Compact Inverter FVR-E7S

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1. Introduction

As the market for general-purpose inverters has expanded, a satisfying supply to meet the demand for general-purpose inverters with lower cost and smaller size has further triggered new demand. This demand-supply cycle has been repeated for years.

In addition, market demands have increased for general-purpose inverters which are rugged enough to continue operation during dynamic operations such as swift acceleration and deceleration, sudden load disturbance, or restarting after an instantaneous power failure. General-purpose inverters are also being required to lower their output level of acoustic noise in consideration of environmental harmonization.

This paper summarizes the FVR-E7S series of low noise compact inverters developed by Fuji Electric to meet the aforementioned demands.

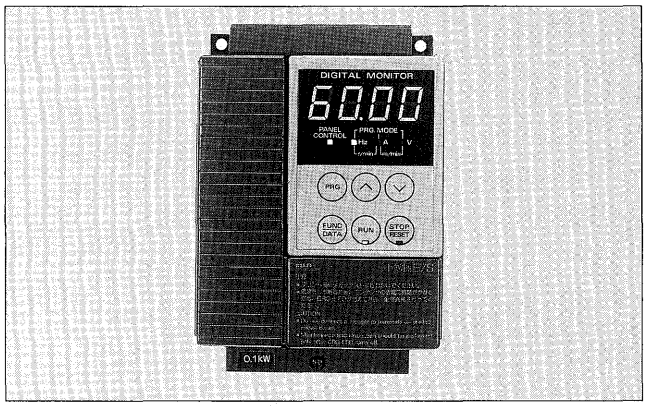
2. Fundamental Features of the FVR-E7S

Figure 1 shows the external appearance of an FVR-E7S series inverter. Main features of these inverters will be described below.

2.1 Expansion of the series

In addition to the three-phase 200V AC and single-phase 200V AC classes of inverter input voltage specifications, an A6 size, three-phase 400V class inverter has also been added to the FVR-E7S series. So that there may be applications with even smaller capacity equipment, the minimum capacity, which is 0.2kW in the former series, has been lowered to 0.1kW in the FVR-E7S 200V series and 0.4kW in the FVR-E7S 400V series.

Fig. 1 External appearance of FVR-E7S



2.2 Significant lower acoustic noise and smaller size

(1) Significant lower acoustic noise

High frequency PWM control is facilitated and very low acoustic noise is realized through utilizing high speed switching power IGBTs as the main power circuit devices in place of power bipolar transistors and also by improving the radiator.

Table 1 Comparison of external dimensions

Compared item		Former series	FVR-E7S	Ratio
0.1kW	Dimensions (mm)	–	105×150×80	–
	Installation area (cm^2)	–	158	–
	Volume (cm^3)	–	1,260	–
0.2kW	Dimensions (mm)	160×170×80	105×150×80	–
	Installation area (cm^2)	272	158	58%
	Volume (cm^3)	2,176	1,260	58%
0.4kW	Dimensions (mm)	160×170×100	105×150×90	–
	Installation area (cm^2)	272	158	58%
	Volume (cm^3)	2,720	1,418	52%
0.75kW	Dimensions (mm)	160×170×115	105×150×119	–
	Installation area (cm^2)	272	158	58%
	Volume (cm^3)	3,128	1,874	60%
1.5kW	Dimensions (mm)	160×200×170	140×150×130	–
	Installation area (cm^2)	300	210	66%
	Volume (cm^3)	5,440	2,730	50%
2.2kW	Dimensions (mm)	Same as above	200×150×140	–
	Installation area (cm^2)		300	94%
	Volume (cm^3)		4,200	77%
3.7kW	Dimensions (mm)	Same as above	200×150×155	–
	Installation area (cm^2)		300	94%
	Volume (cm^3)		4,650	85%

Note: The former series is FVR-K7S.

(2) Control circuit with smaller size

The peripheral digital circuitry for the DSP (Digital Signal Processor) is integrated into a VLSI device. Most of the functions of the control circuit are performed by the DSP and this device.

New LSI has been developed exclusively for the analog circuit portion of the control circuit, for which conventional downsizing techniques had already reached their limits. This analog LSI reduces chip area and improves reliability of the analog circuit portion.

(3) Main circuit with smaller size

The main power circuit portion is modularized through using Fuji Electric's original compound metal printed circuit board with different insulation and excellent heat dispersion properties, and by mounting on this metal printed circuit board the main power circuit devices (at chip level) along with all the other heat generating devices. The main power circuit module improves heat dispersion properties and reduces the area occupied by the main power circuit devices.

As shown in Table 1, through the development of these technologies, inverters with much lower acoustic noise and smaller mounting area and dimensions than the former series have been realized. The length of all the inverters of the FVR-E7S 200V series is standardized at 150mm. The width of the three-phase inverters of 200V and 0.75kW or less and the single-phase inverter of 200V and 0.2kW or less is standardized at 105mm.

2.3 Improved performance

A current limiting function is standard equipment on all the inverters. This enables the inverters to operate under sudden load disturbances, such as an impact load, without tripping. Operation is made more powerful through the realization of over load current tolerances of 200% and 0.5sec.

An electronic thermal overload relay for the motor is also standard equipment in the inverters. This relay is applicable to two different kinds of motors: the general purpose motor and the inverter motor (Fuji FV motor).

2.4 Easy operation

The front operation panel is shown in Fig. 1. Operation is simple with a four digit, Arabic numeral LED display and six mounted keys.

Even during operation, a four digit real value can be selected for display on the LEDs in five different units. This avoid setting errors. Simple and easy opera-

Fig. 2 Circuit configuration and control portion of FVR-E7S

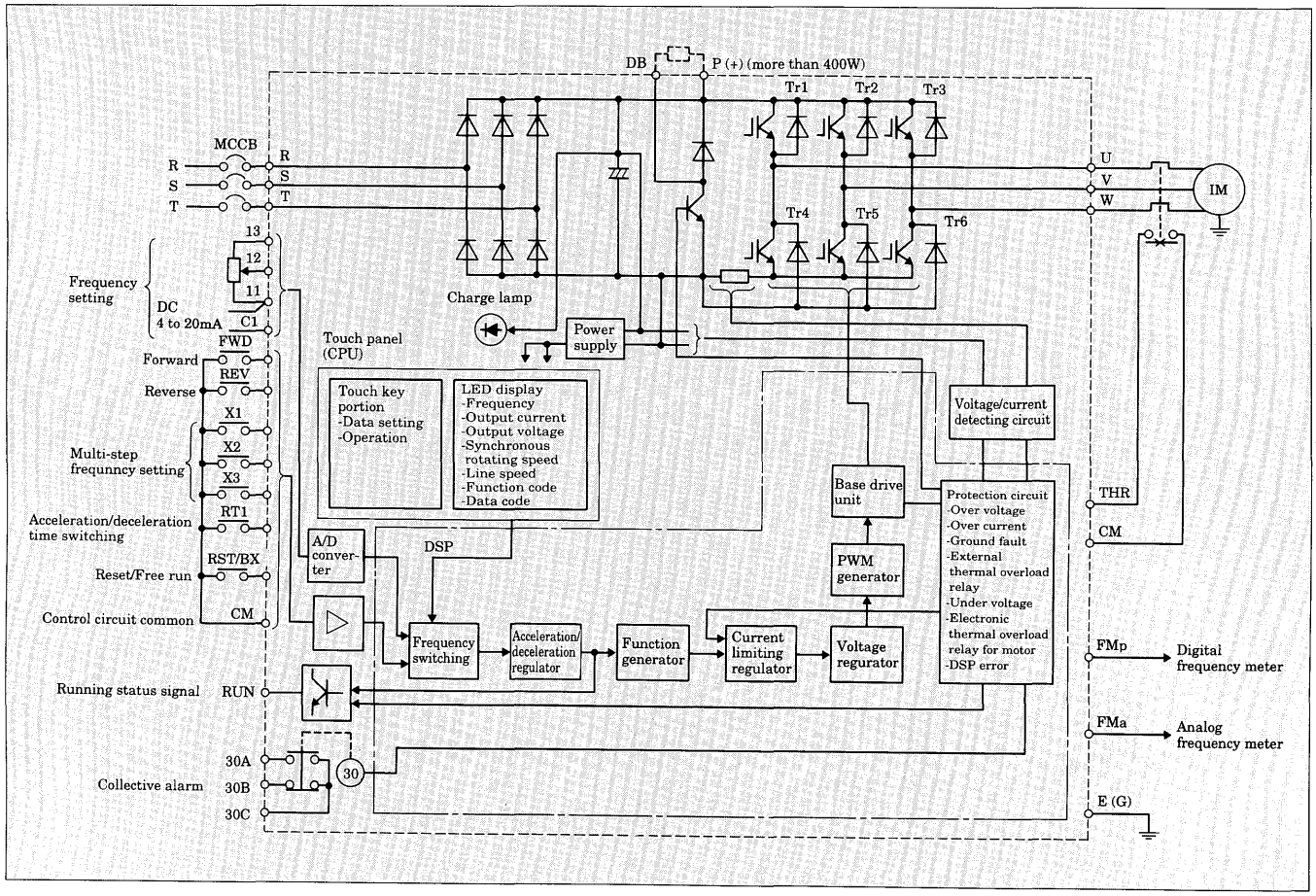


Table 2 Standard specifications

(a) Three-phase 200V series

Item			Specifications						
Model			FVR001 E7S-2	FVR002 E7S-2	FVR004 E7S-2	FVR008 E7S-2	FVR015 E7S-2	FVR022 E7S-2	FVR037 E7S-2
Standard applicable motor (kW)			0.1	0.2	0.4	0.75	1.5	2.2	3.7
Output rating	Rated capacity (kVA)		0.30	0.57	1.1	1.9	3.0	4.2	6.5
	Voltage		Three-phase three-wire type 200 to 230V						
	Rated current (A)	Standard operation <Note 1>	0.8	1.5	3	5	8	11	17
		At low noise <Note 2>	0.7	1.3	2.5	4	7	10	16.5
	Over load current rating		150% 1min, 200% 0.5s Inverse time-lag characteristic						
	Rated output frequency		50 to 400Hz						
Power supply	Phase, Voltage, Frequency		Three-phase, 200 to 230V, 50Hz or 60Hz						
	Allowable fluctuation		Voltage: +10%, −15% (Unbalance within 3%), Frequency: ±5%						
	Tolerance against voltage drop		Operation is continuous at 165V or more. Below 165V, operation is continued for 15ms.						
Degree of protection (JEM1030)			IP20 enclosure						
Cooling system			Self-cooling type				Forced air cooling type		
Mass (kg)			0.8	0.8	0.9	1.1	2.0	2.7	3.0

(b) Single-phase 200V series

Item			Specifications					
Model			FVR001 E7S-7	FVR002 E7S-7	FVR004 E7S-7	FVR008 E7S-7	FVR015 E7S-7	FVR022 E7S-7
Standard applicable motor (kW)			0.1	0.2	0.4	0.75	1.5	2.2
Output rating	Rated capacity (kVA)		0.30	0.57	1.1	1.9	3.0	4.2
	Voltage		Three-phase three-wire type 200 to 240V					
	Rated current (A)	Standard operation <Note 1>	0.8	1.5	3	5	8	11
		At low noise <Note 2>	0.7	1.3	2.5	4	7	10
	Over load current rating		150% 1min, 200% 0.5s Inverse time-lag characteristic <Note 3>					
	Rated output frequency		50 to 400Hz					
Power supply	Phase, Voltage, Frequency		Single-phase two-wire type 200 to 240V, 50Hz or 60Hz					
	Allowable fluctuation		Voltage: 180 to 264V, Frequency: ±5%					
	Tolerance against voltage drop		Operation is continuous at 165V or more. Below 165V, operation is continued for 15ms.					
Degree of protection (JEM1030)			Fully enclosed type, IP40 (Fan portion IP20)					
Cooling system			Self-cooling type				Forced air cooling type	
Mass (kg)			1.0	1.0	1.8	2.1	2.9	3.0

(c) Three-phase 400V series

Item			Specifications				
Model			FVR004 E7S-4	FVR008 E7S-4	FVR015 E7S-4	FVR022 E7S-4	FVR037 E7S-4
Standard applicable motor (kW)			0.4	0.8	1.5	2.2	3.7
Output rating	Rated capacity (kVA)		1.2	1.9	2.8	4.2	6.9
	Voltage		Three-phase three-wire type 380 to 460V				
	Rated current (A)	Standard operation <Note 1>	1.6	2.5	3.7	5.5	9.0
		At low noise <Note 2>	1.4	2.1	3.7	5.3	8.7
	Over load current rating		150% 1min, 200% 0.5s Inverse time-lag characteristic				
	Rated output frequency		50 to 400Hz				
Power supply	Phase, Voltage, Frequency		Three-phase, 380 to 460V, 50Hz or 60Hz				
	Allowable fluctuation		Voltage: 323V to 506V (Unbalance within 3%), Frequency: −5%				
	Tolerance against voltage drop		Operation is continuous at 165V or more. Below 165V, operation is continued for 15ms.				
Degree of protection (JEM1030)			Fully enclosed type, IP40 (Fan portion IP20)				
Cooling system			Self-cooling type		Forced air cooling type		
Mass (kg)			2.0	2.1	3.0	3.0	3.3

(d) Common items

Item			Specifications
Output-frequency	Adjustment	Maximum frequency	0.2 to 400Hz Variable setting
		Base frequency	0.2 to 400Hz Variable setting
		Starting frequency	0.2 to 15Hz Variable setting
	Accuracy		Analog setting: ±0.2% of maximum frequency (at 25℃ ±10℃) Setting from touch panel: ±0.01% of maximum frequency (at −10 to +50℃)
	Resolution of setting data		Analog setting: 0.02Hz Setting from touch panel: 0.01Hz (up to 9.99Hz), 0.1Hz (up to 99.90Hz), 1Hz (100.0Hz or more)
Control	Operation		Forward drive command (FWD), Reverse drive command (REV), Free run command (BX), Fault reset (RST), External alarm (THR), Acceleration/deceleration time 2 (RT1) Multi-step speed setting (X1, X2, X3), Touch panel RUN, STOP/RESET Key
	Frequency setting signal		Voltage: DC0 to +10V (DC0 to +5V), Current: DC4 to 20mA, Touch panel △, ▽ Key
	Operation status signal		Collective alarm output (1c Contact, Contact capacity AC250V 0.3A $\cos\phi = 0.3$) Operating signal (Open collector output, DC27V 50mA max.)
	Output signal for frequency meter		Analog: DC0 to +10V Pulse: 1,440Hz (At max. frequency)
	Display	system	7 segment LED 4 digits
		Operation display	Output frequency (Hz), Set frequency (Hz), Output current (A), Output voltage (V), Rotating speed (r/min), Line speed (m/min)
		Setting display	Function code & set data are displayed.
		Protection display	OC1, OC2, OC3, LV, OV, OH1, OH2, Err1, Err2, Err3, OL1, Four fault histories are displayed.
		Unit display	Displays Hz, A, V, r/min, m/min with LEDs.
	Charge lamp		Illuminated when power supply is ON
	Acceleration/deceleration time		0.01 to 3,600s (Acceleration & deceleration independent) Acceleration/deceleration time 2
	Voltage/frequency range		Voltage : 1 to 230V (200V series) 2 to 460V (400V series) Frequency: 0.2 to 400Hz (For base and maximum frequencies)
	Torque boost		32 modes selectable
	Main installed functions		Operation sound selection, Frequency meter adjustment, Parameter protection, Restart after instantaneous power failure, Upper/lower Limiter, Current limitation, Bias, Gain, Multi-step speed operation, Initialization of data, etc.
	Start torque		Max. 200% (at 6Hz, instantaneous) (200V series), 150% (400V series)
Protection	Overload		Current limitation, Inverter over load
	Instantaneous over current		Over current, Short-circuit for output terminal, Output ground fault before operation
	Over voltage		Over voltage at braking
	Radiator overheating		Inverter overheating, Failure of radiator fan, Abnormal ambient temp.
	Motor protection		Motor overload (electronic thermal relay), External alarm
Environment	Installation location		Indoors at an altitude 1,000m or less. Avoid direct sunlight, corrosive gas, oil mist, etc.
	Ambient temperature		−10 to +50℃ (When the ambient temp. exceeds +40℃, remove upper and lower ventilation covers)
	Ambient humidity		Relative humidity 20 to 90% RH or less (with no condensation)
	Vibration		5.9m/s^2 or less (JIS C0911 applicable)
	Storage temperature		−25 to +65℃

Note 1: Motor drive sound selection at F12 = 1, 2, 3
Note 2: Motor drive sound selection at F12 = 4, 5
Note 3: 200% 0.5sec is the tolerance for rated current at low noise.

tion is realized through the use of a function setting method which directly selects a real value assigned to each function code.

3. Specification and Circuit Configuration

The circuit configuration of the FVR-E7S series and the block diagram of its control circuit are shown in Fig. 2. The standard specifications are listed in Table 2.

3.1 High speed current limiting circuit and high speed voltage regulation operation

By continuously sampling the load current and the DC link voltage at high speed with an A-D converter, and by quickly processing this sampled load current and DC link voltage in a 32 bit DSP, stable control during load disturbances and voltage fluctuations is realized.

3.2 Ample setting frequencies and output signal frequencies

(1) Frequency setting

In addition to frequency setting by an external analog signal (of 0 to +10V or 4 to 20mA, with a potentiometer), eight steps of digital frequencies can be set by key operation. From 2 to 8 steps of frequency settings can be selected from external terminals (X1 to X3).

(2) Frequency signal output

The operation frequency may be monitored from a digital LED display on the touch panel, or from two types of output signals: an analog output of DC 0 to 10V for maximum frequency or a pulse output of 1,440Hz/60Hz.

3.3 IGBT protection function

The inverters are equipped with a protection function to keep the temperature rise during overload of the main power circuit devices within the tolerance of these devices. This function is essential to realize a down-sized inverter with improved cooling capability and reliability.

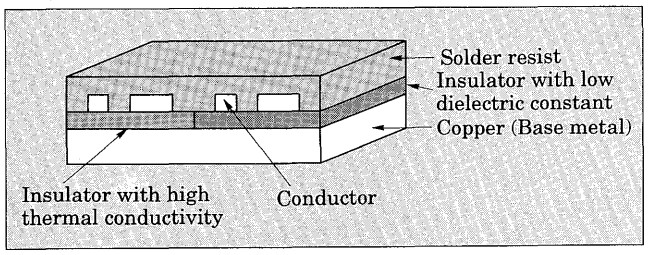
Junction temperature of the IGBT can be estimated through simulation by adding the average loss of the power devices for a cycle of the output frequency (calculated from the output current and the carrier frequency), to the weighted temperature ripple in the low output frequency region (in which the IGBT's heat capacity, thermal conduction time constant, and output frequency of the inverter can no longer be ignored with respect to the thermal time constant), and then by adding the result of this compensating calculation to temperature detected by a temperature sensor.

Reliability of FVR-E7S series of inverters is increased with the addition of the IGBT protection function, based on the calculated value of the junction temperature.

3.4 Compound metal printed circuit board with different insulation

A metal printed circuit board with its excellent thermal conductivity is an effective means for suppressing temperature rises, caused by heat generated from the main power circuit devices. However, electromagnetic properties which affect noise can cause problems for control circuit since a main power circuit which handles high voltage and large current, and a control circuit which handles weak signals are both mounted on the same printed circuit board. A new compound metal printed circuit board with different insulation which meets both requirements has been developed by using an insulator with high thermal conductivity in the main power circuit portion and an insulator with low dielectric constant in the control circuit portion. The structure of the metal printed circuit board with different insulation is shown in Fig. 3.

Fig. 3 Structure of compound metal printed circuit board with different insulation



4. Operation Performance and Application

4.1 Acoustic noise during operation

Acoustic noise data of present and conventional inverters is compared in Fig. 4.

The acoustic noise of the conventional inverter is especially high in the low frequency region. The main component of the high acoustic noise in the low frequency region is a harsh grating metallic sound caused by the low frequency PWM control. This harsh grating metallic sound is eliminated from the FVR-E7S series through the use of the high frequency PWM control.

4.2 Current limiting control

Figure 5 shows the current limiting control characteristics of the present inverter under impact load. If the impact load causes an increase in inverter output current, the 32 bit DSP will perform high speed computation to control the output current at a constant value.

The current limiting level, adjustable from 30 to 150% of the rated inverter current, is effective for controlling the motor torque based on machine specifications, making the operation more durable. The response speed of the output frequency control can be adjusted with the function settings for various types of loads.

The current limiting function which automatically limits the motor current when a load is connected to

Fig. 4 Comparison of motor noise

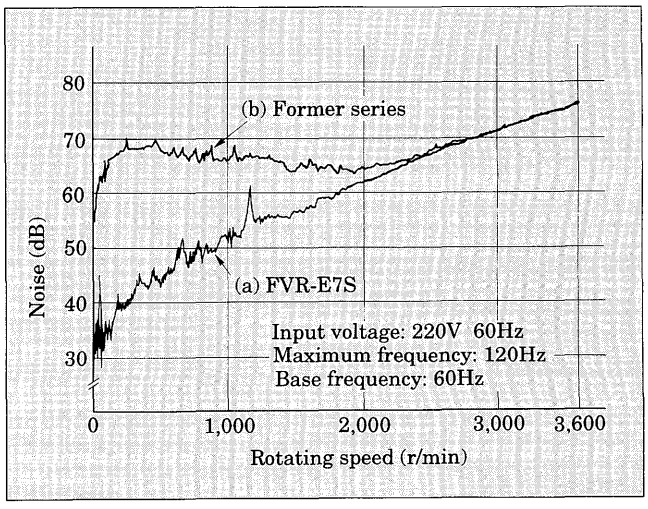
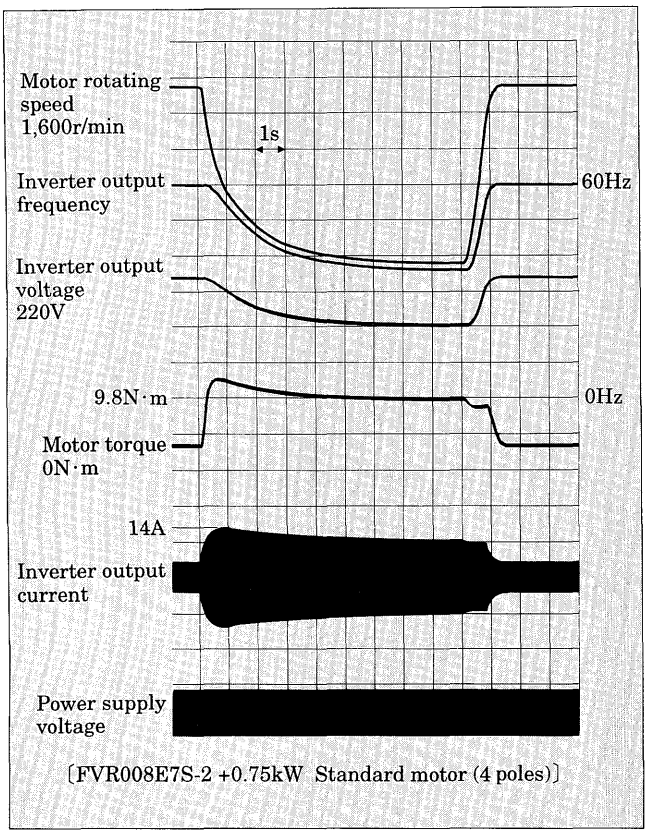


Fig. 5 Example of current limiting characteristics

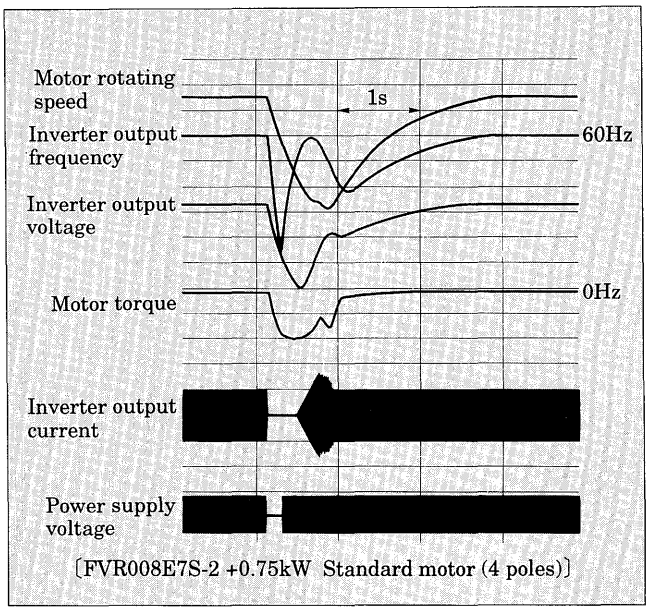


the system enables to optimize inverter capacity .

4.3 Restarting after instantaneous power failures

Figure 6 shows an example of the dynamic characteristics when, after an instantaneous failure, power has been restored in case the restart function selected. When there is an instantaneous failure, the inverter cuts off the output. At power restoration, the inverter searches for the motor speed and performs a pulling-in

Fig. 6 Example of operating characteristics during an instantaneous power failure



operation so that the motor current may remain within a predetermined range. In this manner, stable inverter operation can continue even when an instantaneous power failure occurs.

5. Conclusion

This paper has summarized the very low noise compact inverter series FVR-E7S. The FVR-E7S series of inverters, which utilize IGBTs to drastically lower noise and decrease equipment size, have a wide range of applications.

Fuji Electric is continuing its efforts to develop and improve inverters.