

An Apparatus for Detecting a Step-Out in a Synchronous Motor,  
a Method for Detecting the Step-Out in the Synchronous Motor,  
a Drive of a Closed Compressor, and  
a Drive of a Fan Motor

Background of the Invention

Field of the Invention

This invention relates to an apparatus and a method for detecting a step-out (out-of-synchronism) in a synchronous motor for driving the synchronous motor without using a positioning sensor for detecting a position of a rotor.

Description of the Related Art

Fig. 9 illustrates a configuration of a general inverter apparatus according to the related art. In Fig. 9, a direct current power supply unit 1, an inverter apparatus 2, a plurality of switching devices 3, a U-phase upper switching device 3a, a V-phase upper switching device 3b, a W-phase upper switching device 3c, a U-phase lower switching device 3d, a V-phase lower switching device 3e, a W-phase lower switching device 3f, a plurality of flywheel diodes 4 connected in parallel to the plurality of switching devices 3, an inverter main circuit 5 including the plurality of switching devices 3 and the plurality of flywheel diodes 4, and a direct current brushless motor 6 are illustrated.

A current detector 7a detects a phase current in one phase among

currents supplied to the direct current brushless motor 6, a current detector 7b detects a phase current in another phase which is different from the phase detected by the current detector 7a, and an inverter controller 8 controls ON / OFF of the switching devices 3 in the inverter main circuit 5 based on phase current values detected by the current detectors 7a and 7b.

A PWM (Pulse Width Modulation) signal generator 9 generates a PWM signal for controlling ON / OFF of the switching devices 3 based on output voltage command values obtained in the inverter controller 8, and a phase current calculator 10 calculates phase current values in three phases based on the phase current values in two phases detected by the current detectors 7a and 7b. A 3-phase to 2-phase converter 11 converts the phase current values in three phases obtained by the phase current calculator to current values in a d-q coordinate system, and a voltage command value calculator 12 obtains output voltage command values in the d-q coordinate system for driving the direct current brushless motor based on the current values in the d-q coordinate system obtained by the 3-phase to 2-phase converter 11. An output voltage vector calculator 13 obtains an output voltage vector based on the output voltage command values in the d-q coordinate system obtained by the voltage command value calculator 12, and a direct current voltage detector 14 detects a direct current voltage of the direct current power supply unit 1. An overcurrent detector 70 detects an overcurrent state of a phase current.

With reference to Fig. 9, an operation in the inverter apparatus and the direct current brushless motor configured as stated above is explained.

As illustrated in Fig. 9, in the inverter apparatus 2, the current detectors 7a and 7b detect the phase currents in two phases among the phase currents supplied to the direct current brushless motor 6. The inverter controller 8 calculates output voltage command values, e.g., voltage value, voltage phase, etc. output by the inverter main circuit 5 for driving the direct current brushless motor 6 based on the detected phase currents in two phases, e.g., U-phase current  $I_u$  and V-phase current  $I_v$ , and outputs the PWM signal for controlling ON / OFF of the switching devices 3 in the inverter main circuit 5.

The PWM signal is output from the inverter controller 8 as follows. The phase current calculator 10 calculates phase currents  $I_u$ ,  $I_v$ , and  $I_w$  in three phases based on the phase currents  $I_u$  and  $I_v$  detected by the current detectors 7a and 7b, and the 3-phase to 2-phase converter converts the phase currents  $I_u$ ,  $I_v$ , and  $I_w$  in three phases to currents  $I_d$  and  $I_q$  in the d-q coordinate system. The voltage command value calculator 12 calculates output voltage command values  $V_d^*$  and  $V_q^*$  in the d-q coordinate system based on the currents  $I_d$  and  $I_q$  in the d-q coordinate system. The output voltage vector calculator 13 calculates output voltage vector  $V_x^*$  based on the output voltage command values  $V_d^*$  and  $V_q^*$  in the d-q coordinate system. The PWM signal generator 9 calculates the PWM signal for controlling ON / OFF of the switching devices 3 based on a direct current voltage  $V_{dc}$  obtained by the direct current voltage detector 14 and the output voltage vector  $V_x^*$ , and outputs the PWM signal.

The switching devices 3 in the inverter main circuit 5 are turned ON / OFF by the PWM signal output by the PWM signal generator 9. By an ON / OFF operation of the switching devices 3, an electric power is supplied from the inverter main circuit 5 to the direct current brushless motor 6, and the direct current brushless motor 6 is driven.

In the inverter apparatus according to the related art, a step-out is detected in a following manner. When the direct current brushless motor 6 steps out, a peak level of a phase current becomes higher than a peak level in a synchronous operation. By monitoring this change in a state, the step-out is detected. For example, an overcurrent detector 70 compares a phase current value with an overcurrent level, when the phase current exceeds the overcurrent level, it is judged as an error due to an overcurrent, and the step-out is detected based on the error due to the overcurrent. The overcurrent detector 70 is configured as a hardware or a software.

Another example of an apparatus for detecting the step-out in the synchronous motor according to the related art is disclosed in Japanese Unexamined Published Patent Application Hei 11 - 18499. In the apparatus for detecting the step-out in the synchronous motor disclosed in Japanese Unexamined Published Patent Application Hei 11 - 18499,  $\gamma$ - $\delta$  axes are set on a rotor in the controller for rotating at an estimated velocity  $\omega_r$ , and a difference  $\theta_e$  between  $\gamma$ - $\delta$  axes and d-q axes on the rotor is calculated. It discloses an example of providing a state estimator for estimating  $\gamma$  axis induced voltage and  $\delta$  axis induced voltage by using  $\theta_e$  as a function, which

occurs in the d-q axes, and detecting the step-out in the synchronous motor by comparing two estimated values sequentially.

Another example of the apparatus for detecting the step-out in the synchronous motor according to the related art is disclosed in Japanese Unexamined Published Patent Application 2001 - 25282. In the apparatus for detecting the step-out in the synchronous motor disclosed in Japanese Unexamined Published Patent Application 2001 - 25282, an example of detecting the step-out by comparing a cycle of a voltage output from the inverter apparatus with a cycle of a current supplied to a sensorless brushless motor is disclosed. Further, an example of detecting the step-out by comparing a d axis current which is an exciting current component with a step-out detection level is disclosed.

#### Summary of the Invention

Since the apparatus for detecting the step-out in the synchronous motor according to the related art is configured as stated above, the step-out was detected based on the overcurrent state, and it was difficult to detect the step-out accurately. Further, even while a synchronous operation is continued without stepping out, the overcurrent can be caused by the current increase due to an increase of a load and an over-reduction of a velocity, etc. Therefore, it was difficult to extract the step-out state from the overcurrent state. Further, an overcurrent level used for detecting the overcurrent is a value set based on a demagnetization tolerance of a magnet used for the rotor of the direct current brushless motor or a limiting current level of a device used in

the inverter apparatus. Therefore, it was difficult to set a detection level used for detecting the step-out independently.

In some combination of the inverter apparatus and the direct current brushless motor, the current at a time of stepping out is lower than the current in a synchronous state. In such case, it was impossible to detect the step-out based on the overcurrent.

When the step-out state continues as stated above, it causes a problem of vibrations and a noise of the rotor of the motor. Further, there was even a case in which an apparatus was broken due to the vibrations of the motor. Further, when the current supplied to the synchronous motor increased, there was a problem that a semiconductor device, etc. used in the inverter apparatus was broken.

In the apparatus for detecting the step-out in the synchronous motor disclosed in Japanese Unexamined Published Patent Application Hei 11-18499, a mechanism for estimating an induced voltage of the motor is necessary for detecting the step-out. Hence, a load of calculating in a microcomputer, etc. is increased.

In the apparatus for detecting the step-out in the synchronous motor disclosed in Japanese Unexamined Published Patent Application 2001-25282, the step-out is detected by comparing the cycle of the voltage output from the inverter apparatus with the cycle of the current supplied to the sensorless

brushless motor. Therefore, when there is no difference between the voltage cycle output from the inverter apparatus and the cycle of the current supplied to the synchronous motor at a time of stepping out, it is impossible to detect the step-out. Further, in a mechanism of detecting the step-out by comparing a d axis current which is an exciting current component with a step-out detection level, since the exciting current changes according to a velocity and a condition of a load torque, it is necessary to set a step-out detection level for each operation condition, and setting the step-out detection level has to be complicated.

This invention is intended to solve the above-stated problems. Particularly, this invention intends to provide the apparatus and method for detecting the step-out in the synchronous motor accurately in a simplified operation.

Further, this invention also intends to provide a drive of a closed compressor and a drive of a fan motor in which the above-stated apparatus for detecting the step-out in the synchronous motor is packaged.

According to an aspect of this invention, an apparatus for detecting a step-out in a synchronous motor in an inverter apparatus for driving the synchronous motor without using a positioning sensor for detecting a position of a rotor includes a current detector for detecting a current supplied to the synchronous motor, a d-q coordinate converter for converting a current signal obtained by the current detector into an exciting current component (d axis current) and a torque current component (q axis current), an alternating

current component detector for obtaining alternating current components of d-q axes currents obtained by the d-q coordinate converter, and a step-out detector for detecting a step-out by comparing at least one of alternating current components of the d-q axes currents with a predetermined step-out level signal.

According to another aspect of this invention, an apparatus for detecting a step-out in a synchronous motor in an inverter apparatus for driving the synchronous motor without using a positioning sensor for detecting a position of a rotor includes a current detector for detecting a current supplied to the synchronous motor, a d-q coordinate converter for converting a current signal obtained by the current detector into an exciting current component (d axis current) and a torque current component (q axis current), an alternating current component detector for obtaining alternating current components of d-q axes currents obtained by the d-q coordinate converter, an alternating current component averaging unit for averaging the alternating current components of the d-q axes currents by obtaining one of an effective value and an averaged absolute value of the alternating current components of the d-q axes currents obtained by the alternating current component detector, and a step-out detector for detecting a step-out by comparing at least one of the effective value and the averaged absolute value of the alternating current components of the d-q axes currents obtained by the alternating current component averaging unit with a predetermined step-out level signal.

According to another aspect of this invention, an apparatus for detecting a step-out in a synchronous motor in an inverter apparatus for driving the synchronous motor without using a positioning sensor for detecting

a position of a rotor includes a current detector for detecting a current supplied to the synchronous motor, a d-q coordinate converter for converting a current signal obtained by the current detector into an exciting current component (d axis current) and a torque current component (q axis current), a current difference calculator for calculating a difference between the d-q axes currents obtained by the d-q axes converter and command values of the d-q axes currents, a current difference alternating current component detector for detecting alternating current components in the difference about the d-q axes currents obtained by the current difference calculator, and a step-out detector for detecting a step-out by comparing at least one of the alternating current components in the difference about the d-q axes currents obtained by the current difference alternating current component detector with a predetermined step-out level signal.

In one embodiment, an apparatus for detecting the step-out in a synchronous motor includes an output voltage command calculator for calculating output voltage command values applied to the synchronous motor based on a current signal obtained by the current detector, an output voltage vector calculator for calculating an output voltage vector based on the output voltage command values obtained by the output voltage command calculator, an output voltage error detector for comparing a scalar of the output voltage vector obtained by the output voltage vector calculator with a step-out detection level, and wherein the step-out detector detects a step-out based on a

comparison result obtained by the output voltage error detector.

According to another aspect of this invention, a method for detecting a step-out in a synchronous motor in an inverter apparatus for driving the synchronous motor without using a positioning sensor for detecting a position of a rotor includes current detecting step for detecting a current supplied to the synchronous motor, d-q coordinate converting step for converting a current signal obtained in current detecting step into an exciting current component (d axis current) and a torque current component (q axis current), alternating current component detecting step for obtaining alternating current components of d-q axes currents obtained in d-q coordinate converting step, and step-out detecting step for detecting a step-out by comparing at least one of alternating current components of the d-q axes currents obtained in alternating current component detecting step with a predetermined step-out level signal.

According to another aspect of this invention, a method for detecting a step-out in a synchronous motor in an inverter apparatus for driving the synchronous motor without using a positioning sensor for detecting a position of a rotor includes current detecting step for detecting a current supplied to the synchronous motor, d-q coordinate converting step for converting a current signal obtained in current detecting step into an exciting current component (d axis current) and a torque current component (q axis current), alternating current component detecting step for obtaining alternating current components of d-q axes currents obtained in d-q coordinate converting step, alternating current component averaging step for averaging the alternating current components of the d-q axes currents by obtaining one of an effective

value and an averaged absolute value of the alternating current components of the d-q axes currents obtained in alternating current component detecting step, and step-out detecting step for detecting a step-out by comparing at least one of the effective value and the averaged absolute value of the alternating current components of the d-q axes currents obtained in alternating current component averaging step with a predetermined step-out level signal.

According to another aspect of this invention, a method for detecting a step-out in a synchronous motor in an inverter apparatus for driving the synchronous motor without using a positioning sensor for detecting a position of a rotor includes current detecting step for detecting a current supplied to the synchronous motor, d-q coordinate converting step for converting a current signal obtained in current detecting step into an exciting current component (d axis current) and a torque current component (q axis current), current difference calculating step for calculating a difference between the d-q axes currents obtained in d-q coordinate converting step and command values of the d-q axes currents, current difference alternating current component detecting step for obtaining alternating current components in the difference about the d-q axes currents obtained in current difference calculating step, and step-out detecting step for detecting a step-out by comparing at least one of the alternating current components in the difference about the d-q axes currents obtained in current difference alternating current component detecting step with a predetermined step-out level signal.

In one embodiment, a method for detecting the step-out in a synchronous motor output voltage command calculating step for calculating output voltage command values applied to the synchronous motor based on a

current signal obtained in current detecting step, output voltage vector calculating step for calculating an output voltage vector based on the output voltage command values obtained in output voltage command calculating step, output voltage error detecting step for comparing a scalar of the output voltage vector obtained in output voltage vector calculating step with a step-out detection level, and wherein the step-out detecting step detects a step-out based on a comparison result obtained in output voltage error detecting step.

Further features and applications of the present invention will become apparent from the detailed description given hereinafter. However, it should be understood that the detailed description and specific examples, while indicating preferred embodiments of the invention, are given by way of illustration only, since various changes and modifications within the spirit and scope of the invention will become apparent to those skilled in the art from this detailed description.

Other objects features, and advantages of the invention will be apparent from the following description when taken in conjunction with the accompany drawings.

#### Brief Description of the Drawings

Fig. 1 shows a configuration of an apparatus for detecting a step-out detector in a synchronous motor in Embodiment 1;

Fig. 2 shows an explanatory chart of various waveforms at a time of a synchronous operation in Embodiment 1;

Fig. 3 shows an explanatory chart of various waveforms at a time of stepping out in Embodiment 1;

Fig. 4 shows a flow chart in detecting the step-out in Embodiment 1;

Fig. 5 shows an explanatory chart of various waveforms at a time of stepping out in Embodiment 1;

Fig. 6 shows a flow chart in detecting the step-out in Embodiment 1;

Fig. 7 shows a configuration of an apparatus for detecting the step-out in the synchronous motor in Embodiment 2;

Fig. 8 shows a flow chart in detecting the step-out in Embodiment 2;  
and

Fig. 9 shows a configuration of the apparatus for detecting the step-out in the synchronous motor according to the related art.

#### Detailed Description of the Preferred Embodiments

##### Embodiment 1.

Figs. 1 - 6 illustrate Embodiment 1. Fig. 1 illustrates a configuration of an inverter apparatus. Fig. 2 shows an explanatory chart of various waveforms at a time of a synchronous operation. Fig. 3 shows an explanatory chart of various waveforms at a time of stepping out. Fig. 4 shows a flow chart in detecting the step-out. Fig. 5 shows an explanatory chart of various waveforms at a time of stepping out. Fig. 6 shows a flow chart in detecting the step-out.

In Fig. 1, a direct current power supply unit 1, an inverter apparatus 2, a plurality of switching devices 3, a U-phase upper switching devices 3a, a V-

phase upper switching device 3b, a W-phase upper switching device 3c, a U-phase lower switching device 3d, a V-phase lower switching device 3e, a W-phase lower switching device 3f, a plurality of flywheel diodes 4 connected in parallel to the plurality of switching devices 3, an inverter main circuit 5 including the plurality of switching devices 3 and the plurality of flywheel diodes 4, and a direct current brushless motor 6 are illustrated.

A current detector 7a detects a phase current in one phase among currents supplied to the direct current brushless motor 6, and a current detector 7b detects a phase current in another phase which is different from the phase detected by the current detector 7a. An inverter controller 8 controls ON / OFF of the switching devices 3 in the inverter main circuit 5 based on phase current values detected by the current detectors 7a and 7b.

A PWM signal generator 9 generates a PWM signal for controlling ON / OFF of the switching devices 3 based on output voltage command values obtained in the inverter controller 8, and a phase current calculator 10 calculates phase current values in three phases based on the phase current values in two phases detected by the current detectors 7a and 7b. A 3-phase to 2-phase converter 11 is a d-q coordinate converter for converting the phase current values in three phases obtained by the phase current calculator 10 to current values in a d-q coordinate system. A voltage command value calculator 12 obtains output voltage command values in the d-q coordinate system for driving the direct current brushless motor based on the current values in the d-q coordinate system obtained by the 3-phase to 2-phase

converter 11, and an output voltage vector calculator 13 obtains an output voltage vector based on the output voltage command values in the d-q coordinate system obtained by the voltage command value calculator 12. A direct current voltage detector 14 detects a direct current voltage of the direct current power supply unit 1.

An alternating current component detector 15 detects alternating current components of the currents in the d-q coordinate system obtained by the 3-phase to 2-phase converter 11, and a step-out detector 16 detects the step-out by comparing the step-out detection level with the alternating current components of the currents in the d-q coordinate system obtained by the alternating current component detector 15.

With reference to Fig. 1, an operation in the inverter apparatus configured as stated above is explained.

As illustrated in Fig. 1, in the inverter apparatus 2, the current detectors 7a and 7b detect the phase currents in two phases among the phase currents supplied to the direct current brushless motor 6. The inverter controller 8 calculates output voltage command values, e.g., voltage value, voltage phase, etc. output by the inverter main circuit 5 for driving the direct current brushless motor 6, and outputs the PWM signal for controlling ON / OFF of the switching devices 3 in the inverter main circuit 5.

The PWM signal is output from the inverter controller 8 as follows. The phase current calculator 10 calculates phase currents  $I_u$ ,  $I_v$ , and  $I_w$  in

three phases based on the phase currents  $I_u$  and  $I_v$  detected by the current detectors 7a and 7b, and the 3-phase to 2-phase converter 11 converts the phase currents  $I_u$ ,  $I_v$ , and  $I_w$  in three phases to currents  $I_d$  and  $I_q$  in the d-q coordinate system. The voltage command value calculator 12 calculates output voltage command values  $V_d^*$  and  $V_q^*$  in the d-q coordinate system based on the currents  $I_d$  and  $I_q$  in the d-q coordinate system. The output voltage vector calculator 13 calculates output voltage vector  $V_x^*$  based on the output voltage command values  $V_d^*$  and  $V_q^*$  in the d-q coordinate system. The PWM signal generator 9 calculates the PWM signal for controlling ON / OFF of the switching devices 3 based on a direct current voltage  $V_{dc}$  obtained by the direct current voltage detector 14 and the output voltage vector  $V_x^*$ , and outputs the PWM signal.

The switching devices 3 in the inverter main circuit 5 are turned ON / OFF by the PWM signal output by the PWM signal generator 9. By an ON / OFF operation of the switching devices 3, an electric power is supplied from the inverter main circuit 5 to the direct current brushless motor 6, and the direct current brushless motor 6 is driven.

Out of the currents  $I_d$  and  $I_q$  in the d-q coordinate system obtained by the 3-phase to 2-phase converter 11, the alternating current component detector 15 detects alternating current components  $I_{d\_AC}$  and  $I_{q\_AC}$  of currents  $I_d$  and  $I_q$  in the d-q coordinate system. The step-out detector 16 compares the alternating current components  $I_{d\_AC}$  and  $I_{q\_AC}$  of the currents in the d-q coordinate system with a step-out detection level  $Error\_Level$ .

When  $I_{d\_AC}$  or  $I_{q\_AC}$  exceeds the step-out detection level  $Error\_Level$ , it is judged as the step-out, and an abnormal stop signal is output.

When the abnormal stop signal is output by the step-out detector 16, the PWM signal generator 9 outputs a signal for turning off all the switching devices 3 in the inverter main circuit 5, and the inverter main circuit 5 stops supplying the electric power to the direct current brushless motor 6. At the same time, the operation of the inverter controller 8 is stopped.

With reference to Figs. 2 and 3, a method for detecting the step-out according to this embodiment is explained in details. Fig. 2 illustrates an example of various waveforms when the direct current brushless motor 6 is performing a normal synchronous operation. In Fig. 2, a waveform (a) is a waveform of a phase current  $I_u$  obtained by the current detector 7a, a waveform (b) is a waveform of a d axis current  $I_d$  obtained by the 3-phase to 2-phase converter, a waveform (c) is a waveform of a q axis current  $I_q$  obtained by the 3-phase to 2-phase converter 11, and a waveform (d) is a waveform of an alternating current component  $I_{q\_AC}$  of the q axis current  $I_q$ .

Fig. 3 illustrates an example of various waveforms when the direct current brushless motor is stepping out. In Fig. 3, a waveform (a) is a waveform of a phase current  $I_u$  obtained by the current detector 7a, a waveform (b) is a waveform of a d axis current  $I_d$  obtained by the 3-phase to 2-phase converter, a waveform (c) is a waveform of a q axis current  $I_q$  obtained by the 3-phase to 2-phase converter 11, and a waveform (d) is a waveform of an

alternating current component  $I_{q\_AC}$  of the q axis current  $I_q$ .

As illustrated in Figs. 2 and 3, when the direct current brushless motor is in a synchronous operation, the currents  $I_d$  and  $I_q$  in the d-q coordinate system are mostly direct currents. However, when the direct current brushless motor is stepping out, alternating current components are created in  $I_d$  and  $I_q$ . As illustrated in the waveform (d) in Fig. 3, the alternating current components  $I_{d\_AC}$  and  $I_{q\_AC}$  of  $I_d$  and  $I_q$  are compared with the step-out detection level  $Error\_Level$ , and if the alternating current components exceed the step-out detection level, it is judged as the step-out. The step-out is detected through this operation.

It will be explained as follows why the alternating current components are created in  $I_d$  and  $I_q$ . When, a motor, e.g., IPMSM (Interior Permanent Magnet Synchronous Motor), in which an inductance of d axis and an inductance of q axis differ from each other, is in the synchronous operation, a constant phase difference is being kept between a phase of the rotor and an output voltage phase of the inverter, i.e., in the d-q coordinate system which is based on the output voltage phase of the inverter, the inductance of d axis of the rotor and the inductance of q axis of the rotor are constant (each of the inductance of d axis of the rotor and the inductance of q axis of the rotor has constantly a same value). Therefore, the d axis current  $I_d$  and the q axis current  $I_q$  are mostly direct currents.

In the step-out state, a phase difference between the phase of the rotor and the output voltage phase of the inverter fluctuates, i.e., supposing the output voltage phase of the inverter as a standard, the inductance of the d axis

and the inductance of the q axis fluctuate. Therefore, the d axis current and the q axis current change in each rotation phase, and the alternating current components are created in each rotation phase. As stated, by detecting the alternating current components of the d-q axes currents, a fluctuation (an operation state of the rotor) in the inductance of the d axis and the q axis of the rotor can be detected by comparing with the output voltage phase of the inverter. Accordingly, the step-out in the synchronous motor can be detected.

With reference to Fig. 4, a mechanism of using the q axis current  $I_q$  equivalent to an output torque component of the current supplied to the motor is explained as an example of a step-out detector in Embodiment 1. Fig. 4 shows a flow chart in detecting the step-out. In Fig. 4, processing STP1 of starting to detect the step-out, processing STP2 of detecting the phase current, processing STP3 of calculating the phase current, processing STP4 of converting three phases to two phases, processing STP5 of detecting the alternating current component, processing STP6 of comparing with the step-out detection level, processing STP7 of stopping by PWM, processing STP8 of terminating in abnormal condition, and processing STP9 of terminating in normal condition are illustrated.

A flow in detecting the step-out is described as follows. In processing STP1, processings of detecting the step-out are started. In processing STP2 of detecting the phase current, the currents  $I_u$  and  $I_v$  in two phases supplied to the direct current brushless motor 6 are detected by the current detectors 7a and 7b. In processing STP3 of calculating the phase current, the currents  $I_u$ ,

$I_v$  and  $I_w$  in three phases are obtained based on the currents  $I_u$  and  $I_v$  in two phases obtained in processing STP2. In processing STP4 of converting three phases to two phases, the currents  $I_u$ ,  $I_v$  and  $I_w$  in three phases obtained in processing STP3 are converted into the currents  $I_d$  and  $I_q$  in the d-q coordinate system. In processing STP5 of detecting the alternating current component, the alternating current component  $I_{q\_AC}$  of the q axis current  $I_q$  obtained in processing STP4 is detected by using the high-pass filter.

In processing STP6 of comparing with the step-out detection level, the alternating current component  $I_{q\_AC}$  of the q axis current is compared with the step-out detection level  $Error\_Level$ . If  $I_{q\_AC} \geq Error\_Level$ , it is judged as the step-out, and the processing goes to processing STP7. If  $I_{q\_AC} < Error\_Level$ , it is judged as the synchronous operation, and the processing goes to processing STP9. In processing STP7 of stopping by the PWM, when it is judged as the step-out in processing STP6, the PWM signals indicating all the switching devices 3 to stop are output by the PWM signal generator 9, and the operation of the inverter controller is stopped. In processing STP8 of terminating in abnormal condition, the processing of detecting the step-out is terminated in abnormal condition due to the step-out. In processing STP9 of terminating in normal condition, the processings of detecting the step-out are terminated in normal condition.

As stated, the step-out in the direct current brushless motor is detected by detecting a difference between the d-q axes currents at the time of the normal operation and the d-q axes currents at the time of stepping out.

Therefore, the step-out can be detected more accurately according to this invention than a method of detecting the step-out based on the overcurrent state according to the related art.

Further, since the q axis current  $I_q$  equivalent to the output torque component of the current supplied to the motor is proportional to the output torque, if detecting of the step-out is made based on a level of the q axis current, an error in detection can happen. Therefore, by detecting the alternating current component of  $I_q$ , the step-out can be detected more accurately, even if the output torque condition varies

Further, since a variable used for calculating the output voltage command values in the inverter controller 8 is used, a mechanism, e.g., induced voltage estimator, etc. is not necessary. Therefore, the processing for detecting the step-out can be simplified.

With reference to Fig. 5, another example of the step-out detector of the synchronous motor in Embodiment 1 of this invention is explained. A configuration of the inverter apparatus is same as Fig. 1. Fig. 5 illustrates various waveforms at the time of the direct current brushless motor 6 being stepping out. In Fig. 5, a waveform (a) is a waveform of a phase current  $I_u$  obtained by the current detector 7a, a waveform (b) is a waveform of a d axis current  $I_d$  obtained by the 3-phase to 2-phase converter, a waveform (c) is a waveform of a q axis current  $I_q$  obtained by the 3-phase to 2-phase converter, a waveform (d) is a waveform of an alternating current component  $I_{q\_AC}$  of the

q axis current  $I_q$ , a waveform (e) is a waveform of an absolute value  $|I_{q\_AC}|$  of the alternating current component of the q axis current which is obtained by rectifying the alternating current component  $I_{q\_AC}$  of the q axis current, and a waveform (f) is a waveform of  $I_{q\_AC\_Fi1}$  obtained by filtering the absolute value of the alternating current component of the q axis current by a low-pass filter.

As illustrated in Figs. 2 and 5, when the direct current brushless motor is in a synchronous operation, the currents  $I_d$  and  $I_q$  in the d-q coordinate system are mostly direct currents. However, when the direct current brushless motor is stepping out, alternating current components are created in  $I_d$  and  $I_q$ . As illustrated in the waveform (f) in Fig. 5, values of  $I_{d\_AC\_Fi1}$  and  $I_{q\_AC\_Fi1}$  which are obtained by filtering the absolute values of the alternating current components of  $I_d$  and  $I_q$  by the low-pass filter are compared with the step-out detection level  $Error\_Level$ . If the filtered values exceed the step-out detection level, it is judged as the step-out. The step-out can be detected through this operation.

With reference to Fig. 6, as an example of the step-out detector, a mechanism of using the q axis current  $I_q$  equivalent to an output torque component of the current supplied to the motor is explained. Fig. 6 shows a flow chart in detecting the step-out. In Fig. 6, processing STP1 of starting to detect the step-out, processing STP2 of detecting the phase current, processing STP3 of calculating the phase current, processing STP4 of converting three phases to two phases, processing STP5 of detecting the alternating current

component, processing STP10 of rectifying (calculating the absolute value), processing STP11 of filtering by the low-pass filter, processing STP12 of comparing with the step-out detection level, processing STP7 of stopping by PWM, processing STP8 of terminating in abnormal condition, and processing STP9 of terminating in normal condition are illustrated.

A flow in detecting the step-out is described as follows. In processing STP1, the processings of detecting the step-out are started. In processing STP2 of detecting the phase current, the currents  $I_u$  and  $I_v$  in two phases supplied to the direct current brushless motor 6 are detected by the current detectors 7a and 7b. In processing STP3 of calculating the phase current, the currents  $I_u$ ,  $I_v$  and  $I_w$  in three phases are calculated based on the currents  $I_u$  and  $I_v$  in two phases obtained in processing STP2. In processing STP4 of converting three phases into two phases, the currents  $I_u$ ,  $I_v$  and  $I_w$  in three phases obtained in processing STP3 are converted into the currents  $I_d$  and  $I_q$  in the d-q coordinate system. In processing STP5 of detecting the alternating current component, the alternating current component  $I_{q\_AC}$  of the q axis current  $I_q$  obtained in processing STP4 is detected by using the high-pass filter.

In processing STP10 of rectifying (calculating the absolute value), the alternating current component  $I_{q\_AC}$  of the q axis current obtained in processing STP5 is rectified, and an absolute value  $|I_{q\_AC}|$  of  $I_{q\_AC}$  is obtained. In processing STP11 of filtering,  $|I_{q\_AC}|$  is filtered by the low-pass filter, and a filtered value  $I_{q\_AC\_F11}$  of the absolute value of the

alternating current component of  $I_q$  is obtained. In processing STP12 of comparing with the step-out detection level,  $I_{q\_AC\_Fil}$  and the step-out detection level  $Error\_Level$  are compared. If  $I_{q\_AC\_Fil} \geq Error\_Level$ , it is judged as the step-out, and the processing goes to processing STP7. If  $I_{q\_AC\_Fil} < Error\_Level$ , it is judged as the synchronous operation, and the processing goes to processing STP9. In processing STP7 of stopping by the PWM, when it is judged as the step-out in processing STP6, the PWM signals indicating all the switching devices 3 to stop are output by the PWM signal generator 9, and the operation of the inverter controller is stopped. In processing STP8 of terminating in abnormal condition, the processing of detecting the step-out is terminated in abnormal condition due to the step-out. In processing STP9 of terminating in normal condition, the processings of detecting the step-out are terminated in normal condition.

As stated, the step-out in the direct current brushless motor is detected based on the difference between the d-q axes currents at the time of the normal operation and the d-q axes currents at the time of stepping out. Therefore, the step-out can be detected more accurately according to this invention than a method for detecting the step-out based on the overcurrent state according to the related art.

Further, the q axis current  $I_q$  equivalent to the output torque component of the current supplied to the motor is proportional to the output torque. Therefore, if the detection of the step-out is made simply based on a level of the q axis current, the step-out detection level must be set in

accordance with a condition of a velocity or a condition of a load torque. Hence, the configuration becomes complex. However, by detecting the alternating current component of  $I_q$  as in Embodiment 1 of this invention, the step-out can be detected accurately even if the condition of the output torque varies.

Similarly, even if the d axis current value is used for detecting the step-out, since the d axis current value changes according to the operation condition of the synchronous motor, e.g., velocity and load torque, the step-out detection level must be set in accordance with a condition of velocity or a condition of the load torque if detection of the step-out is made simply based on a level of the d axis current as in the related art. Hence, the configuration becomes complex. However, by detecting the alternating current component of  $I_d$  as in Embodiment 1 of this invention, the step-out can be detected accurately even if the operation condition of the synchronous motor varies.

Further, since the variable used for calculating the output voltage command values in the inverter controller 8 is used, a mechanism, e.g., induced voltage estimator, etc. is not necessary. Therefore, the processing for detecting the step-out can be simplified.

Then, an absolute value  $|I_{q\_AC}|$  of the alternating current component  $I_{q\_AC}$  of the q axis current is obtained, and the absolute value is filtered by the low-pass filter to obtain a filtered value  $I_{q\_AC\_Fil}$ . By using the filtered value for detecting the step-out, the accuracy in detecting the step-out can be

improved as follows.

The alternating current component  $I_{q\_AC}$  of the q axis current may increase due to a rapid change in the load torque or in a voltage of the direct current power supply unit 1, without the step-out being occurred. By using  $I_{q\_AC\_Fil}$  for detecting the step-out, it is possible to prevent an erroneous detection of the step-out in the above-stated state.

An example of setting the step-out detection level for comparing at the time of detecting the step-out is explained. Even during the synchronous operation, the alternating current component  $I_{q\_AC}$  of the q axis current value  $I_q$  is created due to the fluctuation in the load torque, etc. However, a level of  $I_{q\_AC}$  created in a normal operation is lower than a level of  $I_{q\_AC}$  created at the time of stepping out. Therefore, it is possible to set the step-out detection level at a value which is higher than the level of  $I_{q\_AC}$  created in the normal operation and lower than the level of  $I_{q\_AC}$  created at the time of stepping out. Since there is a clear difference between the level of  $I_{q\_AC}$  created in the normal operation and the level of  $I_{q\_AC}$  created at the time of stepping out, the error detection level can be set easily.

An example of a set value of the step-out detection level is explained.

At the direct current brushless motor requiring a current of approximately 0.5A in a rating operation, a level of an average value of the alternating current component  $I_{q\_AC\_Fil}$  of the q axis current  $I_q$  created at the time of the normal operation is 50 % or less of an effective value of a rating current during the rating operation. However, the level of the average value

of the alternating current component  $I_{q\_AC\_Fil}$  of the q axis current created at the time of stepping out is 250 % or more of the effective value of the rating current during the rating operation. Therefore, it is possible to set the step-out detection level at 200% of the effective value of the rating current in considering an influence from the fluctuation in the load torque and the direct current voltage.

Another example of setting the step-out detection level is explained.

As an example of a load of the synchronous motor, in a compressor, especially a compressor of single rotary type of which load fluctuates much during a rotation, the alternating current component  $I_{q\_AC}$  created in the q axis current  $I_q$  is slightly larger because of a torque ripple caused by the fluctuation in the load. However,  $I_{q\_AC}$  at the time of stepping out is not so small. Therefore, for such compressor, it is possible to set the step-out detection level slightly higher than a regular level.

In the method for detecting the step-out in Embodiment 1 of this invention, in some combination of the inverter apparatus and the direct current brushless motor, the current supplied to the direct current motor during a low velocity rotation may be low. Therefore, it becomes difficult to detect the step-out during the low velocity rotation. In such a case, the step-out state can be detected by increasing the velocity until a velocity in a regular operation just after starting the motor. The step-out continues till the step-out is detected. However, a time of step-out is a few seconds, and the current supplied to the motor is lower than the current supplied to the motor during

the rating operation. Therefore, there is almost no bad influence on the inverter apparatus and the synchronous motor.

When a velocity of the brushless motor is increased or decreased, the alternating current component is created in the currents  $I_d$  and  $I_q$  in the d-q coordinate system in some cases. This can cause an error in detecting the step-out. In such cases, the step-out can be detected during a period without increasing or decreasing the velocity instead of performing a processing for detecting the step-out during a period of increasing or decreasing the velocity.

In the flow charts in detecting the step-out in Figs. 4 and 6, when the alternating current components are detected in the currents in the d-q coordinate system in processing STP5, the accuracy in detecting the step-out can be improved by detecting only a particular frequency component by using a band-pass filter, FFT (Fast Fourier Transformation), etc. An example of the particular frequency component is a frequency twice as high as a frequency of a voltage output from the inverter apparatus. This is because, in the operation of a four pole motor for example, the currents in the d-q coordinate system at the time of stepping out include a component of a frequency twice as high as the rotation frequency of the voltage output by the inverter apparatus. The particular frequency component is determined, for example, based on a number of poles of the motor.

As a method for detecting the step-out according to Embodiment 1, a mechanism for using the q axis current value was explained. It is also

possible to detect the step-out based on the d axis current value, a difference between the d axis current and the d axis current command value, and a difference between the q axis current and the q axis current command. The d axis current command value and the q axis current command value are command values for controlling the synchronous motor appropriately in driving control of the synchronous motor. The d axis current command value and the q axis current command value are determined based on an operation condition of the synchronous motor.

When the step-out is detected based on the difference between the d axis current and the d axis current command value or the difference between the q axis current and the q axis current command value, firstly differences between the currents in the d-q coordinate system and the current command values in the d-q coordinate system are obtained; the currents in the d-q coordinate system are obtained by the 3-phase to 2-phase converter 11 for converting a current value in three phases obtained by the phase current calculator 10 to current values in the d-q coordinate system. Then, alternating current components of the obtained differences in the d-q axes currents are detected. Then, at least one of the detected alternating current components of the differences in the d-q axes currents is compared with a predetermined step-out level signal, and the step-out is detected.

When the q axis current value is used for detecting the step-out, the q axis current is equivalent to a torque component of the current supplied to the synchronous motor. Therefore, when the alternating current component

created in the d axis current is high, the fluctuation in the output torque of the motor is big, and the motor is in an abnormal operation. Even in a normal operation, the alternating current component is created in the q axis current by the fluctuation in the load torque. However, the alternating current component in the normal operation is lower than the alternating current component created at the time of stepping out. As stated, since a change in the q axis current can be related to an operation of the motor, it is easy to distinguish the normal operation and the step-out. Therefore, according to the mechanism for using the q axis current for detecting the step-out, the step-out detection level, etc. can be set easily.

When the d axis current is used for detecting the step-out, since an alternating current component is created in the d axis current at the time of stepping out as in the q axis current, the step-out can be detected as in a case of the q axis current.

When both the d axis current and the q axis current are used, since the step-out is detected based on a plurality of data, the step-out can be detected more accurately. It is also possible to convert the d axis current value and the q axis current value into at least one certain detecting value by using a coordinate conversion and an arithmetic expression, and in such case, the step-out can be also detected more accurately.

In the d axis current and the q axis current, it is general to define a magnetic-polar direction of the rotor of the motor as the d axis and a phase

advanced by 90 degrees in a rotating direction from the d axis as the q axis. However, when the synchronous motor is driven without positioning-sensor, it is difficult to detect the d-q axes accurately. Therefore, there is a case in which an axis equivalent to the d axis is defined as a  $\delta$  axis and an axis equivalent to the q axis is defined as a  $\gamma$  axis in a coordinate system for controlling. It is needless to say that a same effect can be realized in a same configuration with the  $\delta$  -  $\gamma$  axes coordinate system.

In the above-stated embodiment, an absolute value of the alternating current components of the d-q axes currents is obtained, and the absolute value is filtered to obtain an average value of the alternating current components of the d-q axes currents. However, an effective value of the alternating current components of the d-q axes currents can be treated as the average value of the alternating current components of the d-q axes currents.

#### Embodiment 2.

Figs. 7 and 8 illustrate Embodiment 2. Fig. 7 illustrates a configuration of the inverter apparatus. Fig. 8 shows a flow chart in detecting the step-out. In Fig. 7, the direct current power supply unit 1, the inverter apparatus 2, the plurality of switching devices 3, the U-phase upper switching device 3a, the V-phase upper switching device 3b, the W-phase upper switching device 3c, the U-phase lower switching device 3d, the V-phase lower switching device 3e, the W-phase lower switching device 3f, the plurality of flywheel diodes 4 connected in parallel to the plurality of switching devices 3, the inverter main circuit 5 including the plurality of switching devices 3 and

the plurality of flywheel diodes 4, and the direct current brushless motor 6 are illustrated.

The current detector 7a detects a phase current in one phase among currents supplied to the direct current brushless motor 6, and the current detector 7b detects a phase current in another phase which is different from the phase detected by the current detector 7a. The inverter controller 8 controls ON / OFF of the switching devices 3 in the inverter main circuit 5 based on phase current values detected by the current detectors 7a and 7b.

The PWM signal generator 9 generates the PWM signal for controlling ON / OFF of the switching devices 3 based on output voltage command values obtained in the inverter controller 8, and the phase current calculator 10 calculates phase current values in three phases based on the phase current values in two phases detected by the current detectors 7a and 7b. The 3-phase to 2-phase converter 11 converts the phase current values in three phases obtained by the phase current calculator to current values in a d-q coordinate system, and the voltage command value calculator 12 obtains output voltage command values in the d-q coordinate system for driving the direct current brushless motor based on the current values in the d-q coordinate system obtained by the 3-phase to 2-phase converter 11. The output voltage vector calculator 13 obtains an output voltage vector based on the output voltage command values in the d-q coordinate system obtained by the voltage command value calculator 12, and the direct current voltage detector 14 detects a direct current voltage of the direct current power supply

unit 1.

An output voltage error detector 17 compares a scalar  $|V_x^*|$  of the output voltage vector  $V_x^*$  obtained by the output voltage vector calculator 13 with the step-out detection level  $V\_Error\_Level$ , and a step-out detector 18 detects the step-out based on a comparison result from the output voltage error detector 17.

With reference to Fig. 7, an operation in the inverter apparatus configured as stated above is explained.

As illustrated in Fig. 7, in the inverter apparatus 2, the current detectors 7a and 7b detect the phase currents in two phases among the phase currents supplied to the direct current brushless motor 6. The inverter controller 8 calculates output voltage command values, e.g., voltage value, voltage phase, etc. output by the inverter main circuit 5 for driving the direct current brushless motor 6, and outputs the PWM signal for controlling ON / OFF of the switching devices 3 in the inverter main circuit 5.

The PWM signal is output from the inverter controller 8 as follows. The phase current calculator 10 calculates phase currents  $I_u$ ,  $I_v$ , and  $I_w$  in three phases based on the phase currents  $I_u$  and  $I_v$  detected by the current detector 7a and 7b, and the 3-phase to 2-phase converter 11 converts the phase currents  $I_u$ ,  $I_v$ , and  $I_w$  to currents  $I_d$  and  $I_q$  in the d-q coordinate system. The voltage command value calculator 12 calculates output voltage command values  $V_d^*$  and  $V_q^*$  in the d-q coordinate system based on the currents  $I_d$  and

$I_q$  in the d-q coordinate system. The output voltage vector calculator 13 calculates output voltage vector  $V_x^*$  based on the output voltage command values  $V_d^*$  and  $V_q^*$  in the d-q coordinate system. The PWM signal generator 9 calculates the PWM signal for controlling ON / OFF of the switching devices 3 based on a direct current voltage  $V_{dc}$  obtained by the direct current voltage detector 14 and the output voltage vector  $V_x^*$ , and outputs the PWM signal.

The switching devices 3 in the inverter main circuit 5 are turned ON / OFF by the PWM signal output by the PWM signal generator 9. By an ON / OFF operation of the switching devices 3, an electric power is supplied from the inverter main circuit 5 to the direct current brushless motor 6, and the direct current brushless motor 6 is driven.

Based on the output voltage vector  $V_x$  obtained by the output voltage vector calculator 13, a scalar  $|V_x^*|$  of the output voltage vector  $V_x$  is obtained by the output voltage error detector 17, then the scalar  $|V_x^*|$  of the output voltage vector  $V_x^*$  is compared with the step-out detection level  $V\_Error\_Level$ . When the scalar  $|V_x^*|$  of the output voltage vector  $V_x^*$  is below the step-out detection level  $V\_Error\_Level$ , it is judged as the step-out. When the scalar  $|V_x^*|$  of the output voltage vector  $V_x^*$  is exceeding the step-out detection level  $V\_Error\_Level$ , it is judged that the normal synchronous operation is performed.

As a result of detecting the output voltage error, if  $|V_x^*|$  is below the step-out detection level  $V\_Error\_Level$ , the step-out detector 18 judges as the

step-out, and outputs an abnormal stop signal to the PWM signal generator 9. When the PWM signal generator 9 receives the abnormal stop signal, the PWM signal generator 9 outputs a signal for turning off all the switching devices 3 in the inverter main circuit 5. At the same time, operation of the inverter controller 8 is stopped. In this way, the step-out can be detected.

With reference to Fig. 8, an example of a flow in detecting the step-out in Embodiment 2 is explained. Fig. 8 shows a flow chart of detecting the step-out. In Fig. 8, processing STP1 of starting to detect the step-out, processing STP13 of detecting the output voltage vector, processing STP14 of detecting a scalar of the output voltage vector, processing STP15 of comparing with the step-out detection level, processing STP7 of stopping by the PWM, processing STP8 of terminating in abnormal condition, and processing STP9 of terminating in normal condition are illustrated.

In processing STP1, the processings for detecting the step-out are started. In processing STP13 of detecting the output vector, an output voltage vector  $V_{x^*}$  obtained by the output voltage vector calculator 13 is detected. In processing STP14 of detecting a scalar of the output vector, a scalar  $|V_{x^*}|$  of the output voltage vector  $V_{x^*}$  detected in processing STP13 is obtained. In processing STP15 of comparing with the step-out level, the scalar  $|V_{x^*}|$  of the output voltage vector is compared with the step-out level  $V\_Error\_Level$ . If  $|V_{x^*}| < V\_Error\_Level$ , it is judged as the step-out, and the processing goes to processing STP7. If  $|V_{x^*}| \geq V\_Error\_Level$ , it is judged that the normal synchronous operation is performed, and the processing goes to processing

STP9.

When it is judged as the step-out in processing STP6, the PWM signals indicating all the switching devices 3 to stop are output by the PWM signal generator 9 in processing STP7, and further the operation of the inverter controller is stopped. In processing STP8 of terminating in abnormal condition, the detection of the step-out is terminated in abnormal condition due to the step-out. In processing STP9 of terminating in normal condition, the processings of detecting the step-out are terminated in normal condition.

When the direct current brushless motor is driven, if the output voltage is not enough to maintain the synchronous operation, the synchronous operation can not be maintained, and the step-out occurs. Therefore, it is possible to detect the step-out by monitoring the out voltage level. It is possible to detect the step-out by the operation illustrated in Embodiment 2. The scalar  $|V_x^*|$  of the output voltage vector changes according to an operation condition. Therefore, the step-out detection level  $V\_Error\_Level$  ought to be set according to the operation condition.

As stated, the step-out in the direct current brushless motor is detected by detecting the difference in the scalar  $|V_x^*|$  of the output voltage vector between the normal synchronous operation and the step-out. Therefore, the step-out can be detected according to this method more accurately than the method for detecting the step-out based on the overcurrent state according to the related art.

Since the variable used for calculating the output voltage command values in the inverter controller 8 is used, a mechanism, e.g., induced voltage estimator, etc. is not necessary. Hence, the processing for detecting the step-out can be simplified.

In Embodiment 1 and Embodiment 2 of this invention, the direct current brushless motor is given as an example of the synchronous motor. However, it is needless to say that a similar effect can be realized by using a motor such as a permanent magnet synchronous motor, synchronous reluctance motor, and switched reluctance motor.

A compressor drive of a refrigerator and an air conditioner can be given as examples of an apparatus in which the apparatus for detecting the step-out in the synchronous motor according to this invention is packaged. By packaging the apparatus for detecting the step-out in the compressor drive, it is possible to solve the problems arising when the step-out continues, e.g., a noise of the compressor, a damage in a cooling pipe due to vibrations of the compressor, demagnetization of the magnet used for the rotor of the motor, and a damage in a semiconductor element of the inverter apparatus due to an increase in the current. Accordingly, a reliable refrigerator and a reliable air conditioner can be realized.

A fan motor drive of the refrigerator and the air conditioner can be given as examples of an apparatus in which the apparatus for detecting the

step-out in the synchronous motor according to this invention is packaged. By packaging the apparatus for detecting the step-out in the fan motor drive, it is possible to solve the problem, e.g., a noise of the fan motor, vibrations of the fan motor, demagnetization of the magnet used for the rotor of the motor, and a damage in a semiconductor element of the inverter apparatus due to an increase in the current arising when the step-out continues. Accordingly, a reliable refrigerator and a reliable air conditioner can be realized.

An apparatus for detecting a step-out in a synchronous motor according to this invention includes a current detector for detecting a current supplied to the synchronous motor, a d-q coordinate converter for converting a current signal obtained by the current detector into an exciting current component (d axis current) and a torque current component (q axis current), an alternating current component detector for obtaining alternating current components of d-q axes currents obtained by the d-q coordinate converter, and a step-out detector for detecting a step-out by comparing at least one of alternating current components of the d-q axes currents with a predetermined step-out level signal. Therefore, the step-out can be detected accurately in a simplified configuration. Further, it is possible to prevent demagnetization of the magnet in the rotor or a damage in the switching devices in the inverter main circuit due to an increase in the current, arising when the step-out state continues. Further, it is also possible to prevent a noise and vibrations of the synchronous motor arising when the step-out state continues.

The apparatus for detecting a step-out in a synchronous motor

according to this invention includes a current detector for detecting a current supplied to the synchronous motor, a d-q coordinate converter for converting a current signal obtained by the current detector into an exciting current component (d axis current) and a torque current component (q axis current), an alternating current component detector for obtaining alternating current components of d-q axes currents obtained by the d-q coordinate converter, an alternating current component averaging unit for averaging the alternating current components of the d-q axes currents by obtaining one of an effective value and an averaged absolute value of the alternating current components of the d-q axes currents obtained by the alternating current component detector, and a step-out detector for detecting a step-out by comparing at least one of the effective value and the averaged absolute value of the alternating current components of the d-q axes currents obtained by the alternating current component averaging unit with a predetermined step-out level signal. Therefore, the step-out can be detected accurately in a simplified configuration. Further, since the averaged values are used for detecting, an error in detecting the step-out due to a fluctuation in a load torque of the synchronous motor or a fluctuation in a voltage can be prevented. Further, it is possible to prevent the demagnetization of the magnet in the rotor of the synchronous motor and the damage in the switching devices in the inverter main circuit due an increase in the current, arising when the step-out state continues. Further, it is also possible to prevent a noise and vibrations of the synchronous motor arising when the step-out state continues.

The apparatus for detecting a step-out in a synchronous motor

according to this invention includes a current detector for detecting a current supplied to the synchronous motor, a d-q coordinate converter for converting a current signal obtained by the current detector into an exciting current component (d axis current) and a torque current component (q axis current), a current difference calculator for calculating a difference between the d-q axes currents obtained by the d-q axes converter and command values of the d-q axes currents, a current difference alternating current component detector for detecting alternating current components in the difference about the d-q axes currents obtained by the current difference calculator, and a step-out detector for detecting a step-out by comparing at least one of the alternating current components in the difference about the d-q axes currents obtained by the current difference alternating current component detector with a predetermined step-out level signal. Therefore, the step-out can be detected accurately in a simplified configuration. Further, it is possible to prevent the demagnetization of the magnet in the rotor or the damage in the switching devices in the inverter main circuit due an increase in the current, arising when the step-out state continues. Further, it is also possible to prevent a noise and vibrations of the synchronous motor arising when the step-out state continues.

The apparatus for detecting the step-out in the synchronous motor according to this invention can improve an accuracy in detecting the step-out as only a particular frequency component is detected when alternating current components are detected from the d-q axes currents.

The apparatus for detecting the step-out in the synchronous motor according to this invention can improve an accuracy in detecting the step-out as the particular frequency component is a frequency twice as high as a frequency of a voltage output from the inverter apparatus.

The apparatus for detecting the step-out in the synchronous motor according to this invention can improve an accuracy in detecting the step-out as only a particular frequency component is detected when alternating current components are detected from the difference about the d-q axes currents.

The apparatus for detecting the step-out in the synchronous motor according to this invention can detect the step-out without an influence from the fluctuation in the load torque and the direct current voltage as the step-out detection level compared with the averaged value of the alternating current component of the q axis current is approximately 200% of a rating current of the synchronous motor.

The apparatus for detecting the step-out in the synchronous motor according to this invention can detect the step-out by increasing a velocity till reaching a velocity of a normal operation immediately after starting when it is difficult to detect the step-out during a low velocity rotation.

The apparatus for detecting the step-out in the synchronous motor according to this invention can detect the step-out by performing a detection operation without increasing or reducing a velocity of the synchronous motor

when there is a possibility of an error in detecting the step-out by increasing or reducing the velocity of the synchronous motor.

The apparatus for detecting a step-out in a synchronous motor according to this invention includes a current detector for detecting a current supplied to the synchronous motor, an output voltage command calculator for calculating output voltage command values applied to the synchronous motor based on a current signal obtained by the current detector, an output voltage vector calculator for calculating an output voltage vector based on the output voltage command values obtained by the output voltage command calculator, an output voltage error detector for comparing a scalar of the output voltage vector obtained by the output voltage vector calculator with a step-out detection level, and a step-out detector for detecting a step-out based on a comparison result obtained by the output voltage error detector. Therefore, the step-out can be detected accurately in a simplified configuration. Further, it is possible to prevent the demagnetization of the magnet in the rotor of the synchronous motor and the damage in the switching devices in the inverter main circuit due to an increase in the current, arising when the step-out state continues. Further, it is also possible to prevent a noise and vibrations of the synchronous motor arising when the step-out state continues.

A method for detecting a step-out in a synchronous motor according to this invention includes current detecting step for detecting a current supplied to the synchronous motor, d-q coordinate converting step for converting a current signal obtained in current detecting step into an exciting current

component (d axis current) and a torque current component (q axis current), alternating current component detecting step for obtaining alternating current components of d-q axes currents obtained in d-q coordinate converting step, and step-out detecting step for detecting a step-out by comparing at least one of alternating current components of the d-q axes currents obtained in alternating current component detecting step with a predetermined step-out level signal. Therefore, the step-out can be detected accurately in a simplified configuration. Further, it is possible to prevent the demagnetization of the magnet in the rotor and the damage in the switching devices in the inverter main circuit due an increase in the current, arising when the step-out state continues. Further, it is also possible to prevent a noise and vibrations of the synchronous motor arising when the step-out state continues.

The method for detecting a step-out in a synchronous motor according to this invention includes current detecting step for detecting a current supplied to the synchronous motor, d-q coordinate converting step for converting a current signal obtained in current detecting step into an exciting current component (d axis current) and a torque current component (q axis current), alternating current component detecting step for obtaining alternating current components of d-q axes currents obtained in d-q coordinate converting step, alternating current component averaging step for averaging the alternating current components of the d-q axes currents by obtaining one of an effective value and an averaged absolute value of the alternating current components of the d-q axes currents obtained in alternating current component detecting step and step-out detecting step for detecting a step-out by

comparing at least one of the effective value and the averaged absolute value of the alternating current components of the d-q axes currents obtained in alternating current component averaging step with a predetermined step-out level signal. Therefore, the step-out can be detected accurately in a simplified configuration. Further, since the averaged values are used for detecting, an error in detecting the step-out due to a fluctuation in a load torque or a voltage can be prevented. Further, it is possible to prevent the demagnetization of the magnet in the rotor or the damage in the switching devices in the inverter main circuit due to an increase in the current, arising when the step-out state continues. Further, it is also possible to prevent a noise and vibrations of the synchronous motor arising when the step-out state continues.

The method for detecting a step-out in a synchronous motor according to this invention includes current detecting step for detecting a current supplied to the synchronous motor, d-q coordinate converting step for converting a current signal obtained in current detecting step into an exciting current component (d axis current) and a torque current component (q axis current), current difference calculating step for calculating a difference between the d-q axes currents obtained in d-q coordinate converting step and command values of the d-q axes currents, current difference alternating current component detecting step for obtaining alternating current components in the difference about the d-q axes currents obtained in current difference calculating step, and step-out detecting step for detecting a step-out by comparing at least one of the alternating current components in the difference about the d-q axes currents obtained in current difference

alternating current component detecting step with a predetermined step-out level signal. Therefore, the step-out can be detected accurately in a simplified configuration. Further, it is possible to prevent the demagnetization of the magnet in the rotor or the damage in the switching devices in the inverter main circuit due to an increase in the current, arising when the step-out state continues. Further, it is also possible to prevent a noise and vibrations of the synchronous motor arising when the step-out state continues.

The method for detecting the step-out in the synchronous motor according to this invention can improve an accuracy in detecting the step-out as only a particular frequency component is detected when alternating current components are detected from the d-q axes currents.

The method for detecting the step-out in the synchronous motor according to this invention can improve an accuracy in detecting the step-out as the particular frequency component is a frequency twice as high as a frequency of a voltage output from the inverter apparatus.

The method for detecting the step-out in the synchronous motor according to this invention can improve an accuracy in detecting the step-out as only a particular frequency component is detected when alternating current components are detected from the difference of the d-q axes currents.

In the method for detecting the step-out in the synchronous motor

according to this invention, the step-out can be always detected without an influence from the fluctuation in the load torque and the direct current voltage as the step-out detection level compared with the averaged value of the alternating current component of the q axis current is approximately 200% of a rating current of the synchronous motor.

In the method for detecting the step-out in the synchronous motor according to this invention, the step-out can be always detected without an influence from the fluctuation in the load torque and the direct current voltage as the step-out is detected by increasing a velocity till reaching a velocity of a normal operation immediately after starting when it is difficult to detect the step-out during a low velocity rotation.

In the method for detecting the step-out in the synchronous motor according to this invention, the step-out is detected by performing a detection operation without increasing or reducing a velocity of the synchronous motor when there is a possibility of an error in detecting the step-out by increasing or reducing the velocity of the synchronous motor.

The method for detecting a step-out in a synchronous motor according to this invention includes current detecting step for detecting a current supplied to the synchronous motor, output voltage command calculating step for calculating output voltage command values applied to the synchronous motor based on a current signal obtained in current detecting step, output voltage vector calculating step for calculating an output voltage vector based

on the output voltage command values obtained in output voltage command calculating step, output voltage error detecting step for comparing a scalar of the output voltage vector obtained in output voltage vector calculating step with a step-out detection level, and step-out detecting step for detecting a step-out based on a comparison result obtained in output voltage error detecting step. Therefore, the step-out can be detected accurately in a simplified configuration. Further, it is possible to prevent the demagnetization of the magnet in the rotor and the damage in the switching devices in the inverter main due to an increase in the current, arising when the step-out state continues. Further, it is also possible to prevent a noise and vibrations of the synchronous motor arising when the step-out state continues.

A drive of a closed compressor according to this invention, by packaging the apparatus for detecting the step-out in the synchronous motor of Claims 1 - 10 can solve the problem, e.g., a noise of the compressor, a damage in a cooling pipe due to vibrations of the compressor, demagnetization of the magnet used for the rotor of the motor, and a damage in a semiconductor element of the inverter apparatus due to an increase in the current, arising when the step-out continues. Accordingly, a reliable refrigerator and a reliable air conditioner can be realized.

A drive of a fan motor according to this invention, by packaging the apparatus for detecting the step-out in the synchronous motor of Claims 1 - 10 can solve the problem, e.g., a noise of the fan motor, vibrations of the compressor, demagnetization of the magnet used for the rotor of the motor, and

a damage in a semiconductor element of the inverter apparatus due to an increase in the current arising when the step-out continues. Accordingly, a reliable refrigerator and a reliable air conditioner can be realized.

Having thus described several particular embodiments of the invention, various alterations, modifications, and improvements will readily occur to those skilled in the art. Such alterations, modifications, and improvements are intended to be part of this disclosure, and are intended to be within the spirit and scope of the invention. Accordingly, the foregoing description is by way of example only and is limited only as defined in the following claims and the equivalents thereto.

CLAIMS:

1. An apparatus for detecting a step-out in a synchronous motor in an inverter apparatus for driving the synchronous motor without using a positioning sensor for detecting a position of a rotor comprising:

a current detector for detecting a current supplied to the synchronous motor;

a d-q coordinate converter for converting a current signal obtained by the current detector into an exciting current component (d axis current) and a torque current component (q axis current);

an alternating current component detector for obtaining alternating current components of d-q axes currents obtained by the d-q coordinate converter; and

a step-out detector for detecting a step-out by comparing at least one of alternating current components of the d-q axes currents with a predetermined step-out level signal.

2. An apparatus for detecting a step-out in a synchronous motor in an inverter apparatus for driving the synchronous motor without using a positioning sensor for detecting a position of a rotor comprising:

a current detector for detecting a current supplied to the synchronous motor;

a d-q coordinate converter for converting a current signal obtained by the current detector into an exciting current component (d axis current) and a torque current component (q axis current);

an alternating current component detector for obtaining alternating current components of d-q axes currents obtained by the d-q coordinate converter;

an alternating current component averaging unit for averaging the alternating current components of the d-q axes currents by obtaining one of an effective value and an averaged absolute value of the alternating current components of the d-q axes currents obtained by the alternating current component detector; and

a step-out detector for detecting a step-out by comparing at least one of the effective value and the averaged absolute value of the alternating current components of the d-q axes currents obtained by the alternating current component averaging unit with a predetermined step-out level signal.

3. An apparatus for detecting a step-out in a synchronous motor in an inverter apparatus for driving the synchronous motor without using a positioning sensor for detecting a position of a rotor comprising:

a current detector for detecting a current supplied to the synchronous motor;

a d-q coordinate converter for converting a current signal obtained by the current detector into an exciting current component (d axis current) and a torque current component (q axis current);

a current difference calculator for calculating a difference between the d-q axes currents obtained by the d-q axes converter and command values of the d-q axes currents;

a current difference alternating current component detector for detecting alternating current components in the difference about the d-q axes currents obtained by the current difference calculator; and

a step-out detector for detecting a step-out by comparing at least one of the alternating current components in the difference about the d-q axes currents obtained by the current difference alternating current component detector with a predetermined step-out level signal.

4. The apparatus for detecting the step-out in the synchronous motor of Claims 1 or 2, wherein only a particular frequency component is detected when alternating current components are detected from the d-q axes currents.

5. The apparatus for detecting the step-out in the synchronous motor of Claim 4, wherein the particular frequency component is a frequency twice as high as a frequency of a voltage output from the inverter apparatus.

6. The apparatus for detecting the step-out in the synchronous motor of Claim 3, wherein only a particular frequency component is detected when alternating current components are detected from the difference about the d-q axes currents.

7. The apparatus for detecting the step-out in the synchronous motor of Claim 2, wherein the step-out detection level compared with the averaged values of the alternating current component of the q axis current is approximately 200% of a rating current of the synchronous motor.

8. The apparatus for detecting the step-out in the synchronous motor of one of Claims 1 - 3, wherein the step-out is detected by increasing a velocity till reaching a velocity of a normal operation immediately after

starting when it is difficult to detect the step-out during a low velocity rotation.

9. The apparatus for detecting the step-out in the synchronous motor of one of Claims 1 - 3, wherein the step-out is detected without increasing or reducing a velocity of the synchronous motor when there is a possibility of an error in detecting the step-out by increasing or reducing the velocity of the synchronous motor.

10. The apparatus for detecting the step-out in a synchronous motor of Claims 1 or 3, comprising:

an output voltage command calculator for calculating output voltage command values applied to the synchronous motor based on a current signal obtained by the current detector;

an output voltage vector calculator for calculating an output voltage vector based on the output voltage command values obtained by the output voltage command calculator;

an output voltage error detector for comparing a scalar of the output voltage vector obtained by the output voltage vector calculator with a step-out detection level; and

wherein the step-out detector detects a step-out based on a comparison result obtained by the output voltage error detector.

11. A method for detecting a step-out in a synchronous motor in an inverter apparatus for driving the synchronous motor without using a positioning sensor for detecting a position of a rotor comprising:

current detecting step for detecting a current supplied to the synchronous motor;

d-q coordinate converting step for converting a current signal obtained in current detecting step into an exciting current component (d axis current) and a torque current component (q axis current);

alternating current component detecting step for obtaining alternating current components of d-q axes currents obtained in d-q coordinate converting step; and

step-out detecting step for detecting a step-out by comparing at least one of alternating current components of the d-q axes currents obtained in alternating current component detecting step with a predetermined step-out level signal.

12. A method for detecting a step-out in a synchronous motor in an inverter apparatus for driving the synchronous motor without using a positioning sensor for detecting a position of a rotor comprising:

current detecting step for detecting a current supplied to the synchronous motor;

d-q coordinate converting step for converting a current signal obtained in current detecting step into an exciting current component (d axis current) and a torque current component (q axis current);

alternating current component detecting step for obtaining alternating current components of d-q axes currents obtained in d-q coordinate converting step;

alternating current component averaging step for averaging the alternating current components of the d-q axes currents by obtaining one of an effective value and an averaged absolute value of the alternating current

components of the d-q axes currents obtained in alternating current component detecting step; and

step-out detecting step for detecting a step-out by comparing at least one of the effective value and the averaged absolute value of the alternating current components of the d-q axes currents obtained in alternating current component averaging step with a predetermined step-out level signal.

13. A method for detecting a step-out in a synchronous motor in an inverter apparatus for driving the synchronous motor without using a positioning sensor for detecting a position of a rotor comprising:

current detecting step for detecting a current supplied to the synchronous motor;

d-q coordinate converting step for converting a current signal obtained in current detecting step into an exciting current component (d axis current) and a torque current component (q axis current);

current difference calculating step for calculating a difference between the d-q axes currents obtained in d-q coordinate converting step and command values of the d-q axes currents;

current difference alternating current component detecting step for obtaining alternating current components in the difference about the d-q axes currents obtained in current difference calculating step; and

step-out detecting step for detecting a step-out by comparing at least one of the alternating current components in the difference about the d-q axes currents obtained in current difference alternating current component detecting step with a predetermined step-out level signal.

14. The method for detecting the step-out in the synchronous motor of Claims 11 or 12, wherein only a particular frequency component is detected when alternating current components are detected from the d-q axes currents.

15. The method for detecting the step-out in the synchronous motor of Claim 14, wherein the particular frequency component is a frequency twice as high as a frequency of a voltage output from the inverter apparatus.

16. The method for detecting the step-out in the synchronous motor of Claim 13, wherein only a particular frequency component is detected when alternating current components are detected from the difference of the d-q axes currents.

17. The method for detecting the step-out in the synchronous motor of Claim 12, wherein the step-out detection level compared with at least one of the effective value and the averaged absolute value of the alternating current components of the q axis current is approximately 200% of a rating current of the synchronous motor.

18. The method for detecting the step-out in the synchronous motor of one of Claims 11 - 13, wherein the step-out is detected by increasing a velocity till reaching a velocity of a normal operation immediately after starting when it is difficult to detect the step-out during a low velocity rotation.

19. The method for detecting the step-out in the synchronous motor of one of Claims 11 - 13, wherein the step-out is detected without increasing or reducing a velocity of the synchronous motor when there is a possibility

of an error in detecting the step-out by increasing or reducing the velocity of the synchronous motor.

20. The method for detecting the step-out in a synchronous motor of claim 11 or 13 comprising:

output voltage command calculating step for calculating output voltage command values applied to the synchronous motor based on a current signal obtained in current detecting step;

output voltage vector calculating step for calculating an output voltage vector based on the output voltage command values obtained in output voltage command calculating step;

output voltage error detecting step for comparing a scalar of the output voltage vector obtained in output voltage vector calculating step with a step-out detection level; and

wherein the step-out detecting step detects a step-out based on a comparison result obtained in output voltage error detecting step.

21. A drive of a closed compressor, wherein the apparatus for detecting the step-out in the synchronous motor of one of Claims 1 - 10 is packaged.

22. A drive of a fan motor, wherein the apparatus for detecting the step-out in the synchronous motor of one of Claims 1 - 10 is packaged.

**An Apparatus For Detecting A Step-Out In A Synchronous Motor,  
A Method For Detecting The Step-Out In The Synchronous Motor, A  
Drive of A Closed Compressor, And A Drive Of A Fan Motor**

**Abstract**

This invention provides an apparatus for detecting a step-out in a synchronous motor (6). In an inverter apparatus (2) for driving the synchronous motor (6) without using a positioning sensor for detecting a position of a rotor, a current detector (7) for detecting current supplied to the synchronous motor (6), a d-q coordinate converter (11) for converting a current signal obtained by the current detector (7) into an exciting current component (d axis current) and a torque current component (q axis current), an alternating current component detector (15) for obtaining alternating current components of d-q axes currents obtained by the d-q coordinate converter (11), and a step-out detector (16) for detecting the step-out by comparing at least one of the alternating current components of the d-q axes currents obtained by the alternating current component detector (15) with a predetermined step-out level signal are provided.

Fig. 1