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TRANSISTOR INVERTER FRENIC 5000G3/P3 FOR GENERAL PURPOSE

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1 FOREWORD

Transistor VVVF Inverters that drive low-cost, small-sized and robust general-purpose cage type induction motor have increased, thanks to technical progress of power transistors and digitalization of control circuits, their ease in handling and economicity, furthermore, expansion of. their capacities, and their field of application is more and more expanding.

In particular, the progress of power transistors is miraculous and up to now, 1,200-V and 300-A elements have already been developed and through establishing of their application techniques and insulating modules suitable for composing main circuits of inverters, inverters of 400 kVA, as the maximum, were made possible to construct. On the other hand, thanks to the development of microelectronics with microcomputers as a central figure, operational calculation that has been too complex have been made possible with comparative ease now, so that the actual aim at present is miniaturization of the machines together with digitalization of control circuits, improvement of performance and diversification of functions.

Fuji Electric's general-purpose transistor inverters FRENIC 5000G/P have registered record of success in many sectors of industries, and in order to cope with the market needs that are being diversified every day, we have introduced these new techniques and brought in a total model change. Specially by adopting large-current and high withstanding voltage power transistor modules with 1,200V and 300A as the main rating, AC 460V power source was made possible to adopt with and expansion of series up to 400 kVA was deviced. Also, by equipping 16-bit microcomputers to all machine models, improvement of functionality was attained and the new models was incorporated into series recently as FRENIC 5000G3/P3.

Here in this report, their outlines, features, standard specifications and application technique are described in a brief form.

2 OUTLINES AND FEATURES

Table 1 shows the composition of models of new inverter series FRENIC 5000G3/P3. In 200V system, 16 models are serialized and in 400V system, 34 models up to 400 kVA. The series has an abundant models.

Table 1 Model composition of FRENIC 5000 G3/P3

<table>
<tr><th rowspan="3">Applied motors (kW)</th><th colspan="4">Inverter capacity (kVA)</th></tr>
<tr><th colspan="2">200V system</th><th colspan="2">400V system</th></tr>
<tr><th>FRENIC 5000 G 3</th><th>FRENIC 5000 P 3</th><th>FRENIC 5000 G 3</th><th>FRENIC 5000 P 3</th></tr>
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<tr><td>200</td><td></td><td></td><td>282</td><td>282</td></tr>
<tr><td>220</td><td></td><td></td><td>335</td><td>335</td></tr>
<tr><td>280</td><td></td><td></td><td></td><td>400</td></tr>
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5000G3 is projected for constant torque general-purpose variable-speed applications such as automatization and energy saving, and has a overcurrent withstanding capability up to 150% for one minute, while 5000P3 is a model seeking economicity suitable for energy-saving operations for loads like fans and pumps.

Structure-wise, in the small-capacity machines up to 33 kVA (except for 200V's of 5000G3), the construction is, as shown in *Fig. 1*, of aluminum die cast frame. By this construction, both miniaturization due to the improvement of

Fig. 1 Small-capacity Inverter

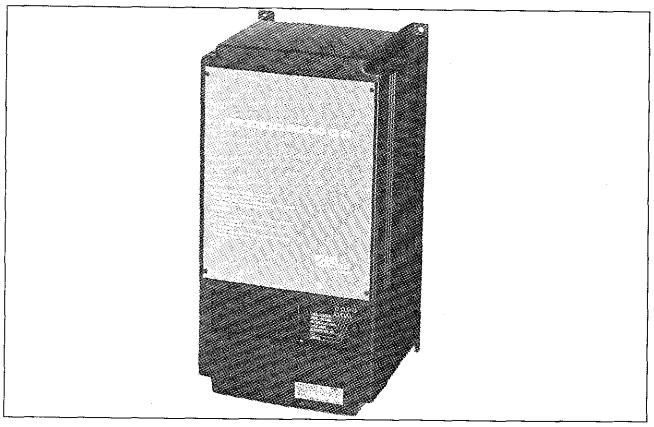

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Fig. 2 Medium-capacity Inverter

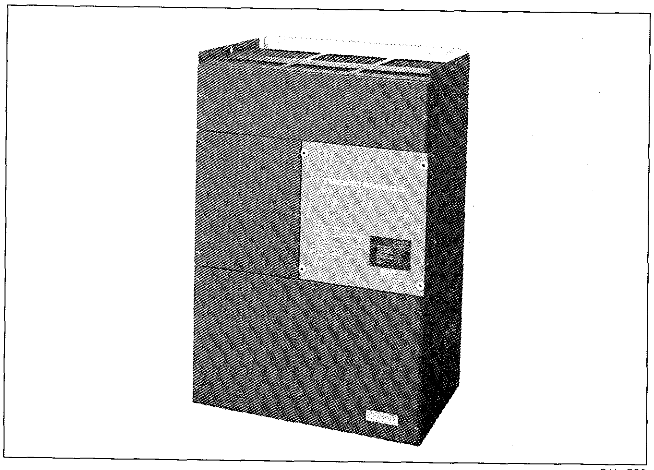

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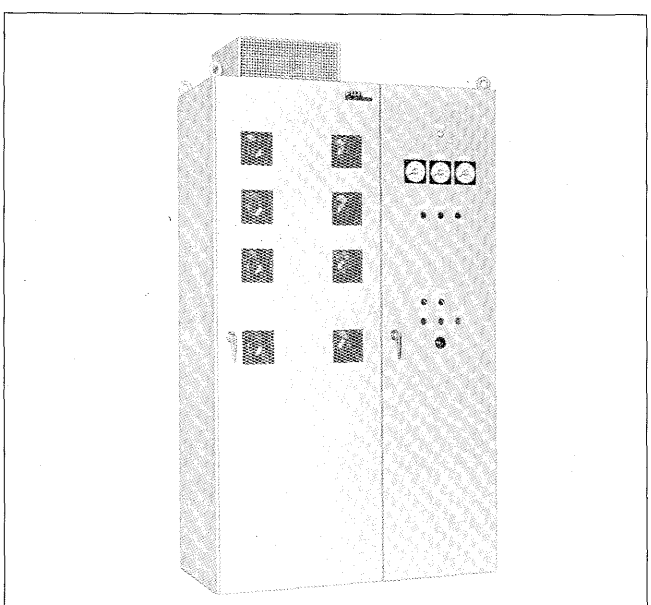
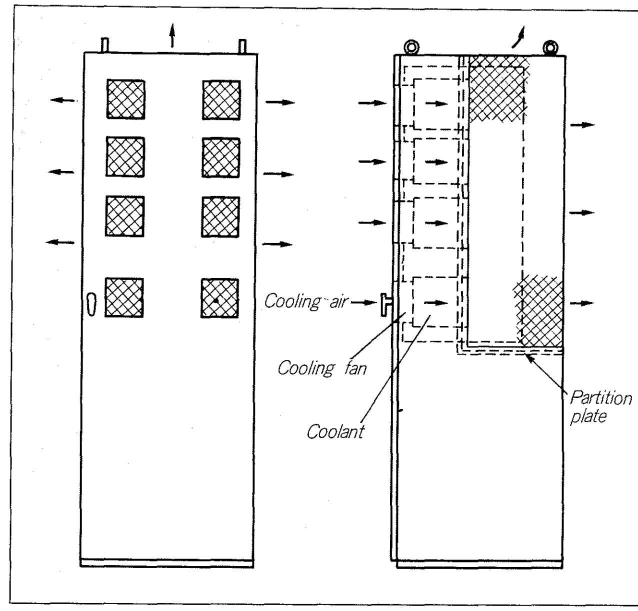
Fig. 3 FRENIC 5000 G3 (335 kVA)



cooling performance and improvement of weather-proofness due to the enclosed construction are attained at the same time. In the medium-capacity machines up to 88 kVA

Fig. 4 Structure of self-standing type 400 kVA inverter



(400V system of 5000P3, up to 104 kVA), they have a steel-plate frame construction as shown in *Fig. 2*, though their designing concept being the same as that of conventional models, their semi-conductor power elements were made much more modulnized by which the policy of miniaturization has been attained. For large-capacity machines more than 104 kVA or 400V system, 1,200V and 300A power transistors are connected in parallel in due consideration of parts configuration utilizing fully the features of transistors in module construction and, at the same time, by adopting specially designed coolant and improving the ventilatioin system, miniaturization in large scale was attained. *Fig. 3* shows 335 kVA FRENIC 5000 G3 model housed in a self-standing cubicle.

In the following, features of this series inverters are described.

(1) Abundant model series and capacity series.

A total of 50 capacity models are available in G Series and P Series together, so that the Customer can select the inverter of most suitable capacity and function for the load requirement in most economic way.

(2) Small in size and light in weight

As the result of effort for obtaining smaller size and lighter weight, some 65% in volume in 200V 33 kVA models and about 60% in 400V 66 kVA models are obtained. In 400 kVA models of 400V system, the volume is about 35% less, and about 25% less in weight in comparison with those of thyristor system inverters. (Comparison on the products of our company).

(3) Availability for various source voltages

For 200V system models, already, input voltage of 200~230V ±10% could cope with thanks to power transistors of V_{CEO} = 600V class, and this time, applying power transistors of V_{CEO} = 1,200V class input voltage of 400~460V ±10% was made possible.

(4) Excellent environmental-proofness

In spite of the fact that they are of forced air cooling type, cooling air is designed to pass through cooling fin only, so that feeble-signal circuits as printed-circuit boards are not polluted directly with atmosphere, so that their environmental-proofness is improved and highly reliable inverters could be constructed. *Fig. 4* shows a construction of 400 kVA inverter housed in self-standing cubicle. Cooling air sucked in from the front panel of the cubicle pass through the cooling fin, then it is evacuated from the top, side or rear part of the cubicle.

(5) High reliability

Together with adoption of semi-custom LSI and hybrid IC in large scale, as well as 16-bit high performance microcomputer in control circuit, a very minute control can be processed by software. By this fact, the number of parts items was reduced by about 50% and reliability was improved in large scale.

Also, in the main circuit, Fuji module transistors incorporating free wheel diodes for main transistors were adopted, and insulating type power modules were introduced to improve the reliability.

(6) Perfectioning of protective function

By equipping as standard specification, the stall prevention function together with frequency control for the increase of current during acceleration and deceleration, and electronic thermal for overload protection aiming at the general-purpose induction motor to be variable speed operated, the protective function as speed-control device was perfectioned.

3 SPECIFICATION AND CIRCUIT COMPOSITION

3.1 Standard Specifications

Table 2 shows the standard specifications of FRENIC 5000 G3/P3. Description is made on the main specifications

Table 2 Standard specifications for FRENIC 5000G3/P3

Inverter			FRENIC 5000 G3	FRENIC 5000 P3
Capacity	200V system		17~84 kVA	17~78 kVA
	400V system		6~335 kVA	6~400 kVA
Input	Voltage and frequency	200V system	Three-phase three wire system 200V/50Hz, 200, 220, 230V/60Hz	
		400V system	Three-phase three-wire system 400V/50Hz, 400, 440V/60Hz, (460V/60Hz, separate order)	
	Allowable variation		Voltage, within ±10%; frequency, within ±5%	
Output	Voltage	200V system	Three-phase three-wire system 200V/50 Hz, 220V/60 Hz.	
		400V system	Three-phase three-wire system,400V/50 Hz, 400, 440V/60 Hz (460V/60 Hz, separate order)	
	Frequency		Selectable among 50 Hz, 60 Hz, 100 Hz, 120 Hz, 150 Hz, 180 Hz, 200 Hz and 240 Hz.	
	Frequency control range		1~240 Hz control range 1:50~1:240	
	Frequency precision		±0.5% of the maximum frequency (at 25 ±10°C)	
	Frequency resolution		0.03 Hz (at 1~60 Hz)	
Control system	Applied load		Constant torque load	Square-number reduction torque load, fan, pump and blower
	Control system		Sinusoidal wave PWM control	
	Voltage/frequency ratio (*V/f*)		*V/f* 14 selectable patterns, torque boost, 16 selectable patterns	
Overcurrent capacity			150%, one minute	120%, one minute
Rotating direction reversible			Also jogging terminal equipped	
Frequency setting signal			DC 0~−10V, DC 0~+10V (input impedance 22 kΩ), 4~20 mA	
Soft start/soft stop function			0.2~200s/60 Hz (time can be adjusted independently)	
Cooling system			Force air cooling	
Braking			Braking torque about 20% (condenser feedback type regenerative braking). Reinforcing of braking torque possible by option	
Protective function	Stall prevention		Functions of overcurrent and overvoltage suppression work to prevent the motor not to stall.	
	Inverter stop		Inverter stop when overcurrent, overvoltage, inverter overload, cooling fin overheat, motor overload, braking resistance overheat fuse blown and electronic thermal.	
	Undervoltage and momentaneous power interruption		Undervoltage, and momentaneous power interruption surpassing 15 ms will stop the inverter operation. With power interruption within 15 ms, operation will continue.	
	Abnormal alarm contact		N.O. or N.C. contact on fault relay (AC 250 V, 3A)	
Display lamp	Failure indication		Individual LED indication for inverter protective operation.	
	Operation indication		Individual LED indication for setting signal and condenser charge voltage	
Accessory functions			Jogging operation, Output frequency upper limiter, Output frequency lower limiter, Bias setting.	
Construction			Enclosed type	
Envoronmental condition	Installing place		Indoors, altitude less than 1,000 m., avoid direct sunbeams, dust and corrosive gas.	
	Temperature		0~+40°C (by removing the front cover when housed in a panel: 0~+50°C)	
	Humidity		Relative humidity 90% or less. There should be no condensation.	

in the following.

(1) Frequency control range

Output frequency is controllable in a range as wide as from 1 to 240 Hz. Eight patterns that can control proportionally the whole range of *V/f*, and 6 patterns that can constant output control (maximum, 1:4) in the frequency range higher than 50Hz/60Hz are available and by switching of digital switch, the user can freely select the frequency.

(2) Switching of torque boost

The torque characteristics when a general-purpose motor is driven by an inverter are determined by inverter output *V/f* patterns. In particular, the torque characteristics around the starting is affected from a voltage drop due to the resistance of primary winding of the motor. Sixteen types of patterns are incorporated so that *V/f* intensifying characteristics can be adjusted according to the characteristics of load to be applied, and that can be switched over by a digital switch.

(3) Frequency setting signal

The frequency setting signal can respond to three sorts of signals, namely 0 to −10V, 0 to +10V and 4 to 20 mA. Furthermore, a bias setting and upper and lower limiter that are often demanded for the automatic operations of fans and pumps are equipped as standard accessories, so that the inverters can cope with various applications. *Fig. 5* shows the characteristics of bias setting and *Fig. 6*, those of upper and lower limiters.

(4) Stall preventing function

In case it is necessary to accelerate or decelerate quickly a motor, the motor has a tendency of getting overcurrent during the acceleration and overvoltage of DC intermediate circuit and motor overcurrent during the deceleration. For this reason, in the open loop control inverters are provided with soft start/soft stop function that can be adjusted according to the load inertia and torque characteristics in order to prevent all these, and that is the general practice. The inverters of this series also have a choice of 32 patterns for accelerating/decelerating time up to the maximum of 200 seconds. However, with this function alone, there are often cases in which the setting of accelerating/decelerating time is a little too short, or the inverter may trip due to the overcurrent or overvoltage protective functions when a load torque is increased. In order to compensate the slight errors of setting and troublesome work for adjustment, the new series of inverters are provided with voltage/current suppressing function incorporated in them so that inertial accelerating/decelerating operations can be made by correcting automatically the soft start/soft stop function by supervising the motor current and DC intermediate circuit voltage when they increase.

Fig. 5 Bias setting

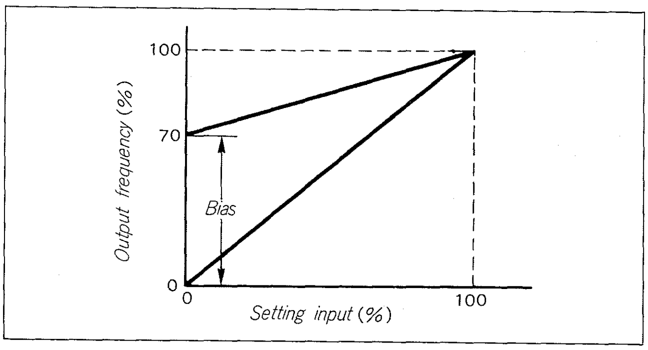
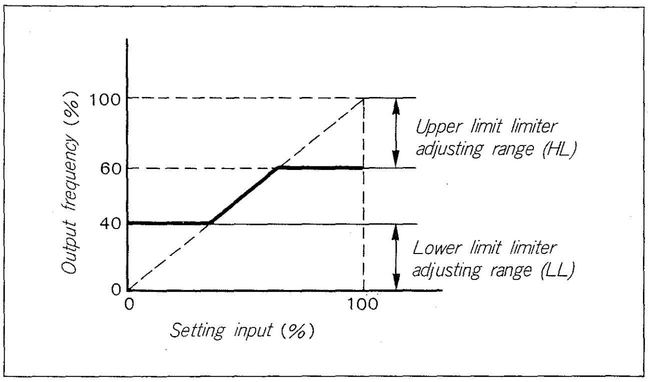


Fig. 6 Upper and lower limit limiters



(5) Electronic thermal relay

Generally, protection against overload of general-purpose motors are carried out by means of thermal relay and for FRENIC 5000G3/P3 inverters, they have current supervising function by micro-computer and by providing inverse time delay characteristics of thermal relay by software, matching of protective function as the whole of variable speed equipment is attained. Also, the operating time of the electronic thermal relay is designed to change over automatically when the output frequency is lowered in due consideration of cooling capacity reduction of the motor in the low-speed region.

3.2 Circuit Composition

Fig. 7 shows fundamental circuit composition of FRENIC 5000G3/P3 Inverter Unit. In the following, description on the outline is made.

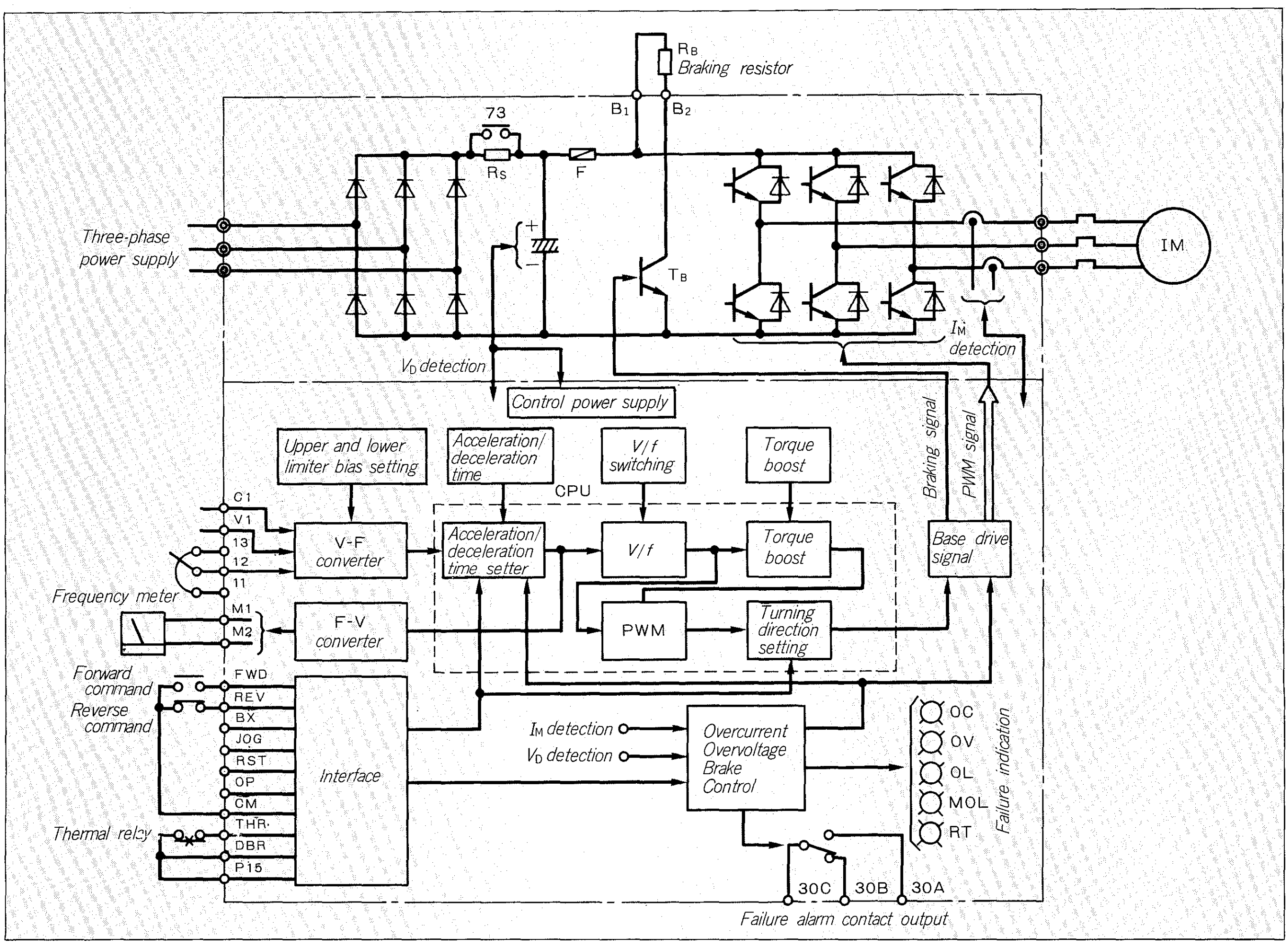
(1) Main circuit

The main circuit rectifies three-phase AC power supply by diode bridge and by converting the DC voltage smoothened by condenser into three-phase AC voltage of variable voltage and variable frequency by transistor inverter, then supplies it to induction motor. In the large-capacity series, transistors are connected in parallel, and good current sharing characteristics are obtained through element characteristics control, parallel wiring technique and base driving technique. And, transistor T_B of DC intermediate circuit and braking resistance R_B are the braking unit disposing energy regenerated from motor during the braking operation. The braking resistance, as it is installed outside, the terminals connecting them are provided. The series resistance R_S is used for suppressing the charge current of condenser in the initial phase of operation and R_S is short circuited during the operation.

(2) Control circuit

Interface receiving frequency setting and rotating direction commands, protective circuits against overcurrent

Fig. 7 Inverter unit fundamental circuit composition



and overvoltage and base driving circuits adopt all hybrid IC in a large scale and with this, they aim to have miniturization of printed circuit boards and improvement of reliability. On the basis of these commands and acceleration/deceleration time setting by digital switch, *V/f* pattern setting and torque boost setting, the operational calculations necessary for inverter control such as the decision on frequency raising and lowering, PWM, direction of phase rotation, various sequencial processing are carried out by 16-bit microcomputer and semi-custom LSI. The failure indication is made individually per each LED for inverters' protective operation function.

3.3 Option

(1) Braking unit

When a motor is turning with inverter operation, if inverter frequency is made lower, the motor turns to braking condition. In general, due to the motor winding and inverter circuit loss, a braking torque from 15 to 20% is obtained. In case the load GD^2 is large or when a rapid deceleration is required, it is necessary to discharge the regenerative energy. For this, discharge resistance and transistor switch are provided as an option.

(2) Power factor improving reactor

As the inverter input circuit constitutes a rectifier circuit of condenser input type, higher harmonic current is contained in the input current and their effective value would increase as mentioned in the separate report of this magazine "Transistor Inverter Application Technique" This is an option for reducing this harmonic and for making the power factor more than 0.9.

(3) Restart after momentaneous power interruption and commercial power switchover unit

When a power interruption within a short period less than several seconds takes place, this optional device detects the rotating speed of motor under "free run" condition, and for raising the speed from that rotating speed up to commanded speed again. Also, this unit can be used for switching between inverter operation and commercial power supply operation by recombining the peripheral sequences.

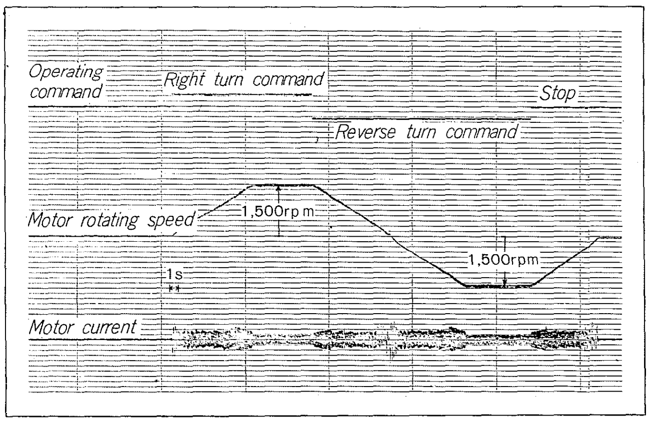
4 OPERATING CHARACTERISTICS AND APPLICATION TECHNIQUE

Main operating characteristics and their application technique of FRENIC 5000G3/P3 are described in the following.

4.1 Accelerating/Decelerating Characteristics

Fig. 8 shows accelerating/decelerating characteristics in case of four-quadrant operation of general-purpose motor of 15 kW with 5000G3, 22 kVA inverter for 200V. In this, a load having GD^2 of motor itself and GD^2 inertia of 5 times more is connected and is driven by an inverter equipped with braking unit. The obtained accelerating/decelerating characteristics are smoothened thanks to a high-speed response control through use of 16-bit micro-computer.

Fig. 8 Oscillogram of 4-quadrant operation



4.2 Operating Characteristics at the Time of Momentaneous Power Interruption

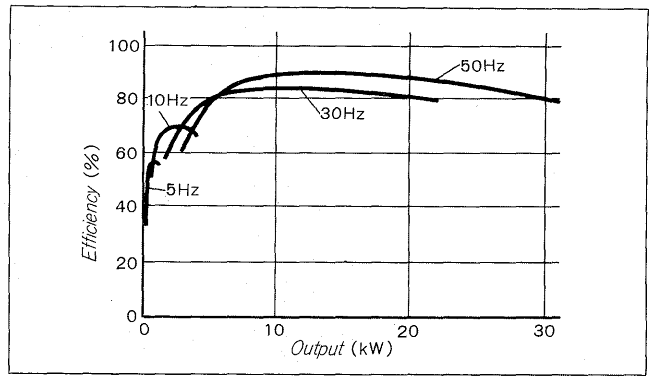
Even when the power supply is interrupted for a short period of time, as long as there exists an electric charge accumulated in smoothing condenser located in the inverter DC intermediate circuit, the inverter can continue operating. For FRENIC 5000G3/P3, the inverter is designed to continue operating for about 15 ms after the service interruption takes place.

When the inertia of the load is extremely small and when the load is heavy, there are cases in which the intermediate voltage drop is increased and inverter may trip when the rush current is excessively large after the recovery of the service. When an automatic restart after the recovery of commercial power supply is desired, or when switchover between the commercial power supply and inverter is desired, a separate option is available.

4.4 Operating Efficiency

By frequency controlling the general-purpose motor, the secondary copper loss can be reduced. In addition to the above, FRENIC 5000G3/P3 attains a very high operating efficiency through improvement of current distortion by sinusoidal wave PWM and low-loss driving of the power transistor. *Fig. 9* shows the performance curve of 30 kW Fuji Standard Electric Motor (4 poles) when it is driven by an inverter. The curve shows that a high operating efficiency is obtained even in the low-speed region.

Fig. 9 Output-efficiency characteristics



5 SUMMARY

In the preceeding report, the outline of Fuji Electric's general-purpose transistor VVVF inverter FRENIC 5000G3/P3 is introduced. The pace of progress for power semi-conductor elements toward higher voltage and larger current will be rapid, making the capacities of converting equipment that utilizes the inverters larger possible. In particular, self-extinguishing type elements will, since they are easier to use and to miniaturize the equipment, be object of many further development attempts, and are expected to be applied for more and more various types of self-exciting converter equipments beginning with inverters. Fuji Electric is now doing their best to develop new devices aiming at making them higher voltage and larger current, as well as higher speed in switching. From now on, besides the new power device application technique, we Fuji Electric will propel our policy of introducing digital control system in large scale, miniturization and obtention of higher reliability through circuit integration technique in order to reduce still more the vibrations, noise and harmonics to produce ideal variable speed drive equipment, for which we will spare no pains.