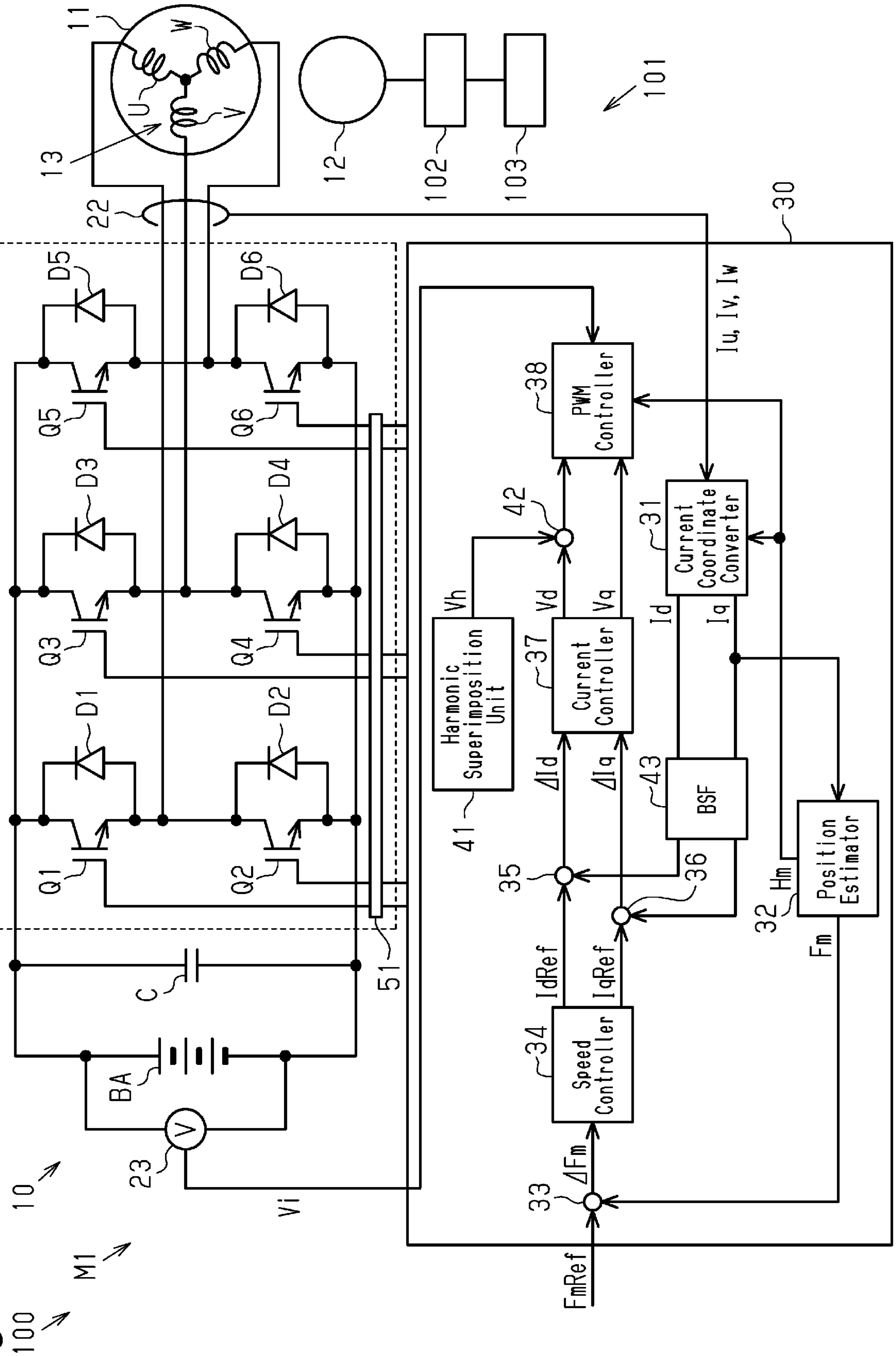

100
M1
10
11
U
V
W
13
12
102
103
101
22
21
D1
D2
D3
D4
D5
D6
Q1
Q2
Q3
Q4
Q5
Q6
C
BA
23
V
Vi
51
30
Iu, Iv, Iw
38
PWM Controller
42
31
Current Coordinate Converter
Vh
Vd
Vq
Id
Iq
37
Current Controller
41
Harmonic Superimposition Unit
ΔId
ΔIq
43
BSF
35
36
32
Hm
Position Estimator
Fm
IdRef
IqRef
34
Speed Controller
ΔFm
33
FmRef

Fig.3

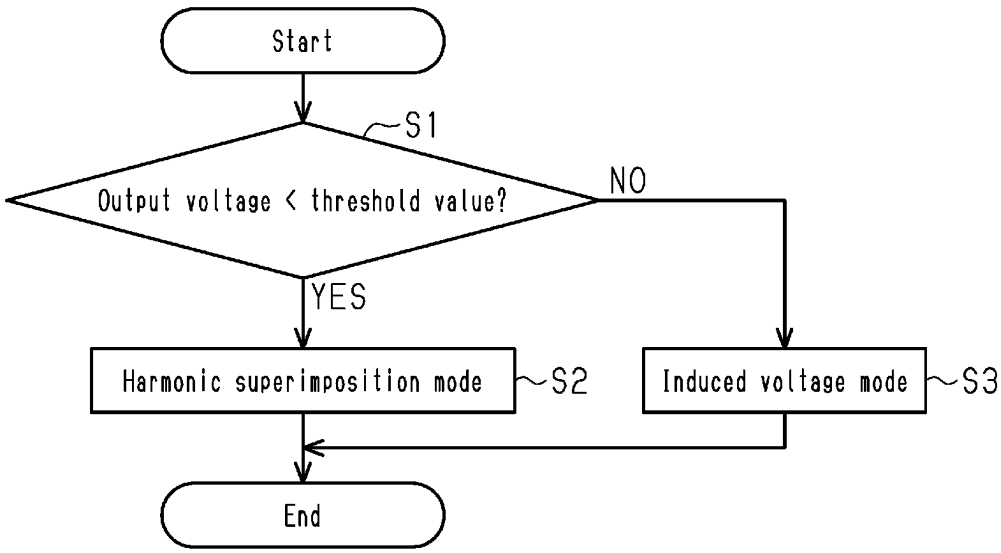
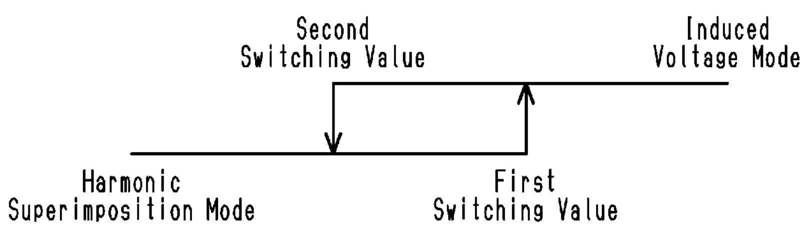

Start
S1
Output voltage < threshold value?
NO
YES
Harmonic superimposition mode
S2
Induced voltage mode
S3
End

Fig.4


Second
Switching Value
Induced
Voltage Mode
Harmonic
Superimposition Mode
First
Switching Value

ELECTRIC MOTOR

BACKGROUND

1. Field

The present disclosure relates to an electric motor.

2. Description of Related Art

When a motor unit is driven through sensorless control of an inverter unit, a controller needs to estimate the position of a rotor of the motor unit. Sensorless control is a control mode of estimating the position of a rotor using software to drive the motor unit without using a hardware position sensor. The mode of estimating the position of a rotor is, for example, an induced voltage mode or a harmonic superimposition mode. The induced voltage mode uses an induced voltage generated by driving of the motor unit to estimate the position of the rotor. The harmonic superimposition mode estimates the position of the rotor by superimposing a harmonic component on a voltage command value or a current command value for the motor unit.

As the speed of the motor unit decreases, the induced voltage decreases. Thus, in the case of using the induced voltage mode, the accuracy of estimating the position of the rotor is reduced when the speed of the motor unit is relatively low. Japanese Laid-Open Patent Publication No. 2011-172324 discloses a controller that estimates the position of a rotor using the harmonic superimposition mode when the speed of the motor unit is lower than a threshold value. This limits situations in which the accuracy of position estimation is reduced when the speed of the motor unit is lower than the threshold value.

The controller disclosed in the above publication switches the mode of estimating the position of the rotor depending on the speed of the motor unit. However, the induced voltage also changes depending on the temperature of the motor and the tolerance of magnets included in the motor unit. Thus, the threshold value needs to be set to be relatively large by taking into account variations in the induced voltage that would result from these factors. This increases a speed range in which the position of the rotor is estimated using the harmonic superimposition mode. When the position of the rotor is estimated using the harmonic superimposition mode, the quietness of the motor unit may be lowered by superimposing a harmonic on the voltage command value or the current command value. Further, the generation of a harmonic current may lower the efficiency of the motor unit. Thus, it is preferred that the speed range in which the position of the rotor is estimated using the harmonic superimposition mode be as narrow as possible.

SUMMARY

This Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key characteristics or essential characteristics of the claimed subject matter, nor is it intended to be used as an aid in determining the scope of the claimed subject matter.

An electric motor according to an aspect of the present disclosure includes a motor unit including a rotor, a stator, and three-phase coils wound around the stator, an inverter unit including a driver and a switching element driven by the driver, the inverter unit being configured to drive the motor unit when the switching element is driven, an output voltage detector configured to detect an output voltage of the inverter unit, and processing circuitry configured to calculate command values and control the switching element, the command values being used to control the switching element. The processing circuitry is configured to estimate the position of the rotor in a mode selected from an induced voltage mode and a harmonic superimposition mode. The induced voltage mode is a mode of estimating the position of the rotor based on an induced voltage that is generated in the three-phase coils. The harmonic superimposition mode is a mode of estimating the position of the rotor by superimposing a harmonic on each of the command values. The processing circuitry is configured to estimate the position of the rotor using the induced voltage mode when the output voltage is greater than or equal to a predetermined threshold value and estimate the position of the rotor using the harmonic superimposition mode when the output voltage is less than the threshold value.

Other features and aspects will be apparent from the following detailed description, the drawings, and the claims.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a schematic diagram of an electric motor.

FIG. **2** is a schematic diagram of the electric motor.

FIG. **3** is a flowchart showing control executed by the processing circuitry.

FIG. **4** is a diagram showing threshold values used in the control of FIG. **3**.

Throughout the drawings and the detailed description, the same reference numerals refer to the same elements. The drawings may not be to scale, and the relative size, proportions, and depiction of elements in the drawings may be exaggerated for clarity, illustration, and convenience.

DETAILED DESCRIPTION

This description provides a comprehensive understanding of the modes, apparatuses, and/or systems described. Modifications and equivalents of the modes, apparatuses, and/or systems described are apparent to one of ordinary skill in the art. Sequences of operations are exemplary, and may be changed as apparent to one of ordinary skill in the art, with the exception of operations necessarily occurring in a certain order. Descriptions of functions and constructions that are well known to one of ordinary skill in the art may be omitted.

Exemplary embodiments may have different forms, and are not limited to the examples described. However, the examples described are thorough and complete, and convey the full scope of the disclosure to one of ordinary skill in the art.

In this specification, “at least one of A and B” should be understood to mean “only A, only B, or both A and B.”

An electric motor according to an embodiment will now be described.

As shown in FIG. **1**, a vehicle air conditioner **100** includes a motor-driven compressor **101** and a refrigerant circuit **103**. The motor-driven compressor **101** includes a compression unit **102** and an electric motor M**1**. The motor-driven compressor **101** compresses refrigerant. The refrigerant circuit **103** includes, for example, a heat exchanger and an expansion valve. The motor-driven compressor **101** compresses the refrigerant, and the refrigerant circuit **103** performs heat exchange of the refrigerant and expands the refrigerant. This allows the vehicle air conditioner **100** to cool or warm the passenger compartment. The motor-driven compressor **101** discharges oil together with the compressed refrigerant.

The compression unit **102** compresses refrigerant. The refrigerant compressed by the compression unit **102** is discharged to the refrigerant circuit **103**. The compression unit **102** may be of any type, such as a scroll type, a piston type, or a vane type.

Electric Motor

The electric motor M**1** includes a motor unit **11**. The motor unit **11** includes a rotor **12** and a stator **13** around which three-phase coils U, V, W are wound. The motor unit **11** is a three-phase motor including three coils U, V, W. The motor unit **11** drives the compression unit **102**.

The electric motor M**1** includes a motor driving device **10**. The motor driving device **10** includes a battery BA, a smoothing capacitor C, an inverter unit **21**, a phase current detector **22**, an input voltage detector **23**, and a controller **30**.

The inverter unit **21** includes six switching elements Q**1** to Q**6**, diodes D**1** to D**6**, and a driver **51**. The switching elements Q**1** to Q**6** are, for example, insulated-gate bipolar transistors (IGBTs). When the switching elements Q**1** to Q**6** are integrated with the diodes D**1** to D**6**, the switching elements Q**1** to Q**6** are metal-oxide-semiconductor field-effect transistors (MOSFETs). The switching element Q**1** and the switching element Q**2** are connected in series. The switching element Q**3** and the switching element Q**4** are connected in series. The switching element Q**5** and the switching element Q**6** are connected in series. The diodes Q**1** to Q**6** are connected in parallel to the switching elements D**1** to D**6**, respectively. The switching elements Q**1** to Q**6** are connected to the battery BA via the smoothing capacitor C.

A connection line that connects the switching element Q**1** to the switching element Q**2** is branched and connected to the coil U. A connection line that connects the switching element Q**3** to the switching element Q**4** is branched and connected to the coil V. A connection line that connects the switching element Q**5** to the switching element Q**6** is branched and connected to the coil W.

The driver **51** drives the switching elements Q**1** to Q**6**. The driving of the switching elements Q**1** to Q**6** drives the motor unit **11**. Driving the switching elements Q**1** to Q**6** refers to switching operations of the switching elements Q**1** to Q**6**, that is, switching between on and off states of the switching elements Q**1** to Q**6**.

The battery BA is a power storage device capable of being charged and discharged. The rated voltage of the battery BA is, for example, 800V.

The phase current detector **22** detects the phase current flowing through the motor unit **11**. The phase current detector **22** detects phase currents of at least two phases. In the present embodiment, the phase current detector **22** detects a u-phase current Iu, a v-phase current Iv, and a w-phase current Iw. The phase currents of two of the three phases may be detected to calculate the phase current of the other one of the three phases from the two-phase currents. The u-phase current Iu, the v-phase current Iv, and the w-phase current Iw flow through their respective phases of the motor unit **11**.

The input voltage detector **23** detects an input voltage Vi that is received by the inverter unit **21** from the battery BA.

Controller

The controller **30** includes a processor and a memory. The processor is, for example, a central processing unit (CPU), a graphics processing unit (GPU), or a digital signal processor (DSP). The memory includes a random access memory (RAM) and a read-only memory (ROM). The memory stores program codes or instructions configured to cause the processor to execute processes. The memory, or a computer-readable medium, includes any type of media that is accessible by general-purpose computers or dedicated computers. The controller **30** may include a hardware circuit such as an application-specific integrated circuit (ASIC) and a field-programmable gate array (FPGA). The controller **30**, which is processing circuitry, may include one or more processors that run according to a computer program, one or more hardware circuits (e.g., ASIC or FPGA), or a combination thereof.

The controller **30** calculates command values. The controller **30** uses the command values to control the switching elements Q**1** to Q**6**. The controller **30** controls the inverter unit **21** through sensorless control. The sensorless control is a mode of controlling the inverter unit **21** without using a hardware position sensor that detects a position Hm of the rotor **12** of the motor unit **11**. The inverter unit **21** is controlled to drive the motor unit **11**. The controller **30** controls the inverter unit **21** while switching between position estimation using an induced voltage mode and position estimation using a harmonic superimposition mode. The induced voltage mode estimates the position Hm of the rotor **12** based on the induced voltage generated in the three-phase coils U, V, W. The harmonic superimposition mode is a mode of estimating the position Hm of the rotor **12** by superimposing a harmonic on a command values.

Position Estimation Using Induced Voltage Mode

The function of the controller **30** in the case of performing position estimation using the induced voltage mode will now be described. The controller **30** includes a current coordinate converter **31**, a position estimator **32**, subtractors **33**, **35**, **36**, a speed controller **34**, a current controller **37**, and a PWM controller **38**.

The current coordinate converter **31** converts the phase currents Iu, Iv, Iw to a d-axis current Id and a q-axis current Iq, based on the position Hm of the rotor **12** estimated by the position estimator **32**. For example, the current coordinate converter **31** converts the phase currents Iu, Iv, Iw of a three-phase (U, V, W) fixed coordinate system into currents Iα, Iβ of a two-phase (α, β) fixed coordinate system. The current coordinate converter **31** uses the position Hm to convert the currents Iα, Iβ into the d-axis current Id and the q-axis current Iq in a two-phase (d, q) rotation coordinate system. The d-axis and the q-axis are coordinate axes in a dq coordinate system. The dq coordinate system is a coordinate system that rotates together with the rotor **12** of the motor unit **11**. The current coordinate converter **31** may directly convert the phase currents Iu, Iv, Iw into the d-axis current Id and the q-axis current Iq, without converting them into the currents Iα, Iβ.

The position estimator **32** estimates the position Hm of the rotor **12** of the motor unit **11** based on the d-axis current Id and the q-axis current Iq output from the current coordinate converter **31** and based on a d-axis voltage command value Vd and a q-axis voltage command value Vq output from the current controller **37**. For example, the position estimator **32** uses the d-axis current Id and q-axis current Iq, the d-axis voltage command value Vd and q-axis voltage command value Vq, which are obtained from the current controller **37**, and a constant defined by the motor unit **11** to calculate induced voltages produced in the coils U, V, W. Then, the position estimator **32** estimates the position Hm based on the induced voltage. Further, the position estimator **32** estimates a rotation speed Fm of the rotor **12** based on the induced voltage.

The subtractor **33** calculates a difference ΔFm between the rotation speed Fm, which has been estimated by the position estimator **32**, and a rotation speed command value FmRef. The controller **30** receives the rotation speed command value FmRef from an external device. The controller **30** receives the rotation speed command value FmRef from, for example, an upper-rank control device for a vehicle.

The speed controller **34** uses the difference ΔFm to calculate the d-axis current command value IdRef and the q-axis current command value IqRef. For example, the speed controller **34** uses feedback control to calculate the d-axis current command value IdRef and the q-axis current command value IqRef such that the difference ΔFm converges to zero. The feedback control is, for example, a proportional-integral control.

The subtractor **35** calculates a difference ΔId between the d-axis current command value IdRef and the d-axis current Id. The subtractor **36** calculates a difference ΔIq between the q-axis current command value IqRef and the q-axis current Iq.

The current controller **37** uses the difference ΔId to calculate the d-axis voltage command value Vd. The current controller **37** uses the difference ΔIq to calculate the q-axis voltage command value Vq. The current controller **37** calculates the d-axis voltage command value Vd and the q-axis voltage command value Vq using, for example, feedback control such that the difference ΔId and the difference ΔIq converge to zero. The feedback control is, for example, a proportional-integral control.

The PWM controller **38** converts the d-axis voltage command value Vd and the q-axis voltage command value Vq into a u-phase voltage command value Vu, a v-phase voltage command value Vv, and a w-phase voltage command value Vw based on the position Hm of the rotor **12**, which has been estimated by the position estimator **32**, and the input voltage Vi. For example, the PWM controller **38** converts the d-axis voltage command value Vd and the q-axis voltage command value Vq from the dq coordinate system into voltage command values Vα, Vβ in a αβ coordinate system. The PWM controller **38** converts the two-phase voltage command values Vα, Vβ into three-phase voltage command values Vu, Vv, Vw. The PWM controller **38** may directly convert the d-axis voltage command value Vd and the q-axis voltage command value Vq into the voltage command values Vu, Vv, Vw, without converting them into the voltage command values Vα, Vβ.

The voltage command values Vu, Vv, Vw are used to control the inverter unit **21**. Specifically, the PWM controller **38** generates a PWM signal based on the voltage command values Vu, Vv, Vw and a carrier frequency, and controls the switching elements Q**1** to Q**6** using the PWM signal.

Position Estimation Using Harmonic Superimposition Mode

The function of the controller **30** in the case of performing position estimation using the harmonic superimposition mode will now be described.

As shown in FIG. **2**, the controller **30** includes the current coordinate converter **31**, the position estimator **32**, the subtractors **33**, **35**, **36**, the speed controller **34**, the current controller **37**, the PWM controller **38**, a harmonic superimposition unit **41**, an adder **42**, and a band-stop filter **43**. The current coordinate converter **31**, the subtractors **33**, **35**, **36**, the speed controller **34**, the current controller **37**, and the PWM controller **38** have the same functions as those in the case of the induced voltage mode, and thus will not be described. The harmonic superimposition unit **41** generates a harmonic Vh. The harmonic Vh is defined by Va*cos 2πft. Here, Va is the amplitude of the harmonic Vh, and f is the frequency of the harmonic Vh. The frequency f is, for example, a frequency that does not depend on the rotation of the motor unit **11**.

The adder **42** adds the harmonic Vh, which has been generated by the harmonic superimposition unit **41**, to the d-axis voltage command value Vd. This causes the harmonic Vh to be superimposed on the d-axis voltage command value Vd.

In the present embodiment, the controller **30** superimposes the harmonic Vh on only the d-axis voltage command value Vd in the harmonic superimposition mode. The controller **30** may cause the position estimator **32** to estimate the position of the rotor **12** by superimposing the harmonic Vh on the d-axis voltage command value Vd and the q-axis voltage command value Vq. Instead, the controller **30** may cause the position estimator **32** to estimate the position of the rotor **12** by superimposing the harmonic Vh on the d-axis current command value IdRef and the q-axis current command value IqRef. Alternatively, the controller **30** may cause the position estimator **32** to estimate the position of the rotor **12** by superimposing the harmonic Vh on only the three-phase voltage command values Vu, Vv, Vw.

The band-stop filter **43** removes frequency components in a specific band from the d-axis current Id and the q-axis current Iq. When the harmonic superimposition unit **41** superimposes the harmonic Vh on the d-axis voltage command value Vd, a frequency component of the harmonic Vh is included in the d-axis current Id and the q-axis current Iq. The band-stop filter **43** removes this frequency component.

The position estimator **32** estimates the position Hm of the rotor **12** and the rotation speed Fm of the rotor **12** from the q-axis current Iq calculated by the current coordinate converter **31**. When the harmonic Vh is superimposed on the d-axis voltage command value Vd, the q-axis current Iq includes a current harmonic that is based on the harmonic Vh. The position estimator **32** estimates the position Hm of the rotor **12** and the rotation speed Fm of the rotor **12** from the current harmonic included in the q-axis current Iq and from an expression model of the motor unit **11**. For example, the position estimator **32** calculates an axis error Mc from the current harmonic. The axis error Mc is the difference between an actual position Hm of the rotor **12** and the position Hm of the rotor **12** that is recognized by the controller **30**. The position estimator **32** estimates the position Hm of the rotor **12** and the rotation speed Fm of the rotor **12** such that the axis error Mc becomes zero.

Control Performed by Controller and Operation of Present Embodiment

The controller **30** switches between the position estimation using the induced voltage mode and the position estimation using the harmonic superimposition mode by performing the following control. The following control is repeatedly executed in a predetermined control cycle during driving of the motor unit **11**.

As shown in FIG. **3**, in step S**1**, the controller **30** determines whether an output voltage Vo of the inverter unit **21** is less than a threshold value. The threshold value is a predetermined value. The output voltage Vo of the inverter unit **21** is a voltage that is received by the motor unit **11**. In the present embodiment, the output voltage Vo of the inverter unit **21** is a combined value of the d-axis voltage command value Vd and the q-axis voltage command value Vq. The output voltage Vo of the inverter unit **21** is calculated from the following equation (1). The controller **30**, which detects the output voltage Vo of the inverter unit **21**, serves as an output voltage detector.

$$Vo=\sqrt{Vd^2+Vq^2} \quad (1)$$

As indicated in the following equation (2), the output voltage Vo of the inverter unit **21** is correlated with the induced voltage generated in the motor unit **11**.

$$\begin{bmatrix} Vd \\ Vq \end{bmatrix} = \begin{bmatrix} R+pLd & -\omega Lq \\ \omega Ld & R+pLq \end{bmatrix} \begin{bmatrix} Id \\ Iq \end{bmatrix} + \begin{bmatrix} 0 \\ e \end{bmatrix} \quad (2)$$

Here, R represents a phase resistance, Ld represents a d-axis inductance, Lq represents a q-axis inductance, co represents an angular velocity, e represents an induced voltage, and p represents a differential term. R, Ld, and Lq are smaller than e. Thus, the output voltage Vo is proportional to the induced voltage. That is, when the output voltage Vo is set to the threshold value, the induced voltage is set to the threshold value.

When the position of the rotor **12** is estimated using the induced voltage mode, the position estimation accuracy decreases as the output voltage Vo decreases. The threshold value is set based on the output voltage Vo that is obtained when the reduction in the position estimation accuracy exceeds an allowable range. That is, when the reduction in the position estimation accuracy of the induced voltage mode exceeds the allowable range, the threshold value is set such that the position estimation using the harmonic superimposition mode is performed.

When the determination result of step S**1** is affirmative, the controller **30** performs the process of step S**2**. When the determination result of step S**1** is negative, the controller **30** performs the process of step S**3**.

In step S**2**, the controller **30** estimates the position Hm of the rotor **12** using the harmonic superimposition mode. The controller **30** uses the harmonic superimposition mode to estimate the rotation speed Fm of the rotor **12**. When the output voltage Vo is less than the threshold value, the controller **30** causes the position estimator **32** to estimate the position Hm of the rotor **12** using the harmonic superimposition mode.

In step S**3**, the controller **30** estimates the position Hm of the rotor **12** using the induced voltage mode. The controller **30** uses the induced voltage mode to estimate the rotation speed Fm of the rotor **12**. When the output voltage Vo is greater than or equal to the threshold value, the controller **30** causes the position estimator **32** to estimate the position Hm of the rotor **12** through the induced voltage mode.

As shown in FIG. **4**, a hysteresis is set for the threshold value. The threshold value includes a first switching value and a second switching value. The second switching value is less than the first switching value. The first switching value is a first threshold value. The second switching value is a second threshold value. The threshold value for the controller **30** to estimate the position Hm of the rotor **12** using the harmonic superimposition mode is the first switching value. The threshold value for the controller **30** to estimate the position Hm of the rotor **12** using the induced voltage mode is the second switching value. The controller **30** uses the first switching value to switch from the harmonic superimposition mode to the induced voltage mode. The controller **30** uses the second switching value to switch from the induced voltage mode to the harmonic superimposition mode.

ADVANTAGES OF PRESENT EMBODIMENT

(1) When the output voltage Vo of the inverter unit **21** is less than the threshold value, the controller **30** causes the position estimator **32** to estimate the position Hm of the rotor **12** using the harmonic superimposition mode. The output voltage Vo of the inverter unit **21** is correlated with the induced voltage generated in the motor unit **11**. When the output voltage Vo of the inverter unit **21** is set to the threshold value, there is no need to set a threshold value by taking into account variations in the induced voltage that would result from the temperature of the motor unit **11**. This limits an increase in the speed range in which the position Hm of the rotor **12** is estimated using the harmonic superimposition mode.

(2) When the output voltage Vo of the inverter unit **21** is greater than or equal to the threshold value, the controller **30** causes the position estimator **32** to estimate the position Hm of the rotor **12** using the induced voltage mode. In the harmonic superimposition mode, the superimposition of the harmonic Vh may deteriorate the quietness of the motor unit **11**. In addition, the generation of a current harmonic may lower the efficiency of the motor unit **11**. When the output voltage Vo is greater than or equal to the threshold value, the position Hm of the rotor **12** is estimated using the induced voltage mode. This limits the deterioration of the quietness of the motor unit **11**. This also limits a decrease in the efficiency of the motor unit **11**.

(3) A hysteresis is set for the threshold value. If the threshold value were to set to a single predetermined value, when the output voltage Vo fluctuates across the threshold value, the harmonic superimposition mode and the induced voltage mode may be often switched. If the harmonic superimposition mode and the induced voltage mode are often switched, the stability of the control may be adversely affected during the switching. By setting a hysteresis for the threshold value, the harmonic superimposition mode and the induced voltage mode will be switched less frequently.

(4) The electric motor M**1** is used in the motor-driven compressor **101**. Depending on the capacity of the motor-driven compressor **101**, the motor-driven compressor **101** may be driven while the motor unit **11** switches between on and off states when the load on the motor unit **11** is relatively low. In this case, there may be a risk that the oil discharged with the refrigerant does not circulate, leading to an oil shortage inside the motor-driven compressor **101**. To prevent the motor unit **11** from switching between on and off states when the load is relatively low, the minimum rotation speed of the motor-driven compressor **101** needs to be lowered. The reduction in the minimum rotation speed of the motor-driven compressor **101** widens the speed range in which the position Hm of the rotor **12** needs to be estimated using the harmonic superimposition mode. In the electric motor M**1** of the present embodiment, the threshold value set for the output voltage Vo is prevented from becoming excessively high. The electric motor M**1** is used in the motor-driven compressor **101**. Thus, even if the minimum rotation speed of the motor-driven compressor **101** is reduced, an excessive increase is prevented in the speed range in which the position Hm of the rotor **12** needs to be estimated using the harmonic superimposition mode.

Modifications

The present embodiment may be modified as follows. The present embodiment and the following modifications can be combined as long as the combined modifications remain technically consistent with each other.

A hysteresis does not need to be set for the threshold value.

The output voltage Vo that is set to the threshold value may be a q-axis voltage command value Vq that includes an induced voltage term.

The output voltage Vo that is set to the threshold value may be an actual voltage output from the inverter unit **21**.

The electric motor M**1** may be mounted on any device. The electric motor M**1** may be used as, for example, a drive source for an air pump or a hydrogen pump that is mounted on a fuel cell electric vehicle.

Various changes in form and details may be made to the examples above without departing from the spirit and scope of the claims and their equivalents. The examples are for the sake of description only, and not for purposes of limitation. Descriptions of features in each example are to be considered as being applicable to similar features or aspects in other examples. Suitable results may be achieved if sequences are performed in a different order, and/or if components in a described system, architecture, device, or circuit are combined differently, and/or replaced or supplemented by other components or their equivalents. The scope of the disclosure is not defined by the detailed description, but by the claims and their equivalents. All variations within the scope of the claims and their equivalents are included in the disclosure.

The invention claimed is:

1. An electric motor, comprising:

a motor unit including a rotor, a stator, and three-phase coils wound around the stator;

an inverter unit including a driver and a switching element driven by the driver, the inverter unit being configured to drive the motor unit when the switching element is driven;

an output voltage detector configured to detect an output voltage of the inverter unit; and

processing circuitry configured to calculate command values and control the switching element, the command values being used to control the switching element, wherein

the processing circuitry is configured to estimate the position of the rotor in a mode selected from an induced voltage mode and a harmonic superimposition mode,

the induced voltage mode is a mode of estimating the position of the rotor based on an induced voltage that is generated in the three-phase coils,

the harmonic superimposition mode is a mode of estimating the position of the rotor by superimposing a harmonic on each of the command values, and

the processing circuitry is configured to:

estimate the position of the rotor using the induced voltage mode when the output voltage is greater than or equal to a predetermined threshold value; and

estimate the position of the rotor using the harmonic superimposition mode when the output voltage is less than the threshold value.

2. The electric motor according to claim **1**, wherein the processing circuitry is configured to:

estimate a rotation speed of the rotor;

convert a phase current into a d-axis current and a q-axis current based on the position of the rotor;

calculate a d-axis current command value and a q-axis current command value based on a difference between the rotation speed and a rotation speed command value, the rotation speed command value being received from an external device;

calculate a d-axis voltage command value based on a difference between the d-axis current and the d-axis current command value;

calculate a q-axis voltage command value based on a difference between the q-axis current and the q-axis current command value;

calculate three-phase voltage command values of three phases based on the d-axis voltage command value and the q-axis voltage command value; and

in the harmonic superimposition mode, estimate the position of the rotor by superimposing a harmonic on only the d-axis voltage command value, on the d-axis voltage command value and the q-axis voltage command value, on the d-axis current command value and the q-axis current command value, or on only the three-phase voltage command values.

3. The electric motor according to claim **1**, wherein

the threshold value includes a first threshold value and a second threshold value that is less than the first threshold value, and

the processing circuitry is configured to use the first threshold value for switching from the harmonic superimposition mode to the induced voltage mode and use the second threshold value for switching from the induced voltage mode to the harmonic superimposition mode.

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