SUPER COMPACT INVERTER FVR-E7S

Yoshiyuki Tsuno
Takao Ichihara
Ryouzou Karatsu

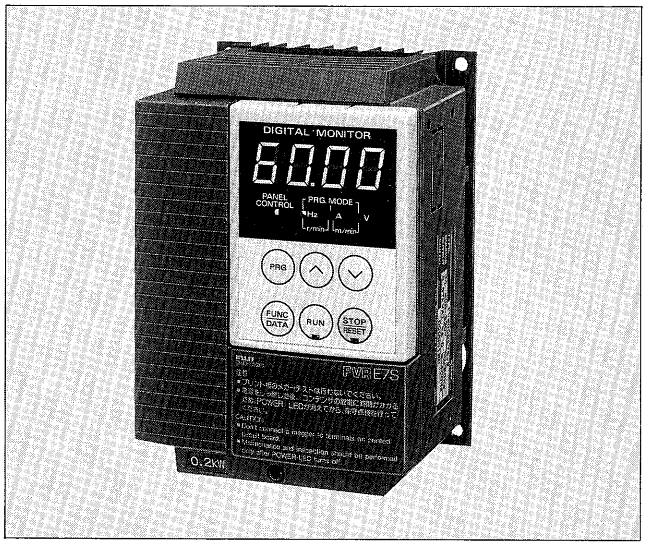
1. INTRODUCTION

Since the emergence of the FVR-G5 digitally controlled inverter in 1985, general purpose inverters such as the high performance FVR-G7 or the low cost, essential function FVR-K7 series have been developed. Inverters have not been unaffected by recent trends, and within the past few years there have been strong demands for downsizing, while maintaining at least the present level of performance and functions. This article will introduce the super compact general purpose inverter series, FVR-E7S, developed in response to these demands. The FVR-E7S utilizes the latest technology such as a custom 32-bit DSP, ASICs, IGBTs (used for the first time in inverters of this class), and a unique printed circuit board composed of a metal substrate layer coated with different resin compounds.

2. FVR-E7S SPECIFICATIONS

Figure 1 shows the front view of the FVR-E7S.

Fig. 1 Front view of FVR-E7S



2.1 Extended capacity range

Whereas the old FVR-K7S series has a minimum power capacity of 0.2kW, the minimum of the new FVR-E7S series has been lowered to 0.1kW in order that it may be used with 0.1kW or less small motors.

2.2 Miniaturization and noise reduction in all models

(1) Control circuit miniaturization

A DSP and a VLSI chip for peripheral circuit have been specially developed. The majority of control circuit functions are contained within these two chips. Previously, integration of the DSP's peripheral analog circuit was difficult and thus miniaturization of the control circuit had almost reached its limit.

With this new series, the analog peripheral circuit for the DSP has been disigned into a custom IC. As a result, circuit board space required have decreased and reliability has been increased.

(2) Main circuit miniaturization

The FVR-E7S series main circuit is mounted on Fuji Electric's original metal base circuit board, a combination of the previously used high thermal conductivity and low dielectric constant circuit boards. Chip-level main circuit components as well as other heat generating components are all mounted on this metal printed circuit board. With the main circuit modularized in this manner, heat dissipation is improved and component space requirements are reduced. Further, in the 0.1-0.75kW series, the traditional cylindrical capacitors in the main circuit have been replaced

Fig. 2 Motor noise

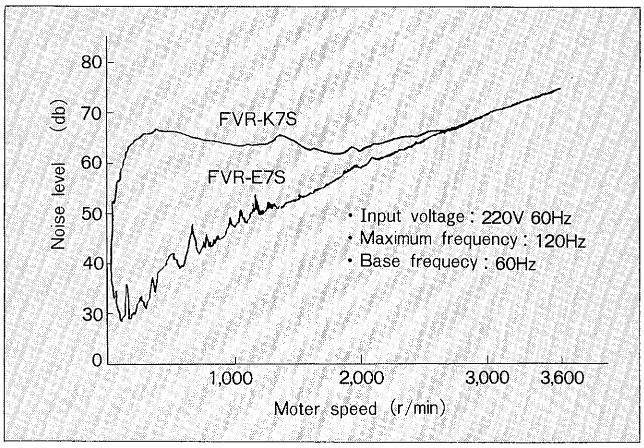


Fig. 3 FVR-E7S block diagram

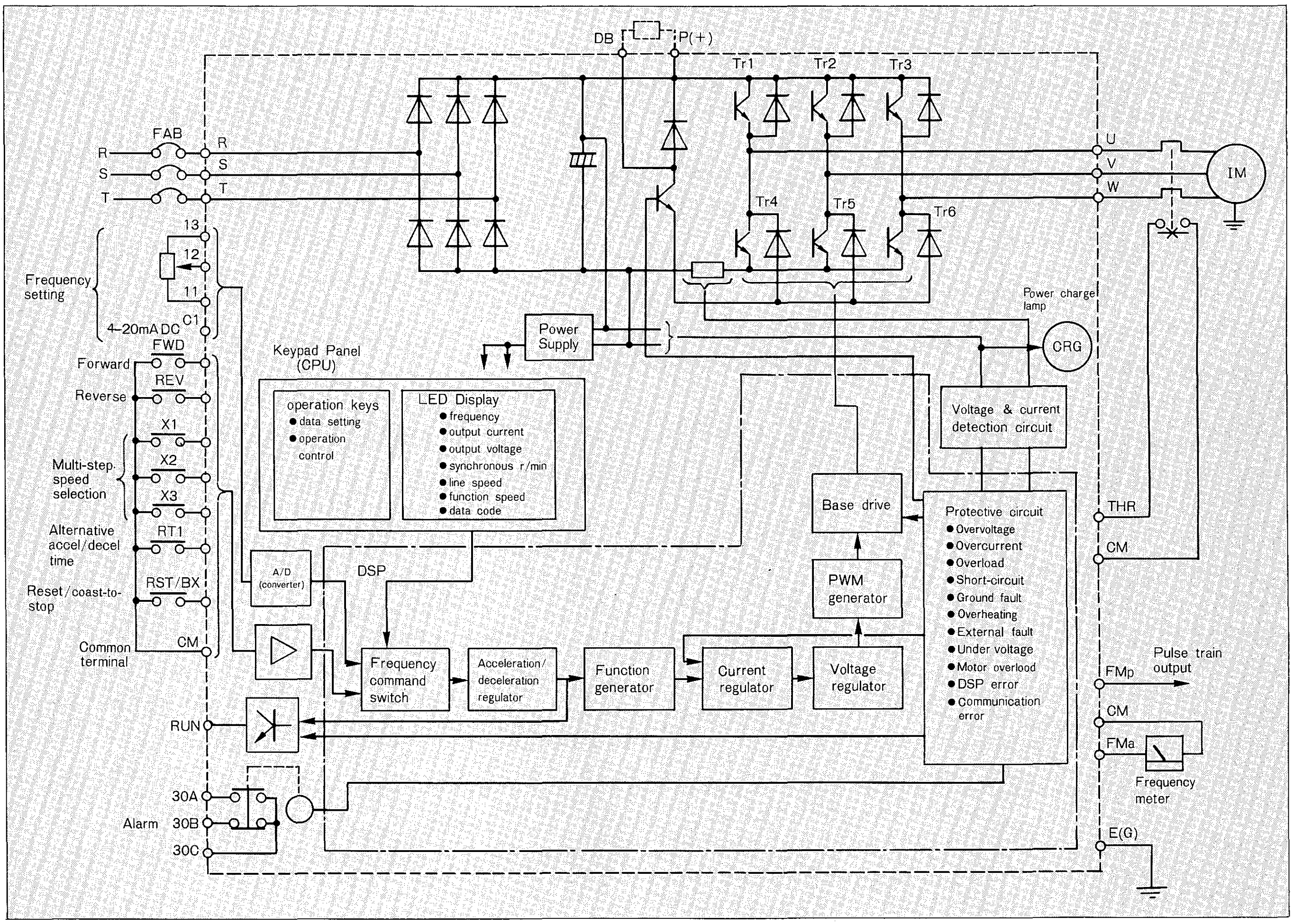


Table 1 Comparison of external dimensions

	Comparison item	FVR-K7S	FVR-E7S	Ratio
0.1 kW use	External dimensions (mm)	–	105×150×80	–
	Installation area (cm²)	–	158	–
	Volume (cm³)	–	1,260	–
0.2 kW use	External dimensions (mm)	160×170×80	105×150×80	–
	Installation area (cm²)	272	158	58%
	Volume (cm³)	2,176	1,260	58%
0.4 kW use	External dimensions (mm)	160×170×100	105×150×90	–
	Installation area (cm²)	272	158	58%
	Volume (cm³)	2,720	1,418	52%
0.75 kW use	External dimensions (mm)	160×170×115	105×150×119	–
	Installation area (cm²)	272	158	58%
	Volume (cm³)	3,128	1,874	60%
1.5 kW use	External dimensions (mm)		140×150×130	–
	Installation area (cm²)		210	66%
	Volume (cm³)		2,730	50%
2.2 kW use	External dimensions (mm)	160×200×170	200×150×140	–
	Installation area (cm²)	300	300	94%
	Volume (cm³)	5,440	4,200	77%
3.7 kW use	External dimensions (mm)		200×150×155	–
	Installation area (cm²)		300	94%
	Volume (cm³)		4,650	85%

by flat capacitors, allowing for more effective (less space consuming) placement.

(3) Motor noise reduction

Heat dissipation considerations and simulations of the effect of heat on the main circuit components in the FVR-E7S series lead to the use of IGBT components as a substitute for the bipolar power transistors (BJT) in the main circuitry. The result is that noise is reduced by raising the switching frequency. **Figure 2** shows noise data compared to the conventional inverter.

Due to modularization of the control circuit board and the main circuitry board, connection between the two boards is possible with a single connector. This enables easier assembly and maintenance as well as increases reliability.

The final result of the above, as compared to Fuji Electric's previous FVR-K7S series, is that in addition to reducing noise, installation space as well as volume has been decreased as shown in **Table 1**.

Additionally, the entire series have been standardized to a uniform height of 150mm, 0.75kW.

2.3 High performance

The FVR-E7S series comes equipped with an electro-

Table 2 Standard specifications

Item			Specification						
Inverter model			FVR001 E7S-2	FVR002 E7S-2	FVR004 E7S-2	FVR008 E7S-2	FVR015 E7S-2	FVR022 E7S-2	FVR037 E7S-2
Applicable motor output (kW)			0.1	0.2	0.4	0.75	1.5	2.2	3.7
Output ratings	Inverter output (kVA)		0.30	0.57	1.1	1.9	3.0	4.2	6.5
	Output voltage (V)		Three-phase, 3-wire, 200 to 230						
	Output frequency (Hz)		50 to 400						
	Output current (A)	Standard operation	0.8	1.5	3	5	8	11	17
		Low noise operation	0.7	1.3	2.5	4	7	10	10.5
	Overload capacity		150% for 1 min, 200% for 0.5s (Inverse time characteristics)						
Braking torque	Regenerative braking		Capacitor regenerative braking (Braking resistor is optional for 0.4kW or longer output models)						
	DC braking		Operation frequency 0.2 to 60Hz, Operation time 0.01 to 30s. Operating voltage 0 to 15%						
Power supply	Input AC voltage rating		Three-phase, 3-wire, 200 to 230V, 50/60Hz						
	Allowable tolerance		Voltage: +10%, −15%, Frequency: ±5%, Supply voltage imbalance: 3% or less						
Protection/cooling system			Enclosed type (IP20)						
Mass (kg)			0.8	0.8	0.9	1.1	2.0	2.7	3.0
Control	Control system		Sinusoidal PWM control with AVR function						
	Frequency control range		0.2 to 400Hz (minimum frequency adjustable between 0.2 and 15Hz)						
	Output frequency stability		Keypad setting: ±0.01% of maximum frequency (−10 to 50°C)						
			Analog setting: ±0.2% of maximum frequency (at 25 ±10°C)						
	Frequency setting resolution		Keypad setting: 0.01Hz (up to 9.99Hz), 0.1Hz (10 to 99.90Hz), 1Hz (100.0Hz and over)						
			Analog setting: 0.02Hz step (at maximum frequency 60Hz)						
	Voltage/frequency characteristic	400V series	Voltage: 380 to 460V, Frequency: 0 to 400Hz						
		200V series	Voltage: 200 to 240V (Single-phase), 200 to 230V (Three-phase), Frequency: 0 to 400Hz						
	Torque boost		32 modes selectable (variable torque mode selectable)						
	Acceleration/deceleration characteristic		0.01 to 3,600s (Independently adjustable acceleration and deceleration), (Alternative acc/dec time available)						
	DC braking		Starting frequency: 0.2 to 60Hz, Operating time: 0.01 to 30s, Voltage: 16 notches						
	Standard functions		Current limiting, Restart after momentary power failure, Multistep speed setting (7 steps) High and low limiter, Bias frequency, carrier frequency selection, Data initializing						
Protection			Stall prevention, Overcurrent, Overvoltage, Undervoltage, Momentary power failure, Inverter overload, Inverter overheating, Motor overload (Electronic thermal OL relay trip), External fault (External thermal OL relay trip), DSP error, Short circuit for output terminal, Ground fault (checked only at starting)						
Operation	Frequency setting input		Frequency setting potentiometer, Voltage input: 0 to +10V DC (0 to +5V DC) (Gain adjustable between 0 and 200%) Current input: 4 to 20mA DC						
	Input signal		Forward command, Reverse command, Multistep speed selection, Alternative acc/dec time selection, External fault, Coast-to-stop command, Alarm reset						
	External output signal	Relay output	Alarm (SPDT, 25V AC 0.3A cos ϕ = 0.3)						
		Open collector output	Inverter running						
Indication	Frequency meter output signal		Analog: 0 to +10V DC (Adjustable between 6.5 and 10.3V), Pulse: 1,440 Hz/Fmax						
	Keypad panel (4 digit LED)	Running	Output frequency, Reference, Output current, Output voltage, Motor synchronous speed, Machine speed						
		Setting	Function code and data code						
		Fault	Overcurrent during acceleration (OC1), Overcurrent during deceleration (OC2), Overcurrent during running at constant speed (OC3), Overvoltage (OU), Undervoltage (LU), Inverter overload/over heating (OH1), Motor overload (Electronic thermal OL relay trip) (OL1), Extermal fault (OH2), Setting error (Err1), Communication error (Err2), DSP error (Err3), Fault memory (Immediately previous 4 faults)						
	Charge lamp		DC intermediate circuit voltage						
Conditions	Installation location		Indoor, not more than 1,000m above sea level. Do not install in a dusty location or expose to corrosive gases or direct sunlight.						
	Ambient temperature, humidity		−10 to +50°C, 20 to 90% RH (Non-condensing)						
	Vibration		5.8m/s² (0.6G) or less (Conforming to JIS C 0911)						
	Storage temperature		−2.5 to +65°C						
	Degree of protection		IP 20 enclosure (Without cooling fan)						
Installation method			Inside switchboard, External cooling						
Option and accessory			Extension cable for remote operation, Braking resistor, Cable for remote keypad						

thermal overload relay as a standard motor protection feature for both the general purpose and inverter (capable of handling full torque at low speeds) motors.

Designed for powerful operation, overload current tolerance is rated at 200% for 0.5 seconds. A current limiting function also comes as a standard feature. Smooth and steady performance is obtainable even under sudden load fluctuations.

2.4 Easy operation

The keypad panel, as can be seen in **Fig. 1**, has a 4-digit LED display and a 6 key touchpad for ease of operation.

Fig. 4 Current limiting control example

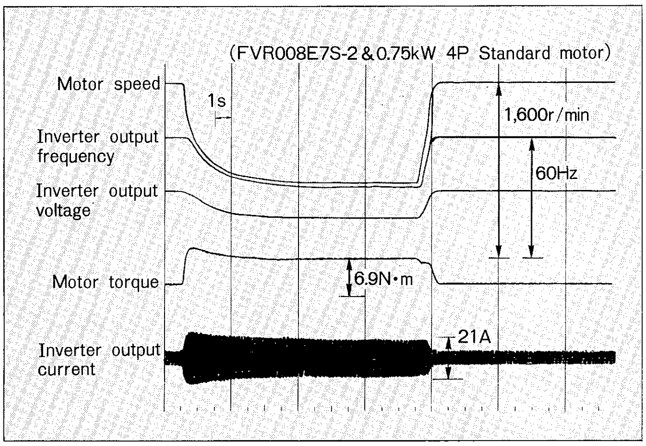
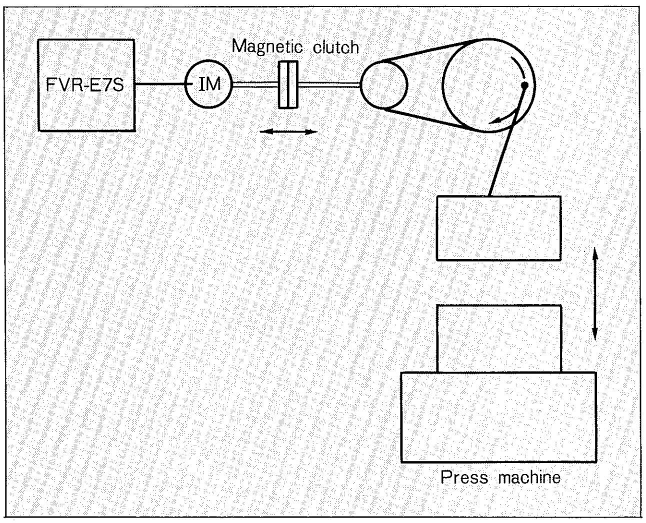


Fig. 5 Press machine application example



The 4-digit LED display may be configured for display in 5 possible units. These may be selected even while the inverter is in operation. Configuration errors can be avoided since values will be displayed in the desired units. Also, during function configuration, the desired units may be specified for each function code.

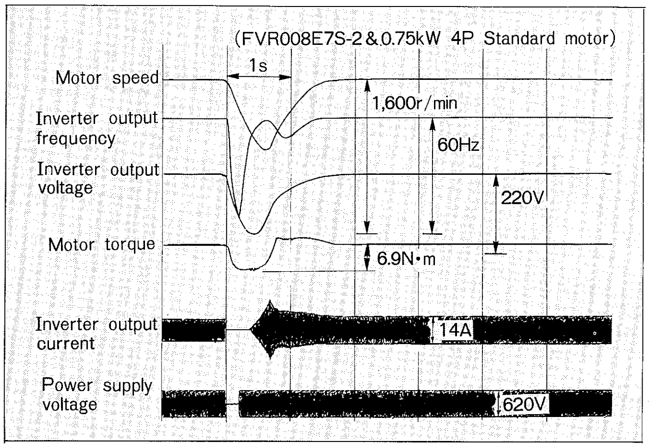
3. SPECIFICATION SUMMARY AND CIRCUIT ORGANIZATION

Figure 3 shows the circuit block diagram and **Table 2** shows the standard specifications for the FVR-E7S.

3.1 Simple current detection

A shunt resistor is used in the main circuit to detect load current. This resistor is physically small and provides accurate current detection over the entire frequency range. A current and voltage detector belonging to the DSP's analog peripheral circuit and a portion of the power supply control circuit have been designed into a custom IC to increase reliability.

Fig. 6 Restart after momentary power failure example



3.2 High speed processing of current limiting and voltage regulation

Load current and the voltage of intermediate DC circuitry are read at high speed by an A/D convertor and processed at high speed by the DSP. This allows stable control even with fluctuation in the load and supply voltages.

3.3 Abundance of frequency settings, frequency signal output

(1) Operating frequency settings

In addition to setting from an external analog signal (variable resistor, 0 to +10V DC, 4 to 20mA), 7 different digital frequency settings are possible by key input. These frequencies are selected by the combination of external signals X1-X3.

(2) Frequency signal output

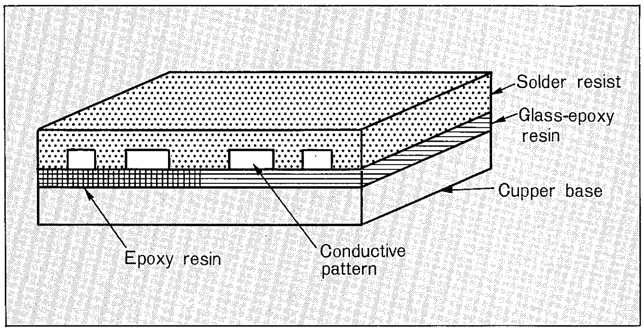
The output frequency may be monitored as a digital LED display on the keypad, or from 2 types of signal output: an analog output of 0-10V DC (max. frequency) or a pulse train output of 1,440Hz (at max. frequency).

4. OPERATING CHARACTERISTICS AND APPLICATIONS

4.1 Current limiting control characteristics

Even when operating under overload conditions such as load impact, smooth and steady operation without tripping is required. For this reason, the FVR-E7S comes equipped with a current limiting function as a standard feature. **Figure 4** shows the current limiting control characteristics in response to impact load. An impact to the load causes an increase in the inverter output current. This is detected and processed at high speed by the 32-bit DSP. The inverter output frequency is then controlled such that the inverter output current will reach some fixed value. In addition to providing smooth, steady operation, the current limiting level may be adjusted over the range of 30-150% of the inverter's current rating. Therefore it may also be used to limit motor torque to meet specific load specifications.

Fig. 7 Structure of metal printed circuit board



In addition, the response speed of the output frequency control may be adjusted during function configuration to be compatible with various different types of loads.

Figure 5 shows an application of the current control function. A magnetic clutch applies/de-applies the load in a mechanical press. Motor current is automatically limited whenever the load is applied. This permits a smaller capacity inverter to be used then compared to inverters without this current limiting function.

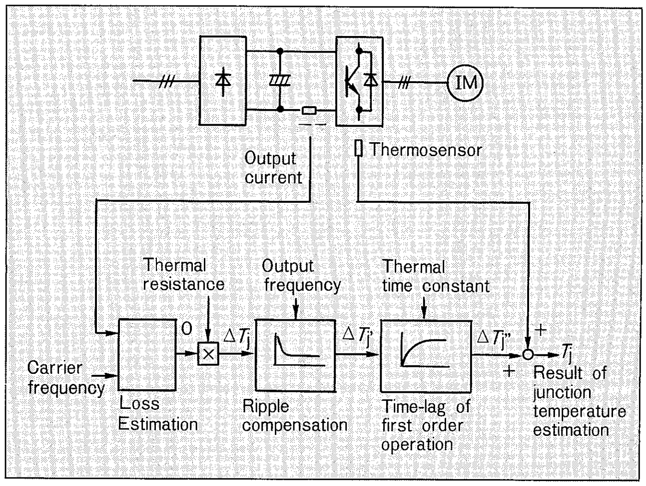
4.2 Restarting after momentary power failure

Figure 6 shows the operating characteristics when the restart function is enabled after a momentary power failure. If there is an instantaneous power failure, the inverter cuts off output but allows the motor to keep rotating with its own inertia. Once power is restored, the motor speed is detected and the inverter is synchronized so that motor current will not exceed a fixed value.

4.3 Metal printed circuit board

Even though the FVR-E7S series is compact, it is still able to achieve low noise operation at high carrier frequencies through the use of high speed switching IGBTs in the main circuitry. Operation at high carrier frequencies increase the amount of heat released by the main circuitry, gate driving circuitry, etc. This fact makes it necessary to implement an efficient cooling system to reduce the temperature of the components and to make miniaturization possible. With the FVR-E7S series, in addition to main circuitry components, the gate driving and power circuitry are all mounted on a metal printed circuit board. The thermal conductivity towards the main coolant is increased, and rises in the internal temperature of the inverter are surpressed. **Figure 7** shows the structure of the metal printed circuit board. Experimental results of insulation materials for the metal core printed circuit board show that an epoxy resin layer with high thermal conductivity is most suited for the main circuitry, and a glass epoxy layer with low dielectric constant is best for the gate driving circuit and the control power supply circuit. Using the latest technology, these two types of insulating layers are formed onto a single copper base substrate.

Fig. 8 Block diagram of IGBT junction temperature estimation



4.4 IGBT protection function

The FVR-E7S series has improved cooling efficiency and has been made compact. To increase product reliability, in case of overload, a protection function is necessary to ensure that rises in temperature do not exceed the tolerance of the main circuit components. The addition of a processor based IGBT protection function to the FVR-E7S series significantly increases reliability.

Figure 8 shows a block diagram of the IGBT protection function. Based on IGBT conduction and switching time loss data, a loss estimator calculates the average loss, Q, per output frequency cycle from the output current and carrier frequency. Next the measured value of thermal resistance is multiplied by Q. This temperature rise is denoted as ΔT_j. When inverter frequency becomes lower, the IGBT thermal time constant cannot be ignored if temperature ripple becomes large over one cycle. For this reason, a ripple compensator multiplies ΔT_j by a compensation constant, whose value is based upon the anticipated ripple at that inverter output frequency, and thereby calculates $\Delta T_j'$. The compensation constant is calculated in advance from simulations of the average temperature rise and the maximum temperature rise. Next, the thermal time constant of the IGBT is taken into consideration. $\Delta T_j'$ is delayed and then processed to calculated $\Delta T_j''$. A temperature reading, measured by thermal sensors mounted on the IGBT's printed circuit board, is added to $\Delta T_j''$. Finally, the absolute value T_j of the junction temperature is calculated. If T_j exceeds the allowable tolerance, the IGBT protection function is activated and inverter operation is halted.

5. CONCLUSION

A brief explanation of the FVR-E7S series has been presented. With its compact and general purpose design, this series represents a new trend in inverters. A wide variety of applications are anticipated. Fuji Electric will continue to make efforts to advance the state of the art of inverter technology.