Recent Variable-Speed Drive Technology

Takashi Aihara
Hidetoshi Umida
Hirokazu Tajima

1. Introduction

Recent trends in variable-speed drive technology for induction-motor drives include the development of high-torque control at low speed[(1)], highly responsive sensor-less vector control, low rotational fluctuation, and minimum time acceleration/deceleration technology.

In addition, adaptive drive technology that includes the mechanical system and high-efficiency sensor-less synchronous motor drives are also being developed.

In this paper, we introduce the following three technologies that are concerned with low rotational fluctuation control, minimum time acceleration/deceleration technology for induction-motor drives, and the sensor-less synchronous motor drive.

(1) High-accuracy output voltage control technology
(2) Minimum time acceleration/deceleration technology
(3) Sensor-less synchronous motor drive technology

2. High-Accuracy Output Voltage Control Technology

High-accuracy output voltage control is very important in obtaining low rotational fluctuation of the *V/f* control and sensor-less vector control.

Three main factors cause rotational fluctuation.

(1) Offset of the output voltage
(2) Unbalance between 3 phases of the output voltage
(3) Distortion of the output voltage caused by PWM dead-time to avoid a short-circuit of the main circuit.

Especially at very low speeds, item (3) is the dominant factor. Since even slight voltage distortion will affect the torque ripple, quick and high-accuracy output voltage control is necessary.

These error factors are caused by timing errors of the PWM control, quantizing errors of the digital processing, and the delay and on-voltage drop of switching devices.

Previously, measures such as software compensation and PWM timing compensation were implemented to counteract these error factors. However, it is very difficult to completely compensate for all the various error factors.

For this reason, Fuji Electric has developed digital voltage control technology, and has achieved low rotational fluctuation with quick and high-accuracy output voltage control.

Figure 1 shows an example of the system configuration. The sensor-less vector control algorithm creates the voltage reference, and voltage feedback is applied so that the output voltage will equal the voltage reference.

The voltage feedback almost completely compensates for the various error factors.

The digital control realizes high-speed sampling and high-accuracy control. LSI technology results in a compact circuit size.

Figure 2 shows the current waveform of an induction motor drive with *V/f* control (no load, 0.06Hz).

Fig.1 System configuration

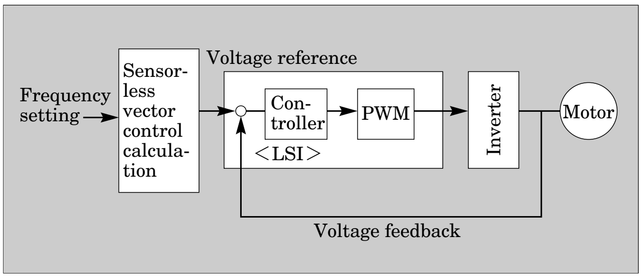


Fig.2 Current waveform at 0.06Hz (12.5 A/div, 5 s/div)

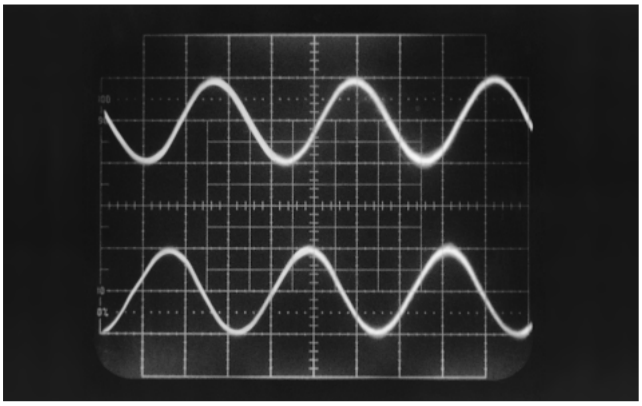
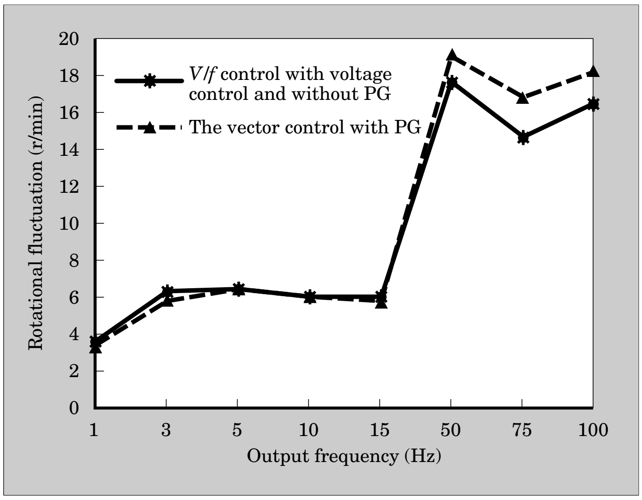


Fig.3 Comparison of rotational fluctuations



Even when the current is not controlled, the voltage feedback control results in a very smooth waveform at low speed.

Figure 3 shows a comparison of the rotational fluctuation. With the digital voltage control, we obtained the same low rotational fluctuation as in the case of vector control with PG (pulse generator).

3. Minimum Time Acceleration/Deceleration Technology

Torque control is made possible by the sensor-less vector control. By controlling the torque to be the maximum of the system, we can realize minimum acceleration/deceleration times.

Figure 4 shows the speed-torque characteristic of the sensor-less vector control. Solid lines indicate actual values, and dotted lines represent ideal values. It can be seen that the system can control the torque almost entirely along the ideal lines. Minimum acceleration/deceleration time can be realized by applying this torque control function.

Figure 5 shows the acceleration/deceleration waveform with applied sensor-less vector control. The current is almost constant for acceleration/deceleration between 0 r/min to 5,400 r/min. Especially in the constant power region (above 1,500 r/min), the torque decrease is inversely proportional to the output frequency. Increasing rate of the output frequency automatically decreases in the high-speed region.

With this function, minimum acceleration/deceleration time can be realized by setting shorter acceleration/deceleration times. Therefore, the setting is very simple, and it is not necessary to tune the acceleration/deceleration time nor the acceleration/deceleration pattern as in conventional systems.

4. Sensor-less Synchronous Motor Drive

The permanent magnet synchronous motor (PMSM) has advantages of low loss and small size, because no secondary loss occurs in the rotor as in the case of induction motors. Due to the merits of small size and high efficiency, the range of applications for PMSM is spreading.

PMSM drive systems such as servomotors utilize position and velocity sensors. However, in high-efficiency applications such as fans and pumps, because these systems are usually used only with a power line, a sensor-less drive is necessary. The sensor-less PMSM drive method utilizing emf of the PMSM has already been established. However, a method of starting from either the stand-still or rotating states and a drive method for low-speeds (less than several tens of r/min) are still in the research and development stages.

Fuji Electric is working to develop these advanced technologies and has proposed a method that utilizes electrical saliency for the method of starting from stand-still and for the low speed[2] drive method. Our method utilizes a special motor in which inductance varies corresponding to the position of the rotor. The system monitors changes in inductance via the power line and calculates the rotor position to realize a sensor-less PMSM drive method. System characteristics are introduced below.

Figure 6 shows the speed waveform at the static

Fig.4 Speed-torque characteristics

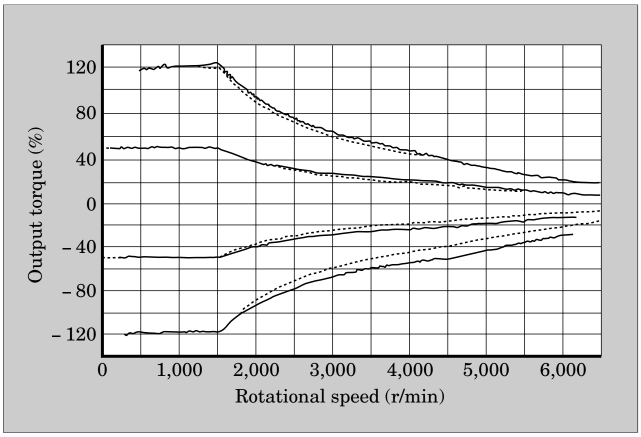


Fig.5 Acceleration/deceleration waveform with torque limiting

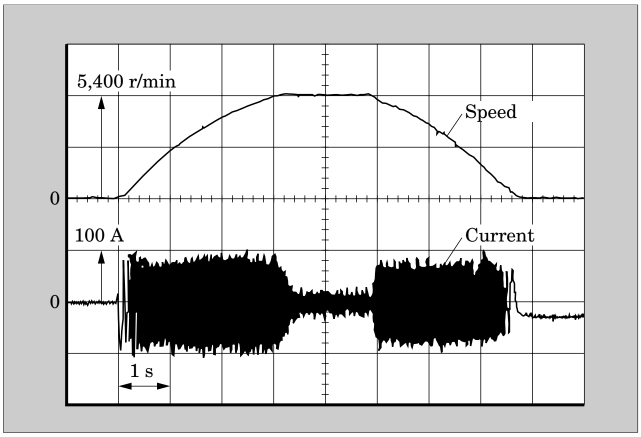


Fig.6 Steady-state operation (10 r/min, no load)

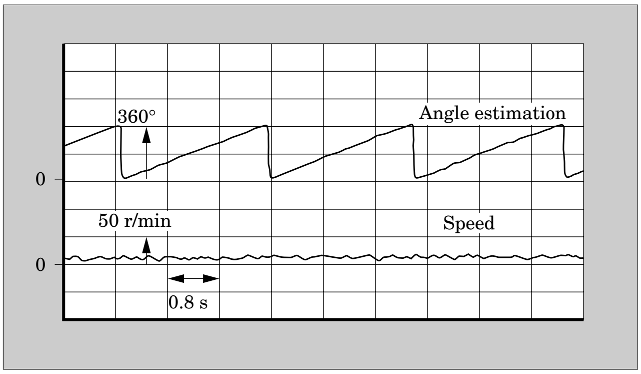
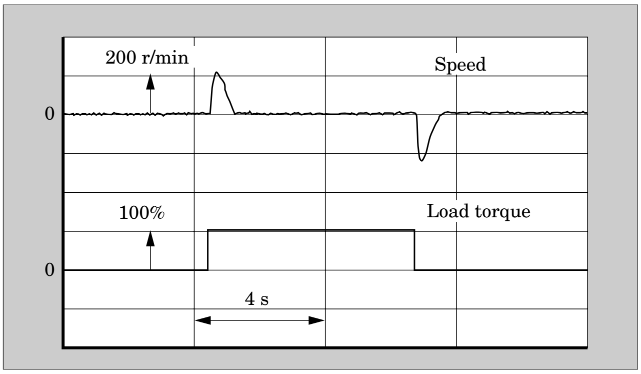


Fig.7 Performance with applied load (rated load)



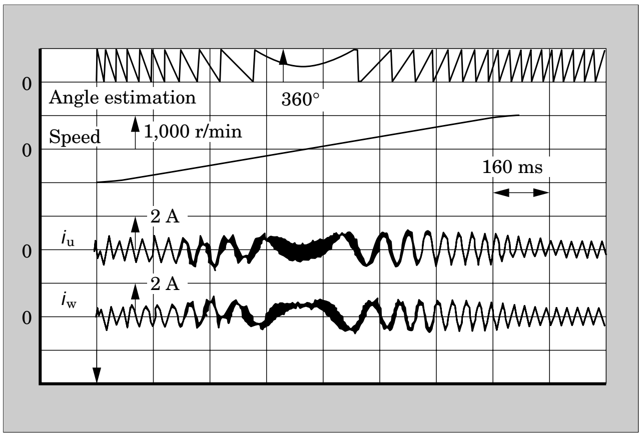
speed reference of 10 r/min. This system can drive PMSM smoothly even at such low speeds.

Figure 7 shows the response when an impact load is applied at the velocity reference of 0 r/min. Even at 0 r/min, this system can maintain the rated torque.

In an application such as a fan, the system must be able to start when wind is causing the motor to rotate. If a system does not have an output voltage sensor, since it usually cannot know the position and velocity of the rotor, it may not be able to start.

Under these conditions, Fuji Electric proposed a starting method that estimates the position and velocity of the rotor instantaneously from the emf of the PMSM. In this method, when starting, the system temporarily short-circuits the motor output using the main circuit of the inverter. The system monitors the motor current, and calculates the position and velocity

Fig.8 Starting from rotating state



of the rotor. After the output voltage is made to equal the motor terminal voltage, a soft start of the system is possible.

Figure 8 shows the velocity and current waveforms when this system starts under free-rotation at – 1,000 r/min and accelerates to + 1,000 r/min. It can be seen that the system achieves a good start and that there is no current shock.

5. Conclusion

This paper has introduced low rotational fluctuation control, minimum time acceleration/deceleration technology for induction-motor drives, and the sensor-less synchronous motor drive as recent variable-speed drive technologies. These technologies will contribute to the high-performance of drive systems in response to market needs.

Fuji Electric will continue to challenge itself to develop new technology to realize market needs.

Reference

(1) M.Yamazoe: General-Purpose Inverter, FRENIC5000 G9S/P9S, Fuji Electric Review, Vol.41, No.1, p.7-12 (1995)

(2) T.Aihara: Sensor-less Torque Control of Salient-Pole Synchronous Motor at Zero Speed Operation, APEC’97, Vol.2, p715-720 (1997)