phase angle estimator 60 calculates a rotary phase angle estimated value of the electric motor M based on current values detected by the current sensors 80, output voltage target values Vα and Vβ of the inverter circuit INV, and a phase angle estimated value θest.

The rotary phase angle estimator 60 includes an αβ/dq converter 62, an estimated error calculator 64, a PLL calculator 66, a low-pass filter FL1, and an integrator 68.

The αβ/dq converter 62 receives a rotary phase angle estimated value θest from the integrator 68, receives the output voltage target vectors Vα and Vβ of the αβ-axis fixed coordinate system from the gate command generator, and receives current values iα_FBK and iβ_FBK of the αβ-axis fixed coordinate system from the three-phase/αβ converter 50. These vector values are converted into a dq-axis coordinate system, and converted values are outputted. The values outputted from the αβ/dq converter 62 are voltage vectors Vdc and Vqc and current vectors idc and iqc of a dcqc coordinate system including an estimated error Δθ.

The estimated error calculator 64 receives the voltage vectors Vdc and Vqc and the current vectors idc and iqc from the αβ/dq converter 62, and calculates the estimated error Δθ based on these vectors. Calculation equations of the estimated error Δθ will be explained hereinafter.

In the magnet-type synchronous motor, a voltage equation when a rotary phase angle error Δθ is zero, that is, when actual dq-axes and estimated dcqc-axes match is expressed by a following [Formula 1].

[Mathematical 1]

$$\begin{bmatrix} v_d \\ v_q \end{bmatrix} = \begin{bmatrix} R + pL_d & -\omega_e L_q \\ \omega_e L_d & R + pL_q \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \omega_e \begin{bmatrix} 0 \\ \Psi_d \end{bmatrix} \qquad \text{[Formula 1]}$$

In the above-mentioned [Formula 1], vd, vq: dq-axes voltages, id, iq: dq-axes currents, R: coil resistance of the electric motor, ωe: electric angle angular velocity, Ld, Lq: dq-axis inductance, p: differential operator (=d/dt).

To modify [Formula 1] by converting [Formula 1] into a dcqc-axes coordinate system which is an estimated coordinate system into the form of an extended induced voltage equation, [Formula 2] to [Formula 4] are obtained.

[Mathematical 2]

rotational speed estimated value ωest, and outputs a multiplied value to the multiplier 72.

The multiplier 72 multiplies a calculated result obtained by the multiplier 71 by a d-axis inductance set value L_{d_FF} and outputs a multiplied value to the subtractor 73 as a q-axis voltage set value V_{q_FF}.

The subtractor 73 subtracts a q-axis voltage set value V_{q_FF} from a q-axis voltage Vqc, and outputs a value obtained by subtraction as a voltage difference ΔVq_NS.

The filter FL2 is a low pass filter, for example, and outputs the voltage difference ΔVq_NS outputted from the subtractor 73 in a state where a high-frequency component contained in the voltage difference ΔVq_NS is removed.

The selector 74 determines whether or not the voltage difference ΔVq_NS outputted from the filter FL2 is zero or more, and outputs a value corresponding to a determination result. That is, the selector 74 sets an output value to "0" when the voltage difference ΔVq_NS is zero or more, and sets the output value to "1" when the voltage difference ΔVq_NS is less than zero.

The selector 75 outputs a correction value θNS based on a value outputted from the selector 74. That is, the selector 75 outputs π (180°) as the correction value θNS when the value outputted from the selector 74 is "1", and outputs 0° as the correction value θNS when the value outputted from the selector 74 is "0".

The correction value θNS outputted from the selector 75 is added to a rotary phase angle estimated value θest' outputted from the rotary phase angle estimator 60 so that the rotary phase angle estimated value θest' is corrected. The corrected rotary phase angle estimated value θest is supplied to the dq/αβ converter 20 and the αβ/dq converter 62 and is used for vector conversion.

FIG. 8 is a view for describing an example of an operation of the inverter control device of the embodiment.

In the inverter control device 1 according to this embodiment, polarity determination is performed in the initial estimation at the time of starting the inverter circuit INV. That is, the calculation of a rotary phase angle estimated value by the rotary phase angle estimator 60 and the magnet magnetic pole determination by the polarity determination part 70 are performed in response to an activation command supplied to the inverter circuit INV. Before starting the inverter circuit INV or before the completion of the initial estimation, the inverter circuit INV is in a stopped state and the electric motor M is in a free run state.

The host controller CTR sets a current command id_ref, iq_ref and a current phase β_ref for supplying a current to the motor, and controls various flags (a current conducting flag (Ion), an initialization flag, an initial estimation

flag, a NS determination calculating flag, an NS determination result reflection flag, a normal control flag). The host controller CTR supplies the initialization flag, the initial estimation flag, the normal control flag and the NS determination calculating flag to the rotary phase angle estimator 60. The host controller CTR supplies the NS determination result reflection flag to the polarity determination part 70. The host controller CTR supplies the current conducting flag (Ion) to the current command generator 10.

When the host controller CTR receives an activation command, the host controller CTR sets an initialization flag to "ON" simultaneously. Subsequently, the host controller CTR sets an initial estimation flag and a current conducting flag (Ion) to "ON" and sets the initialization flag to "OFF".

When the host controller CTR set the initialization flag to "ON", the rotary phase angle estimator 60 performs initialization by setting an estimated rotary phase angle to an initial value and by setting an estimated value of a rotational speed to an initial value. Subsequently, when the host controller CTR sets the initial estimation flag to "ON", the calculation of a rotary phase angle estimated value θest and a rotational speed estimated value ωest is started.

Then, the host controller CTR sets an NS determination calculating flag to "ON". When the host controller CTR sets the NS determination calculating flag to "ON", the polarity determination part 70 calculates a voltage difference ΔVq_NS.

Then, the host controller CTR sets the initial estimation flag and the NS determination calculating flag to "OFF", and sets an NS determination result reflection flag to "ON".

When the host controller CTR sets the NS determination result reflection flag to "ON", the polarity determination part 70 outputs a correction value θNS for a rotation angle corresponding to the value of a voltage difference ΔVq_NS as shown in [Formula 11].

Then, the host controller CTR sets an NS determination result reflection flag to "OFF" and sets an initialization flag to "ON".

When the host controller CTR sets the initialization flag to "ON", the rotary phase angle estimator 60 performs initialization by setting an estimated value of the rotary phase angle and an estimated value of a rotational speed to initial values respectively.

Then, the host controller CTR sets the initialization flag to "OFF" and sets

selector 79 is “0”.

The correction value θNS outputted from the selector 75 is added to a rotary phase angle estimated value θest' outputted from the rotary phase angle estimator 60 so that the rotary phase angle estimated value θest' is corrected. The corrected rotary phase angle estimated value θest is supplied to the dq/αβ converter 20 and the αβ/dq converter 62 and is used for vector conversion.

As described above, according to the inverter control device 1 and the drive system of this embodiment, in the same manner as the previously mentioned first embodiment, also in driving a synchronous motor having a small load magnetic flux, the magnetic pole position can be determined with high accuracy. Further, in the inverter control device 1 and the drive system according to this embodiment, unlike a method of determining a magnetic pole position by making use of a harmonic voltage, polarity determination can be performed with high accuracy even when a rotational speed is increased and hence, there is no possibility that noise occurs.

That is, according to the inverter control device 1 and the drive system of this embodiment, accuracy of a rotary sensorless control of an electric motor can be enhanced.

Next, an inverter control device and a drive system of a third embodiment are described with reference to drawings.

FIG. 12 is a block diagram schematically showing a configuration example of a polarity determination part of the inverter control device of the third embodiment.

The inverter control device 1 of this embodiment differs from the above-mentioned first embodiment and second embodiment with respect to the configuration of a polarity determination part 70.

In this embodiment, the polarity determination part 70 performs polarity determination using a q-axis voltage actual value Vqc, a d-axis current command id_ref, an estimated rotational speed ωest, and an inductance set value L_{d_FF}. In this case, a threshold value setting part Th sets the inductance set value L_{d_FF} such that the inductance set value L_{d_FF} matches an inductance generated when a current is supplied in a +d-axis or an inductance generated when a current is supplied in a -d-axis.

In this case, the polarity determination part 70 calculates an actual d-axis magnetic flux Φ_{d_act} using the above-mentioned [Formula 12]. The polarity determination part 70 calculates a d-axis magnetic flux set value Φ_{d_FF} using the above-mentioned [Formula 13]. The polarity determination part 70 calculates a magnetic flux difference $\Delta\Phi_{d_NS}$ which becomes a reference in polarity determination using the above-mentioned [Formula 14].

In the threshold value setting part Th, for example, assuming the inductance set value L_{d_FF} as an inductance value when a current is supplied in a -d-axis, a relationship between the inductance set value and the magnetic flux difference when a current control is performed with high accuracy is shown in [Formula 15].

[Mathematical 9]

$$\left|\Delta\Phi_{d_NS}\right| = \left|\left(L_d - L_{d_FF}\right)\cdot i_{d_ref}\right| \quad \begin{cases} \geq \text{Threshold value} \cdots (\theta_{NS} = 180\deg) \\ < \text{Threshold value} \cdots (\theta_{NS} = 0\deg) \end{cases} \qquad [\text{Formula 15}]$$

FIG. 13 is a view showing an example of a relationship between a predetermined threshold value and an absolute value of a magnetic flux difference $\Delta\Phi_{d_NS}$.

The polarity determination part 70 determines that polarities (NS) match when an absolute value of the magnetic flux difference $\Delta\Phi_{d_NS}$ is lower than a predetermined threshold value Φd_th at a predetermined timing, and determines that the polarities (NS) are inverted when the absolute value of the magnetic flux difference $\Delta\Phi_{d_NS}$ is equal to or more than the predetermined threshold value Φd_th at the predetermined timing.

In the threshold value setting part Th, in the case where the inductance set value L_{d_FF} is set to an inductance value when a current is supplied in a +d-axis, a determination result opposite to the above-mentioned determination result is obtained. That is, the polarity determination part 70 determines that polarities (NS) are inverted when the absolute value of the magnetic flux difference $\Delta\Phi_{d_NS}$ is lower than the predetermined threshold value, and determines that the polarities (NS) match when the absolute value of the magnetic flux difference $\Delta\Phi_{d_NS}$ is equal to or more than the predetermined threshold value.

The predetermined threshold value Φd_th may be decided corresponding to an inductance difference or voltage detection accuracy when a current is supplied in a ±d-axis. For example, the predetermined threshold value Φd_th may be determined by referencing a table with respect to a supply current.

That is, the polarity determination part 70 of this embodiment includes a divider 76, a multiplier 77, a subtractor 78, a threshold value setting part Th, a filter FL2, an absolute value calculator ABS, and selectors SL, 75.

The divider 76 calculates an actual d-axis magnetic flux Φ_{d_act} by dividing a d-axis voltage actual value Vqc (=ωest·Ld·Idc) by a rotational speed

estimated value ωest, and supplies the actual d-axis magnetic flux Φ_{d_act} to the subtractor 78.

The multiplier 77 calculates a d-axis magnetic flux set value Φ_{d_FF} by multiplying a d-axis current command id_ref and an inductance set value L_{d_FF} to each other, and supplies the d-axis magnetic flux set value Φ_{d_FF} to the subtractor 78.

The subtractor 78 calculates a magnetic flux difference $\Delta\Phi_{d_NS}$ by subtracting a d-axis magnetic flux set value Φ_{d_FF} from an actual d-axis magnetic flux value Φ_{d_act}, and supplies the magnetic flux difference $\Delta\Phi_{d_NS}$ to the filter FL2.

The filter FL2 is a low pass filter, for example, and supplies the magnetic flux difference $\Delta\Phi_{d_NS}$ from which a high frequency component is removed to the absolute value calculator ABS.

The absolute value calculator ABS calculates an absolute value of the magnetic flux difference $\Delta\Phi_{d_NS}$ outputted from the filter FL2, and outputs the absolute value of the magnetic flux difference $\Delta\Phi_{d_NS}$ to the selector SL.

The selector SL compares the absolute value of the magnetic flux difference $\Delta\Phi_{d_NS}$ outputted from the absolute value calculator ABS and a predetermined threshold value Φd_th, determines whether or not the magnetic flux difference $\Delta\Phi_{d_NS}$ is equal to or more than the threshold value Φd_th, and outputs a value corresponding to a determination result. That is, the selector 79 sets an output value to “1” when the magnetic flux difference $\Delta\Phi_{d_NS}$ is equal to or more than the threshold value Φd_th, and sets the output value to “0” when the magnetic flux difference $\Delta\Phi_{d_NS}$ is less than the threshold value Φd_th.

The selector 75 outputs a correction value θNS based on a value outputted from the selector SL. That is, the selector 75 outputs π (180°) as the correction value θNS when the value outputted from the selector SL is “1”, and outputs 0° as the correction value θNS when the value outputted from the selector SL is “0”.

The correction value θNS outputted from the selector 75 is added to a rotary phase angle estimated value θest’ outputted from the rotary phase angle estimator 60 so that the rotary phase angle estimated value θest’ is corrected. The corrected rotary phase angle estimated value θest is supplied to the dq/αβ

synchronism with timing at which a command value of a d-axis current is switched from a negative direction to a positive direction.

FIG. 15 is a block diagram schematically showing another configuration example of a polarity determination part of the inverter control device of the fourth embodiment.

The polarity determination part 70 includes a q-axis voltage difference calculator 710 and a correction value calculator 720. The q-axis voltage difference calculator 710 includes an absolute value calculator 711, trigger output parts 712, 713, a first zero order hold 714, a second zero order hold 715, a subtractor 716, and a filter FL3. The correction value calculator 720 includes selectors 74, 75.

The absolute value calculator 711 calculates an absolute value of a q-axis voltage actual value Vqc, and supplies a calculation result to the first zero order hold 714 and the second zero order hold 715.

The trigger output part 712 outputs a pulse to the first zero order hold 714 in synchronism with timing at which a current phase angle change flag is set to "ON".

Upon receiving a pulse from the trigger output part 712, the first zero order hold 714 holds a value supplied from the absolute value calculator 711 as an output value, and outputs the output value to the subtractor 716.

The trigger output part 713 outputs a pulse to the second zero order hold 715 in synchronism with timing at which the current phase angle change flag is set to "OFF".

Upon receiving a pulse from the trigger output part 713, the second zero order hold 715 holds a value supplied from the absolute value calculator 711 as an output value, and outputs the output value to the subtractor 716.

The subtractor 716 subtracts the value supplied from the second zero order hold 715 from the value supplied from the first zero order hold 714, and supplies a value obtained by the subtraction to the filter FL3. That is, the subtractor 716 outputs a q-axis voltage difference which is obtained by subtracting a q-axis voltage generated when a d-axis current command value changes from positive to negative from a q-axis voltage generated when the d-axis current command value changes from negative to positive.

The filter FL3 is a low pass filter, for example, and outputs a q-axis voltage difference from which a high frequency component is removed to the selector 74.

The selector 74 determines whether or not the q-axis voltage difference outputted from the filter FL3 is equal to or below zero, and outputs a value corresponding to a determination result. That is, the selector 74 sets an output

value to "0" when the q-axis voltage difference is zero or less, and sets the output value to "1" when the q-axis voltage difference is larger than zero.

The selector 75 outputs a correction value θNS based on a value outputted from the selector 74. That is, the selector 75 outputs π (180°) as the correction value θNS when the value outputted from the selector 74 is "1", and outputs 0° as the correction value θNS when the value outputted from the selector 74 is "0".

The correction value θNS outputted from the selector 75 is added to a rotary phase angle estimated value θest' outputted from the rotary phase angle estimator 60 so that the rotary phase angle estimated value θest' is corrected. The corrected rotary phase angle estimated value θest is supplied to the dq/αβ converter 20 and the αβ/dq converter 62 and is used for vector conversion.

FIG. 16 and FIG. 17 are views showing an example of a simulation result of a polarity determination operation performed by the inverter control device of the embodiment. In FIG. 16 and FIG. 17, a simulation result during a period including a period from timing at which the current conducting flag Ion shown in FIG. 8 is set to "ON" to timing at which an NS determination calculation flag is set to "OFF" is shown.

FIG. 16 and FIG. 17 describe an example where the supply of a current starts and the calculation of estimated values of a rotary phase angle and a rotational speed starts at 0 sec, and the initial estimation is completed at 0.1 sec. Further, the calculation of polarity determination is started at a point of time of 0.04 sec.

FIG. 16 shows a simulation result when an actual value and an estimated value of a rotary phase angle are not displaced from each other.

In starting polarity determination, the host controller CTR changes a d-axis current command id_ref from negative to positive and, at the same time, sets an NS determination calculation flag and a current phase angle change flag to "ON". When the current phase angle change flag is set to "ON", an absolute value of a q-axis voltage Vqc is held in the first zero order hold 714 as an output value. When a d-axis current command id_ref changes from negative to positive, an absolute value of a q-axis voltage Vqc is increased.

Next, the host controller CTR changes the d-axis current command id_ref from positive to negative and, at the same time, sets the current phase angle change flag to "OFF". When the current phase angle change flag is set to

CLAIMS

1. An inverter control device comprising:

a current command generator that generates a current command value;

a current detector that detects a current value of an alternating current to be outputted from an inverter circuit to an electric motor;

a gate command generator that generates a gate command to the inverter circuit such that the current command value and the current value detected by the current detector match, and obtains an output voltage target vector of the inverter circuit based on the gate command;

a rotary phase angle estimator that obtains a rotary phase angle estimated value of the electric motor based on the current value detected by the current detector and the output voltage target vector; and

a polarity determination part that, with supply of a current in synchronism with a rotor frequency of the electric motor, performs determination of a magnet magnetic pole of the electric motor using a generated magnetic flux or voltage in synchronism with the generated rotor frequency or both of the magnetic flux and the voltage, and outputs a correction value for the rotary phase angle estimated value based on a result of the determination.

2. The inverter control device according to claim 1, wherein the polarity determination part performs the determination of the magnet magnetic pole of the electric motor based on difference between an actual value of the magnetic flux and a set value of the magnetic flux or based on difference between an actual value of the voltage or a set value of the voltage.

3. The inverter control device according to claim 2, wherein the polarity determination part obtains a set value of the magnetic flux or a set value of the voltage using an inductance set value set within a range between an inductance value when a d-axis current in a positive direction is supplied to the electric motor and an inductance value when a d-axis current in a negative direction is supplied to the electric motor.

4. The inverter control device according to claim 1, wherein the polarity determination part performs the determination of the magnet magnetic pole of the electric motor based on a comparison result between a q-axis voltage value of the electric motor obtained by adding 0° to the rotary phase angle estimated value and a q-axis voltage value of the electric motor obtained by adding 180° to the rotary phase angle estimated value.

5. The inverter control device according to claim 1, wherein the polarity determination part performs the determination of the magnet magnetic pole of the electric motor based on a comparison result between a q-axis voltage value of the electric motor when a current is supplied aiming at a –d-axis direction and a q-axis voltage value of the electric motor when the current is supplied aiming at a +d-axis direction.

6. The inverter control device according to claim 1, wherein calculation of a rotary phase angle estimated value by the rotary phase angle estimator and the determination of the magnet magnetic pole by the polarity determination part are performed in response to an activation command of the inverter circuit.

7. A drive system having magnetic saliency comprising:
the inverter control device according to any one of claims 1 to 6;
a host controller that controls an operation of the inverter control device;
the inverter circuit; and
the electric motor, wherein
the electric motor includes a rotor formed of a magnet or a rotor in which a magnet is embedded.