An Estimation Method of Rotational Direction and Speed for Free-Running AC Machines Without Speed and Voltage Sensor

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***Abstract*—This paper presents an estimation method of rotational direction and speed for free-running ac machines driven by an inverter without speed and voltage sensor. The method has four estimation modes, and it utilizes only the measured phase current of machines. The performance of the proposed method is verified through the experiments for both permanent-magnet synchronous motor and asynchronous machines.**

***Index Terms*—AC machines, estimation of rotational direction and speed, free running, without speed and voltage sensor.**

I. INTRODUCTION

RECENTLY, fan and turbine systems driven by variable speed ac drives have been popular owing to the trend of energy saving for global environment protection. In such system, sometimes ac machines rotate by external torque such as water flow or wind power without being energized by inverters. In those cases, overvoltage or overcurrent faults can occur if the rotating motor and inverter voltage are out of phase. In order to avoid trips, rotating speed and direction of the machine are required to synchronize an inverter with the machine. However, most of the systems are speed sensorless drives. Therefore, speed estimation is required. For example, the inertia of the fan systems is 50–300 times bigger than that of the ac machines, and it does not stop for a few minutes up to several tens of minutes during free running of the machines. Even with such sensorless drives, the inverters are required for smooth and faultless driving of the ac machines. Considering such condition, a speed estimation method for asynchronous machine has been proposed [1], but it has difficulty in implementation from a practical point of view. Some flux and speed estimation methods for permanent-magnet synchronous machines (PMSMs) have been proposed [2]–[4], but they cannot be applied to the speed estimation of the asynchronous machine because back electromotive force (EMF) does not remain long enough for the estimation. This paper proposes an estimation method of rotational direction and speed according to the characteristic of the ac machine. This method is possible to take control of the machine seamlessly by an inverter.

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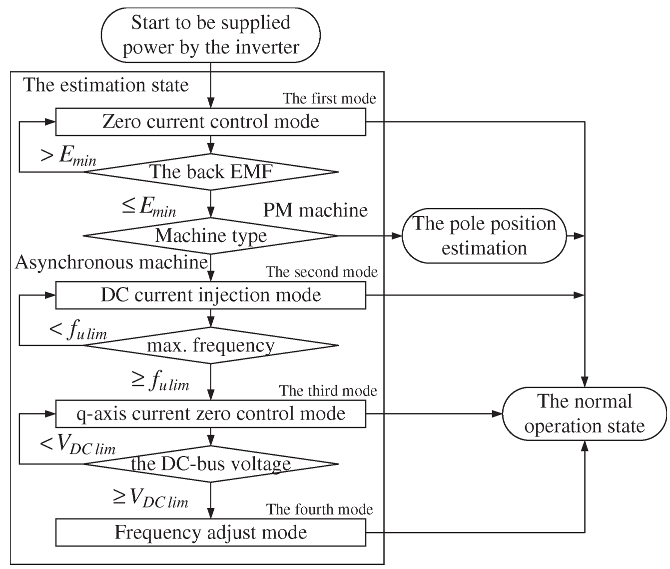


Fig. 1. Flowchart of the estimation mode shift sequence.

II. ESTIMATION METHOD

Fig. 1 shows the flowchart of the mode shift sequence when the inverter supplies the power to a machine. The sequence usually shifts from the estimation state to the normal operation state when speed and rotational direction are estimated by the estimation method. The estimation method of the rotational direction and speed has four modes. The method sequentially executes each mode until the estimation of rotational direction and speed is completed. The proposed method is able to select the executing mode according to the kind of machines and/or the characteristic of the machines.

The first mode is most suitable for estimating PMSM machines or asynchronous machines with a long rotor time constant. In this mode, the rotational direction and speed can be estimated by the back EMF. The first mode detects the back EMF by controlling the motor current to zero. The first mode is called the zero-current control mode. When the back EMF is less than the setting value $E_{\min}$, the speed and the rotational direction cannot be correctly estimated by the first mode. In case of the asynchronous machine, the back EMF reduces even though the machine rotates. Therefore, asynchronous machine needs the estimation mode that is not based on the back EMF. The mode shifts from the first mode to the second mode. Since the back EMF is generated whenever PMSM rotates, it is standstill or low speed. In this case, the method shifts into the pole-position estimation state. The pole position or initial pole-position method of the PMSM is proposed by a high-frequency injection method [5]. However, the magnetic pole-position detection might be disturbed if the rotor were not standstill. In that case, power devices on the P side (or N side) of the inverter are turned on at the same time. Then, the PMSM machine is stopped by a short-circuited current. The method shifts from the pole-position state to the normal operation state. Thus, the estimation method for PMSM machine is applied only in the first mode.

The method shifts from the first mode to the second mode when the first mode is not able to detect the back EMF of the asynchronous machine because the back EMF is too low. The second mode injects dc current to the machine. The q-axis current which is a torque-producing current in the rotational reference frame (d–q frame) flows to the machine, when the free-running machine is excited by the dc current. The rotational direction and the speed are estimated from the frequency of the q-axis current. The second mode is called the dc current injection mode.

The method shifts from the second mode to the third mode when the second mode is not able to detect the frequency from the q-axis current. It is difficult to detect the frequency of the q-axis current of the super-high speed free-running machine due to the limitation of CPU sampling time T_s. If the maximum frequency of the machine is higher than the limit frequency $f_{u\,\mathrm{lim}}$, then the second mode shifts to the third mode.

The third mode injects the exciting current to the d-axis of the machine and adjusts the rotational direction and the speed from the q-axis current which is controlled to zero. The third mode is called the q-axis current zero control mode. However, the q-axis current flows through the back EMF. Inverter internal capacitors are charged by the q-axis current. If the dc-bus voltage rises up to the dc-bus voltage limit level $V_{\mathrm{dc\,lim}}$, then the method shifts from the third mode to the fourth mode.

The fourth mode estimates the speed by adjusting the frequency while observing the output current. The fourth mode is called the frequency-adjust mode.

These modes are explained in detail as follows.

A. Zero-Current Control Mode for PMSM Machine

Fig. 2 shows the block diagram of the zero-current control mode. Fig. 3 shows the timing chart of the zero-current control mode for PMSM machine. The mode starts with turning on all switches from A side to B side; the d-axis current command I_d^*, the q-axis current command I_q^*, the d-axis prevoltage command V_d^*, the q-axis prevoltage command V_q^*, and the flux phase θ are set to zero. If the machine is rotating, the current induced by the back EMF flows during the zero control mode. The amplitude and phase of inverter output voltage will be synchronized with

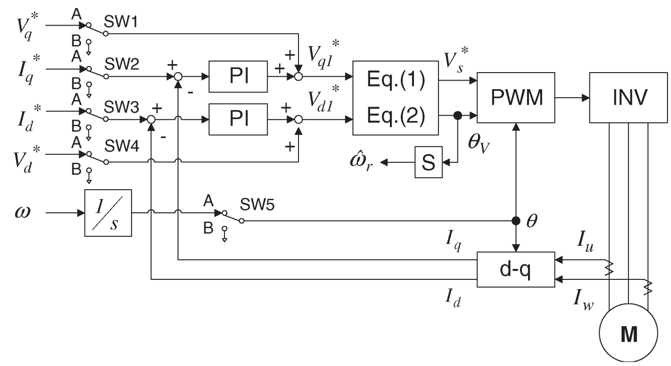


Fig. 2. Block diagram of the zero-current control mode.

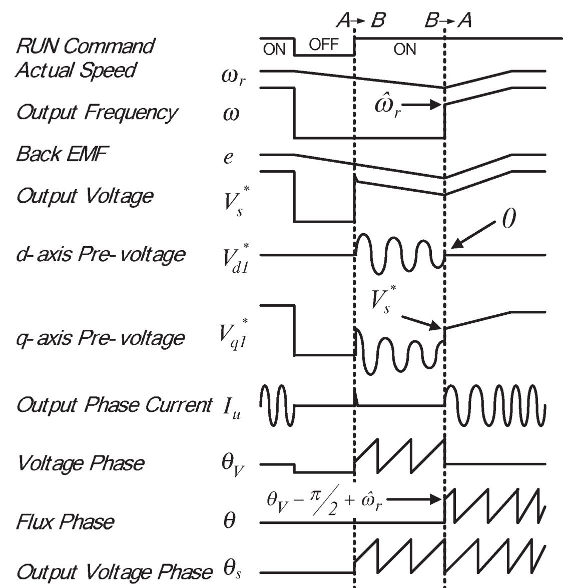


Fig. 3. Timing chart of the zero-current control mode for PMSM.

that of the back EMF if the output current is zero. The output voltage command V_s^* and the voltage phase θ_V are shown in (1) using the d-axis voltage command V_{d1}^* and the q-axis voltage command V_{q1}^*

$$V_s^* = \sqrt{V_{d1}^{*2} + V_{q1}^{*2}} \tag{1}$$

$$\theta_V = \tan^{-1}\frac{V_{q1}^*}{V_{d1}^*}. \tag{2}$$

Fig. 4(a) shows the locus of the output voltage vector and the variations of the d-axis voltage command V_{d1}^* and the q-axis voltage command V_{q1}^* when the machine is rotating in forward direction; Fig. 4(b) shows the case of the reverse direction.

The output voltage phase θ_V contains the information of the rotational direction and the speed. Therefore, the estimated speed $\hat{\omega}_r$ of the machine is calculated from the output voltage phase θ_V as follows:

$$\hat{\omega}_r = \frac{d\theta_V}{dt}. \tag{3}$$

The polarity of the estimated speed $\hat{\omega}_r$ of the machine is plus when the machine is rotating forward. The method shifts from the estimated state to the normal operation state when the

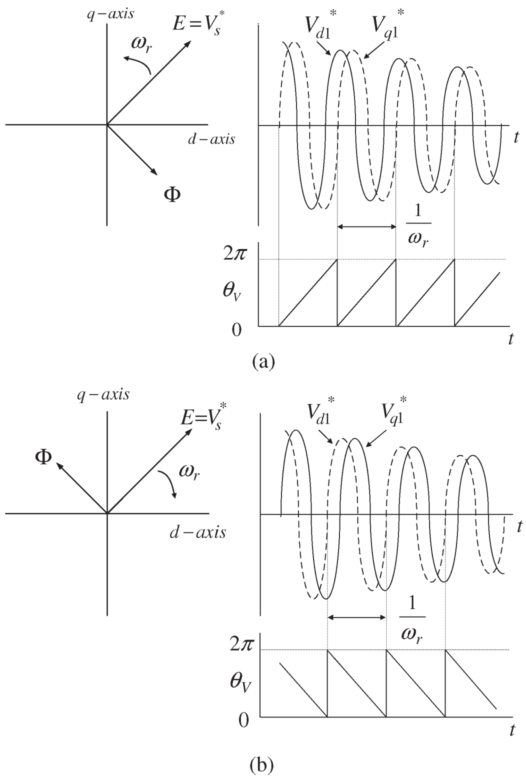


Fig. 4. Locus and the variations of the phase of the output voltage. (a) Forward direction. (b) Reverse direction.

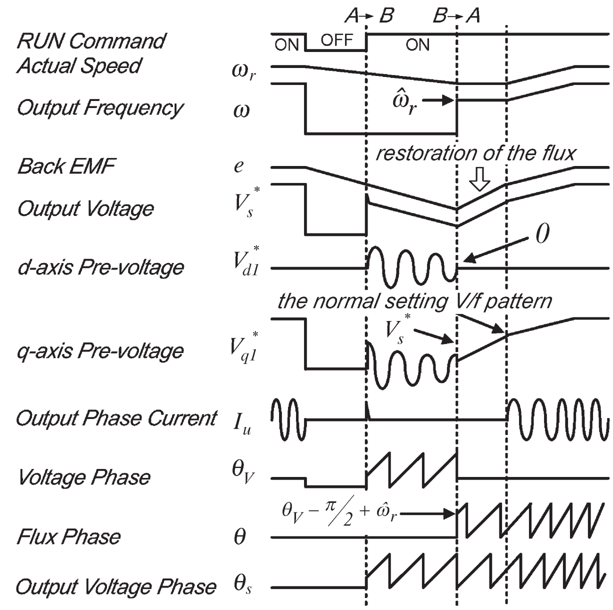


Fig. 5. Timing chart of the zero-current control mode for asynchronous machine.

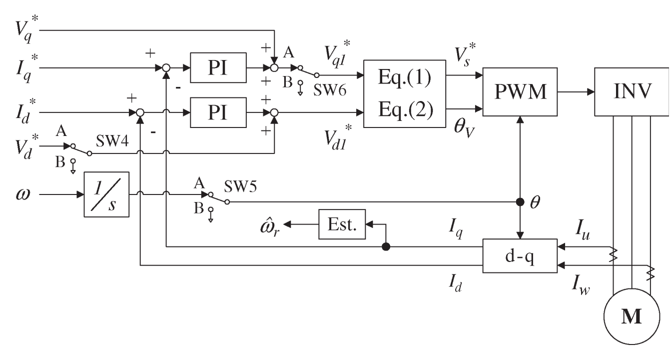


Fig. 6. Block diagram of the dc current injection mode.

method is able to detect them. The amplitude, phase, rotational direction, and frequency of the inverter output voltage are used as an initial condition of the normal operation. The d-axis prevoltage command V_d^* and the q-axis prevoltage command V_q^* are set, respectively, depending on the next equations

$$V_d^* = 0 \tag{4}$$

$$V_q^* = \begin{cases} V_s^* & \text{(forward)} \\ -V_s^* & \text{(reverse)}. \end{cases} \tag{5}$$

The output frequency ω is set the same as the estimated speed in (3)

$$\omega = \hat{\omega}_r. \tag{6}$$

The d-axis is fixed to the u-phase of the stator in the estimated state. However, the d–q-axes should be rotated in the normal operation state. Therefore, the flux phase θ should be set as follows:

$$\theta = \begin{cases} \theta_V - \frac{\pi}{2} + \hat{\omega}_r \cdot T_s & \text{(forward)} \\ \theta_V + \frac{\pi}{2} - \hat{\omega}_r \cdot T_s & \text{(reverse)} \end{cases} \tag{7}$$

where T_s is the sampling time of the current control.

After the estimated state is over, all switches are turned on from B side to A side. Then, the machine starts accelerating or decelerating according to the speed command.

B. Zero-Current Control Mode for Asynchronous Machine

Naturally, the estimation principle of the speed and the rotational direction of the zero-current control mode for asynchronous machine is the same as that of the PMSM machine. Therefore, the same block diagram is used, as shown in Fig. 2. However, the residual flux of the asynchronous machine weakens according to the rotor time constant. The difference between the PMSM machine mode and asynchronous machine in the mode appears in the q-axis voltage amplitude. Therefore, the timing chart changes as shown in Fig. 5. Due to the decay of rotor flux, estimated q-axis voltage is smaller than normal voltage to frequency (V/F) level. Therefore, the q-axis prevoltage command V_q^* is needed to increase up to the voltage referred to the normal V/F level according to output frequency ω. Then, the machine accelerates or decelerates according to the speed command.

C. DC Current Injection Mode

Figs. 6 and 7 show the block diagram and the timing chart of the dc injection mode. It starts with turning on all switches from A side to B side, then the d-axis voltage command V_d^*, the q-axis voltage command V_{q1}^*, and the flux phase θ are set to zero. The d-axis is fixed to the u-phase. It is important to control only the d-axis current because the speed information is detected from the variations of the q-axis current. When the dc

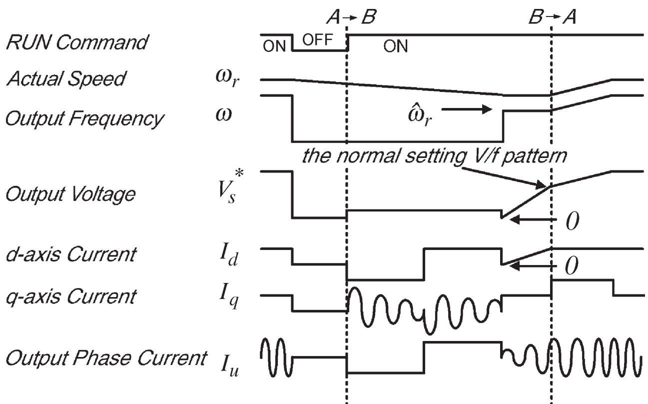


Fig. 7. Timing chart of the dc current injection mode.

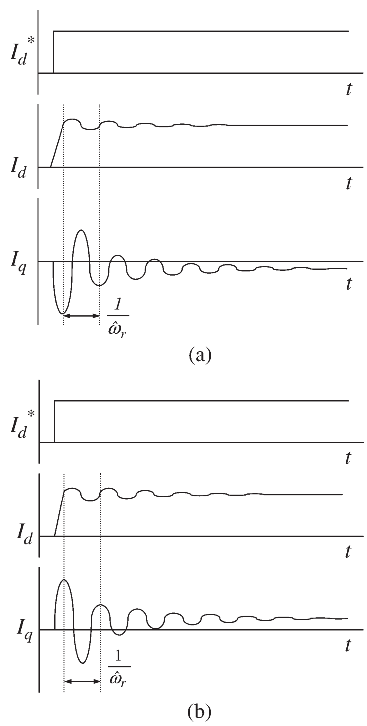


Fig. 8. d-axis current and the q-axis current waves of the injected dc current of the machine. (a) Forward direction. (b) Reverse direction.

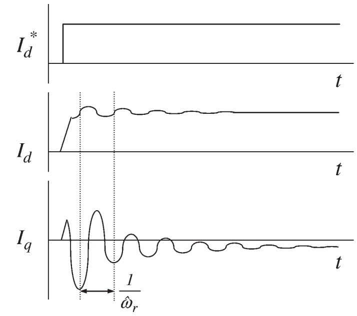


Fig. 9. Effect of the residual flux at forward rotation.

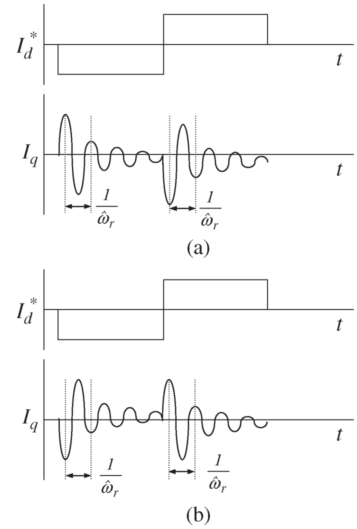


Fig. 10. q-axis current waveform while the dc current is injected into the machine. (a) Forward direction. (b) Reverse direction.

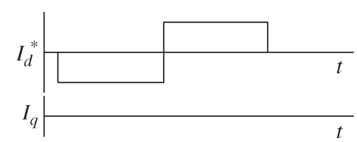


Fig. 11. q-axis current wave of the injected dc current at the stop condition of the machine.

current is injected to the machine, the primary flux is excited. If the machine is rotating, the q-axis current will flow by the generated back EMF in the rotor. The frequency of the q-axis current corresponds to the speed of the machine. The speed of the machine can be estimated by detecting the frequency of the q-axis current.

Fig. 8(a) shows the d-axis current and the q-axis current waveforms of the injected dc current of the machine when the machine is rotating in forward direction, and Fig. 8(b) shows the case of the reverse direction. The phase of the oscillating component in the q-axis current lags compared to that in the d-axis current, or the q-axis current starts from the minus direction when the machine is rotating in forward direction. The phase of the oscillating component in the q-axis current goes ahead of that in the d-axis current, or the q-axis current starts from the plus direction. However, the phase of the exited flux is affected by the phase of the small residual flux in the machine as shown in Fig. 9. The q-axis current might not start from minus direction at forward rotating. The amplitude of the frequency of the q-axis current becomes small as time elapses. Therefore, the residual flux is reduced by the dc current, and then, the rotational direction is estimated. Specifically, the effect of the residual flux can be neglected after the half cycle of the primary flux frequency has passed. Fig. 10(a) shows the q-axis current waveform when negative and positive dc currents are injected to the d-axis while the machine is rotating forward; Fig. 10(b) shows the case of the reverse rotation. The rotational direction of the machine is estimated by the sign of the q-axis current at positive polarity of the d-axis current command setting. The speed of the machine is estimated by the frequency of the q-axis current during dc current injection. If the machine is stopping, the q-axis current is zero shown in Fig. 11 because the injected dc current does not induced q-axis current at zero back EMF condition.

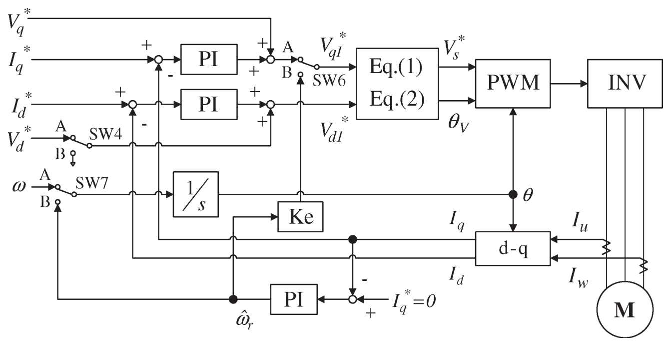


Fig. 12. Block diagram of the q-axis current zero control mode.

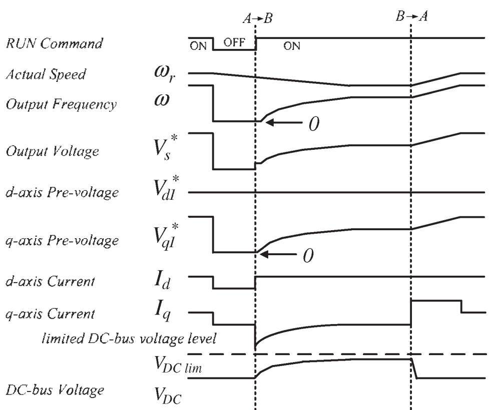


Fig. 13. Timing chart of the q-axis current zero control mode.

The method shifts from the estimated state to the normal operation state when the proceeding detection is over. The output frequency ω is set to the estimated frequency $\hat{\omega}_r$. If the back EMF is zero, the d-axis prevoltage command V_d^*, the q-axis prevoltage command V_q^*, the d-axis current command I_d^*, and the q-axis current command I_q^* are set to zero. The flux phase θ is set to zero. After setting them, all switches are switched from B side to A side. V_q^* and I_d^* should be increased according to the rotor time constant from zero to the normal setting V/f pattern. Then, the output frequency ω increases or decreases according to the speed command.

D. q-Axis Current Zero Control Mode

Figs. 12 and 13 show the block diagram and the timing chart of the q-axis current zero control mode. It starts with turning on all switches from A side to B side; the d-axis prevoltage command V_d^* and the frequency ω are set to zero. The d-axis current command I_d^* is set to the exciting current, and PI controller is used for the current control. When the machine is rotating, then the q-axis current I_q is induced by the back EMF. The dc-bus voltage V_{dc} rises because the q-axis current flows from the machine to the inverter. Although it is easy to control the q-axis current so that the dc-bus voltage does not rise, the q-axis current I_q must not be controlled because it contains the important speed information. If the machine is rotating forward, the q-axis current I_q flows into the minus direction by the back EMF. This principle is explained by using Figs. 14 and 15.

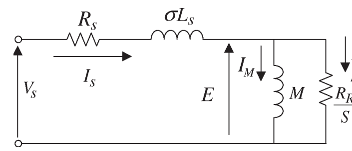


Fig. 14. Equivalent circuit of the asynchronous machine.

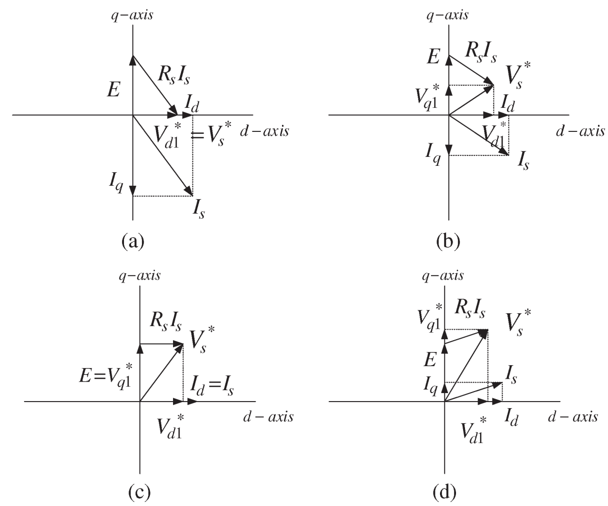


Fig. 15. Voltage and the current vector diagram. (a) $\omega = 0$. (b) $\omega < \hat{\omega}_r$. (c) $\omega = \hat{\omega}_r$. (d) $\omega > \hat{\omega}_r$.

Fig. 14 shows the equivalent circuit of the asynchronous machine, where

R_s stator resistance;
S slip;
R'_R rotor resistance;
σL_s leakage inductance;
M mutual inductance;
V_S stator voltage;
I_s stator current;
I_M excited current;
E back EMF;
I_R rotor current.

Fig. 15 shows the voltage and the current vector diagram of the equivalent circuit shown in Fig. 14. The vector diagram can have four different states according to output frequency and the machine's speed. Fig. 15(a) shows the vector diagram when the output frequency is zero. Fig. 15(b) shows the vector diagram when the output frequency is lower than the machine's speed. In Fig. 15(c), the output frequency corresponds to the machine's speed. In Fig. 15(d), the output frequency is higher than the machine's speed. The output frequency ω is adjusted so that the q-axis current I_q becomes zero, and then, the output frequency ω corresponds to the speed of the machine. If the machine is rotating in reverse direction, the polarity of the generated back EMF in the rotor is minus, and the polarity of the q-axis current I_q is plus. Therefore, rotational direction and speed can be estimated by the q-axis current.

The speed is estimated by a PI controller that adjusts the output frequency ω so as to have the q-axis current I_q zero. The q-axis voltage command V_{q1}^* is calculated by the estimated frequency $\hat{\omega}_r$ and the rotor time constant of the machine. Since the q-axis current I_q is determined by the potential difference

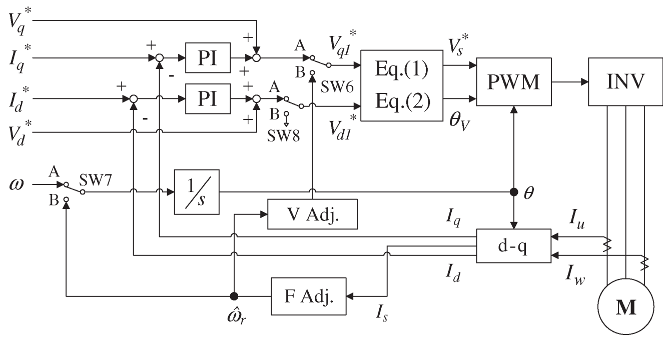


Fig. 16. Block diagram of the frequency-adjust mode.

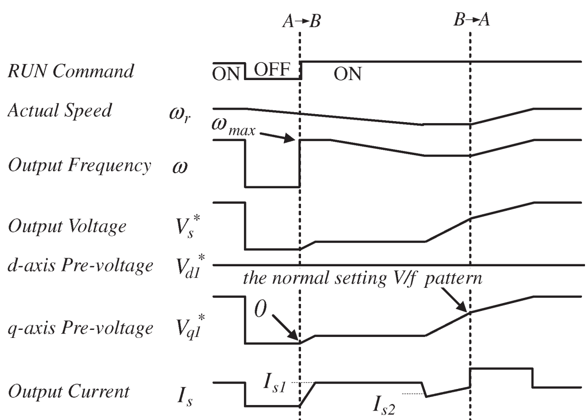


Fig. 17. Timing chart of the frequency-adjust mode.

between V_{q1}^* and the back EMF, it is necessary to keep V_{q1}^* the same as the back EMF which changes according to the rotor time constant.

The method shifts from the estimated state to the normal operation state when the q-axis current becomes zero and the q-axis voltage becomes the value related to the normal set V/f pattern. The frequency ω is set to the estimated frequency $\hat{\omega}_r$. The q-axis prevoltage command V_q^* is set to the q-axis voltage command V_{q1}^*. After then, all switches are switched from B side to A side.

The q-axis current I_q is a function of the machine's speed, the machine's impedance, the machine's inertia, and the free-running speed of the machine, etc. The q-axis current cannot be controlled directly; therefore, the dc-bus voltage V_{dc} can reach the voltage limit level $V_{\mathrm{dc\,lim}}$. In that case, the fourth speed estimation mode can be applied.

E. Frequency-Adjust Mode

Figs. 16 and 17 show the block diagram and the timing chart of the frequency-adjust mode. It starts with switching all switches from A side to B side, and the d-axis voltage command V_{d1}^* is set to zero. The frequency adjustor is set to the maximum frequency of the machine. The voltage adjustor increases the q-axis voltage command V_{q1}^* from zero to the maximum value according to the rotor time constant of the machine.

The estimation principle can be explained with Fig. 14. The amplitude of the output current I_s is determined by slip S that is the difference between the output frequency ω and the actual

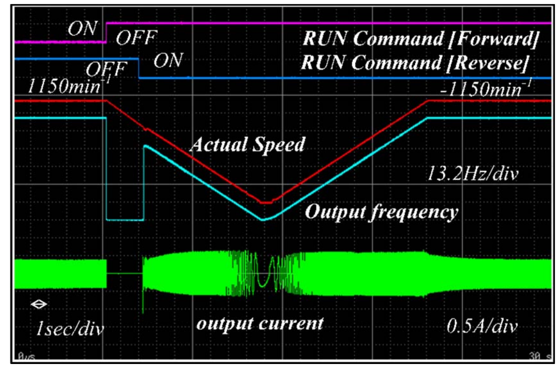


Fig. 18. Waveform in the zero-current control mode for PMSM.

speed ω_r. When the machine is standstill (i.e., the slip $S = 1$), then the output current can be obtained as follows:

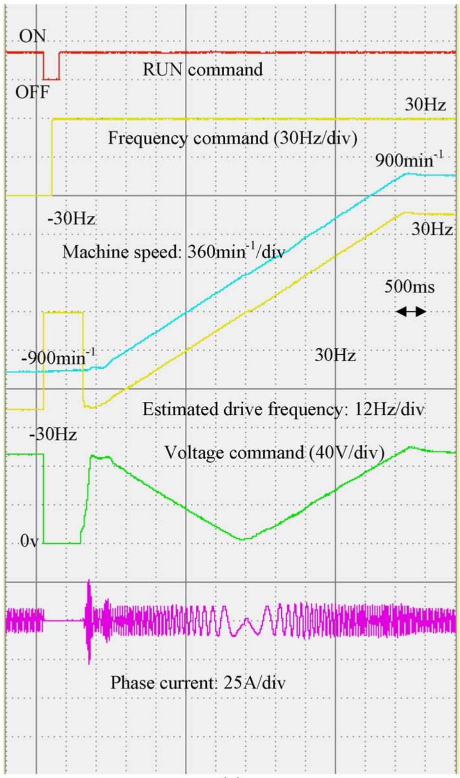
$$I_s = \frac{1}{\sqrt{(R_s + R_R')^2 + \omega^2 \sigma L_s^2}} V_s. \tag{8}$$

In this case, current to the mutual inductance is negligible. When the machine rotate at synchronous speed (i.e., the slip $S = 0$), then the output current can be obtained as follows:

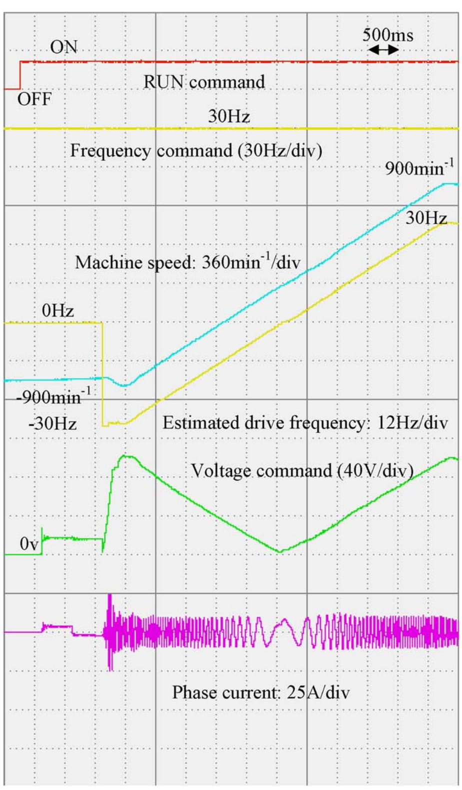
$$I_s = \frac{1}{\sqrt{R_s^2 + (\omega \sigma L_s + \omega M)^2}} V_s. \tag{9}$$

In this case, the output current I_s does not flow to the rotor resistance and (9) is the amplitude of the exciting current or the no-load current.

The output current I_s depends on the stator voltage and slip as shown in (8) and (9). Therefore, I_s increases gradually according to the increase of the stator voltage. Even if the stator voltage reaches the maximum value at the synchronous speed, the amplitude of the output current I_s is obtained from (9). The amplitude of the output current I_s is obtained from (8) when the machine is at stop or low-speed condition. The machine can accelerate to the maximum speed with large starting inrush current. However, the mechanical shock of the machine or the overload fault of the inverter might occur. If the output current I_s is larger than the setting level I_{s1} before the q-axis voltage command V_{q1}^* reaches the maximum, the q-axis voltage command V_{q1}^* is held. The level I_{s1} is set to 15%–25% bigger than the exciting current level. This level is suitable for precise speed estimation preventing torque shock. Then, the q-axis voltage command V_{q1}^* is held while the frequency adjustor reduces the frequency ω. When the current increases further, the frequency command is held and the voltage command V_{q1}^* is reduced. After then, the q-axis voltage command V_{q1}^* is held, while the frequency adjustor reduces frequency ω again. The output current I_s is getting closer to the exciting current level if the output frequency corresponds to the speed of the machine. When the output current I_s is lower than the other setting level I_{s2}, the frequency ω remains constant, and the q-axis voltage command V_{q1}^* is increased again where I_{s2} is set to 5%–10% higher than the exciting current level. The method shifts from the estimated state to the normal operation state when the output current I_s is smaller than the setting level I_{s1} and the same voltage as the normal V/f pattern. The output frequency ω is set



(a)



(b)

Fig. 19. Waveform in the method for asynchronous machine. (a) Zero-current control mode for asynchronous machine. (b) DC current injection mode.

to the estimated frequency $\hat{\omega}_r$. The q-axis prevoltage command V_q^* is set to the q-axis voltage command V_{q1}^*. After setting them, all switches are turned on from B side to A side.

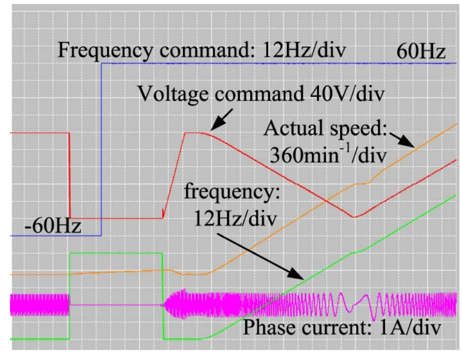


Fig. 20. Waveform in the q-axis current zero control mode and the frequency-adjust mode.

III. Experimental Results

Fig. 18 shows the experimental result when the zero-current control mode is applied to a PMSM machine. The ratings are 200 V, 0.75 kW, 1150 min^{-1}, 6 poles, and 1 A. An inverter drives the PMSM machine forward at 1150 min^{-1} (57.5 Hz). After the run command [forward] is turned off, the inverter switches are base-blocked, and the PMSM machine is in coasting state. After then, reverse run command is applied with a speed command of -1150 min^{-1} (-57.5 Hz). The inverter gets restarted with the proposed method of the zero-current control mode. Fig. 18 shows good performance. An absolute type speed sensor is used for experiments because the PMSM has no built-in speed sensor.

Fig. 19(a) shows the experimental result when zero-current control mode is applied to an asynchronous machine. The ratings are 200 V, 3.7 kW, 1750 min^{-1}, 4 poles, and 14 A. The inverter drives the machine at reverse direction at a speed of 900 min^{-1} (-30 Hz). After turning off the inverter switching, the machine is in coasting state. After then, rotational direction and the speed command changes to 900 min^{-1} (+30 Hz). The inverter restarts quickly while estimating the back EMF. Fig. 19(b) shows the experimental result when the dc current injection mode is applied to the same asynchronous machine. The inverter restarts slowly while fading out the back EMF. In this experiment, it is verified that the zero-current control mode for the asynchronous machine and the dc current injection mode works correctly. Fig. 20 shows the experimental result that the q-axis current zero control mode and the frequency-adjust mode are applied to another asynchronous machine. The rotational direction is estimated by the q-axis current zero control mode; the speed is estimated by the frequency-adjust mode. The machine ratings are 200 V, 0.2 kW, and 1 A. The inverter drives the machine at reverse direction, and the speed is 1800 min^{-1} (-60 Hz). After turning off the inverter switching, the machine is put into a coasting state. The rotational direction command changes to 1800 min^{-1} (+60 Hz), and the inverter restarts. As can be seen, the proposed method is able to estimate the rotational direction and the speed as well.

IV. Conclusion

The proposed method has been verified by the experimental results of the PMSM machine and the asynchronous machine for using fan systems. The zero-current control mode could estimate the rotational direction and the speed by the back EMF of the PMSM machine or the asynchronous machine. The dc current injection mode could estimate the rotational direction and the speed through the frequency of the q-axis current for the asynchronous machine. The q-axis current zero control mode could estimate the rotational direction by the q-axis current for the asynchronous machine. The frequency-adjust mode could estimate the speed by the frequency adjustor and the voltage adjustor for the asynchronous machine.

References

[1] K. Suzuki and S. Kondo, "Position sensorless drive of IPM motor within middle/high speed range considering power interruption," in *Proc. IEE Japan IAS Conf., 4-156*, 2005, pp. 251–252.

[2] Z. Lin, Y. Ito, and M. Matsui, "A control scheme for rotating speed picking-up and constant power acceleration of a flywheel energy storage system," in *Proc. IEE Japan IAS Conf., 4-014*, 2004, p. 21.

[3] A. Toba, K. Fujita, T. Maeda, and T. Kato, "Generating apparatus for gas heat pump system using sensorless-controlled permanent magnet synchronous generator," in *Proc. Int. Power Electron. Conf.*, 2005, pp. 1549–1554.

[4] A. Toba, M. Sato, S. Inatama, and K. Fujita, "Free-run startup techniques for sensorless-drive systems of permanent magnet machine with phase current or DC-bus current detection," *IEEJ Trans. Ind. Appl.*, vol. 126, no. 3, pp. 315–321, 2006.

[5] J.-I. Ha, K. Ide, T. Sawa, and S.-K. Sul, "Sensorless position and initial position estimation of an interior permanent magnet motor," in *Conf. Rec. IEEE IAS Annu. Meeting*, Sep. 2001, vol. 4, pp. 2607–2613.

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