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RECENT VARIABLE-SPEED DRIVE EQUIMENT

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1. FOREWORD

Variable-speed induction-motor drive-use inverters are serialized as standard equipment for each sector of industries according to the contents of technology as power semiconductor elements, control system and inverter circuit in which power semiconductor devices are used, as well as according to how the inverters are applied. FUJI ELECTRIC also has serialized its products in several series as voltage source pulse width modulation (PWM) transistor inverter such as plant-use DC common bus type inverters series (10–200 kVA), and textile use DC common bust type inverters series (15–150 kVA), derived from the former, as well as, general purpose inverter series suitable for constant v/f control in stand-alone type (0.4–280 kW, as a single equipment and about 500 kW in parallel connected group of equipment) and general industry use vector controll transistor inverter series (3.7–400 kW) as standard series.

For the loads corresponding to the capacities larger than those mentioned above, FUJI ELECTRIC utilizes current source thyristor inverters or GTO inverters; and for the former, standard series (200–1600 kVA) of all-digital control equipment are available, while for the latter, by combining with devices having a capacity of 650 kVA each, equipment with a total capacity up to several thousand kVA are made available as standard series of variable-speed drive equipment for large-capacity AC machines.

Besides the above, standardized series are available also for commutatorless motor (PERMOTRON® Series) and cycloconverter. However, in this paper, we like to introduce the use, characteristics, capacity-series, and present and future trends of standardized series inverters used in combination with the three-phase squirrel-cage induction motors by the maximum of 3,600 rpm in rotating speed.

2. STANDARD SERIES OF TRANSISTOR INVERTERS

The products of this series are divided into the following three main types.

(1) The products of the first type are those used for various types of continuous processing line plants, and the individual inverters are combined with main control system composed of higher hierarchy programmable controller connecting by means of data way function. This type of products being used as DDC system can be called as "Plant-use DC common bus inverter series"

(2) The second one is derived from the first one. It is the "series for exclusive use in the specified system" that is specialized for optimum systematic operation in the specific machine installation, and its typical example is the "textile use DC common bus inverters".

(3) The third type is the stand-alone type "General purpose standard series" and in parallel with these general purpose series, industry use vector controll transistor inverter series are available.
The following are the description of the products classified by each series mentioned above.

2.1 Plant-use DC common bus type inverters (FRENIC 4000 VM, VM-T)

They are mainly adopted for the continuous processing line installation, so that from several tens to hundreds of variable-speed drive equipment are used in one single installation. Thus, as main circuit composition shown in

Fig. 1 Composition of main circuits of DC common bus type inverter

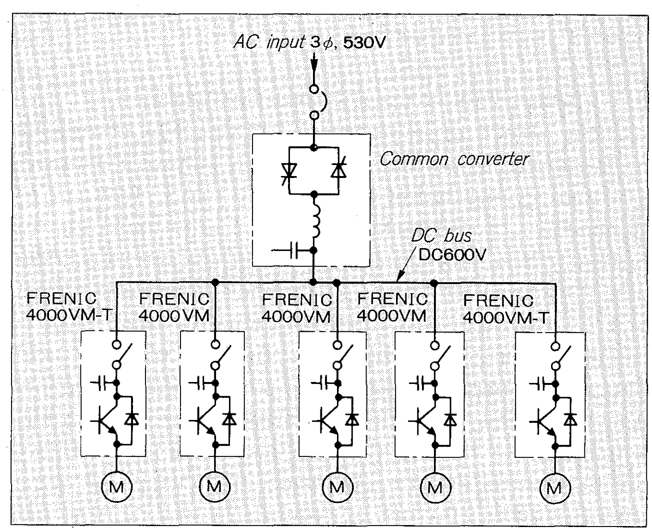

Fig. 2 FRENIC 4000VM inverter panel (6 units housed)

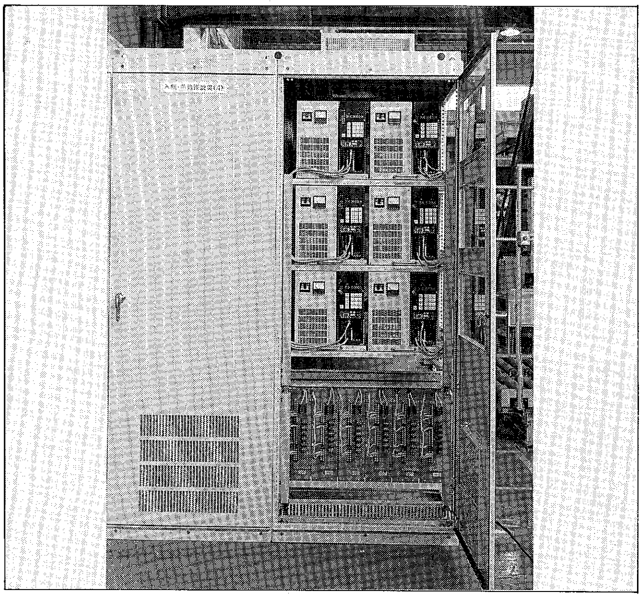

Fig. 3 FRENIC 4000VM inverter unit

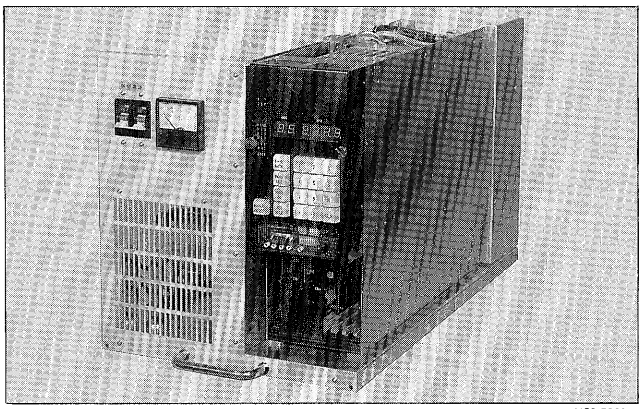

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Table 1 FRENIC 4000 VM, VM-T standard specifications

Specifications \ Inverter		FRENIC 4000VM	FRENIC 4000VM-T
Input voltage		DC600 V	
Output	Voltage	AC400 V	
	Frequency	max. 150 Hz	
Capacity series		10, 15, 30, 60, 100, 150, 200 (kVA)	
Rating		100% continuous, 150%, 1 min.	
Operating mode		4 quadrants	
Control	System	Vector control	
		Speed control	Speed control + torque control
	Control range	1:100	1:100
	Accuracy	Speed ±0.01%	Speed ±0.01%
Ambient condition	Installation place	Indoors, altitude lower than 1,000 m.	
	Temperature	−10 ~ +40°C	
	Humidity	20 ~ 95% RH, no dewing	
Housing panel		Self-standing enclosed type	
Cooling		By forced ventilation	

Fig. 1, when a DC common bus type inverter system supplying DC power to several sinusoidal wave PWM inverters from a single common converter DC power supply is adopted, each driving and breaking power are shared reciprocally through DC common bus, and as all electric motors in the same line not necessarily require full power simultaneously, the capacity of the common converter can be dispensed, in many cases, with the smaller capacity than the total capacity of the inverters, hence the merit of being dispensed with reduced AC input capacity.

Fig. 2 shows the outer view of the inverter panel and *Fig. 3*, that of the inverter unit. Also, the standard specifications of this series are shown in *Table 1*

(1) FRENIC 4000 VM

By combining R2-compensated current model type vector control function of the squirrel-cage induction motor with DDC speed control function, the identical speed control function to that of Leonard control through conventional DC motor drive-use equipment is obtained and, at the same time, RAS function including failure diagnotic function as well as data way function to compose the DDC plant system, are provided.

(2) FRENIC 4000 VM-T

This is a vector controll DDC inverter aiming at torque control, and for vector control, a voltage model method is adopted for improving the control efficiency, attaining the torque control accuracy of ±3%.

In the future, this series will include additionally inverters with speed sensorless vector control and self tuning regulator.

2.2 Textile use DC common bus inverters (FRENIC 4000T2)

These are mainly adopted for textile machine for synthetic fibers and various types of film extruding machines and others. Each inverter is, as indicated in the example of main circuit composition shown in *Fig. 4*, of DC common bus type, sharing the DC intermediate circuits in common. The electric motors they drive are often the permanent magnet type synchronous electric motors (PERMO SYN-MOTOR®), and the control specifications of individual

Fig. 4 FRENIC 4000T2 main circuit composition

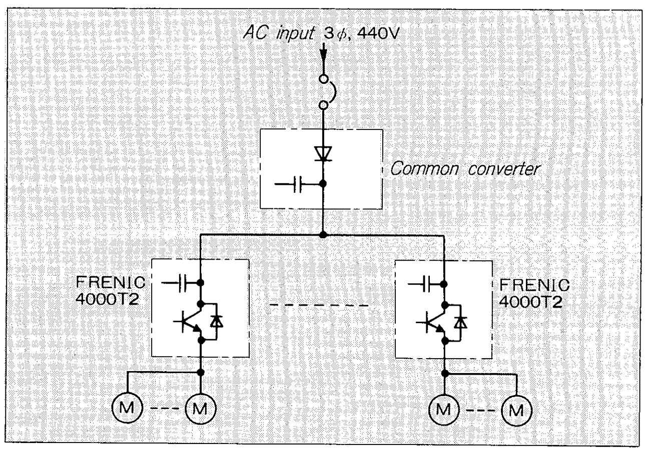
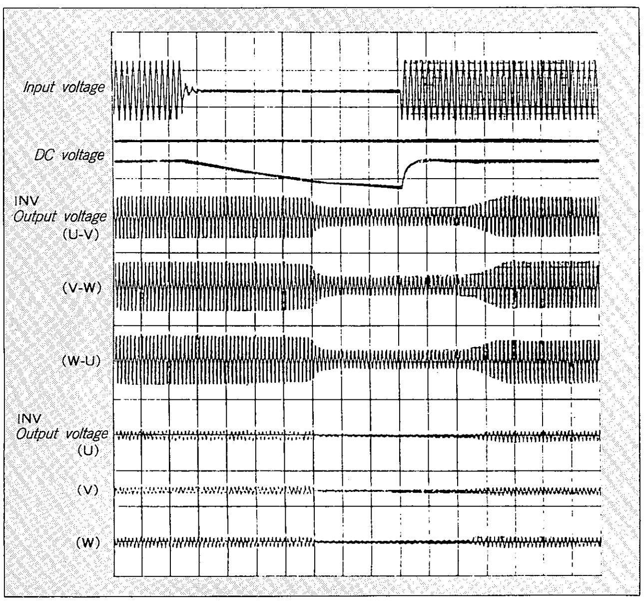


Table 2 FRENIC 4000T2 standard specifications

Item		Specifications
Input voltage		DC600 V ±10%, 50% fall, 1 sec. continuous operation
Output	Voltage	AC400 V
	Frequency	300 Hz (Maximum)
Capacity series		15, 30, 60, 90, 120, 150 (kVA)
Rating		100% continuous, overload 150%, one minute
Control	System	Sinusoidal wave PWM
		V/f constant control
	Accuracy	±0.01%, BCD 5 digit setting resolution 0.01 Hz
	Installation place	Indoors, altitude lower than 1,000 m.
	Temperature	0∼40°C
	Humidity	95% RH or less, no drewing
Housing panel		Self-standing enclosed type
Cooling		By forced ventilation

Fig. 5 PERMOSYNMOTOR processing of instantaneous power failure

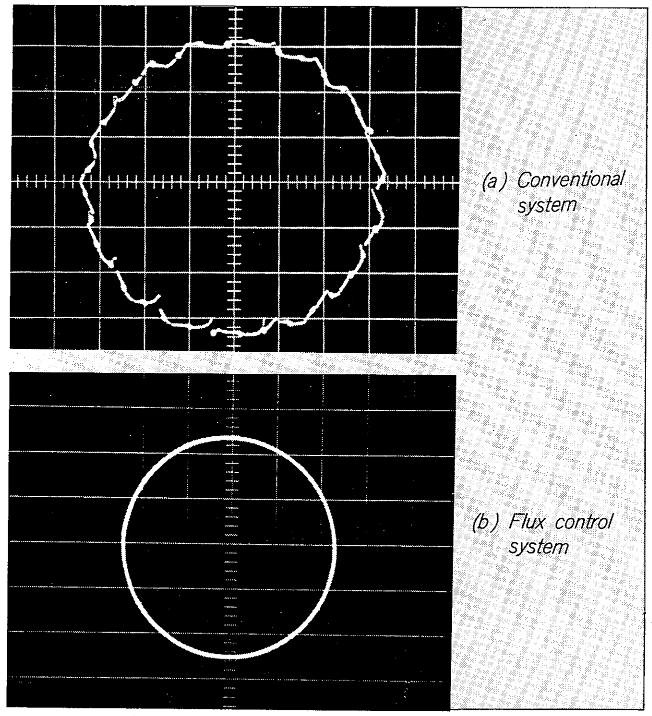


inverters are those of sinusoidal wave PWM, constant V/f control, and as shown in *Table 2*, they have unique characteristics that no other inverters have.

Furthermore, features of this inverter are the operational performance at the time of AC input voltage variation. For example, in case of 50% voltage dip within one second, the operation can be kept going on and, in case an instantaneous power failure less than one second should coour, the inverter is provided with a function permitting an automatic restart of its operation after the power recovery. *Fig. 5.* shows a chart indicating the processing of instantaneous power failure.

Through a higher-hierarchy programmable controller, the control parameters can be set by the data way system. For the immediate future, FUJI ELECTRIC plans to serialize, adding the multi-motor drive inverters of this series, the individual motor drive inverter series.

Fig. 6 Flux vector locus



2.3 Standard inverter series for general purpose

(1) Flux control sinusoidal PWM transistor inverter (FRENIC 5000 G5/P5)

As for sinusoidal-wave PWM control inverters of conventional type constant V/f control system used for energy-saving operation of fluid machinery as fans, pumps and others, and for driving cargo transport equipment as conveyors, due to the adverse influence of the dead time during the transistor switching time, it was difficult to output sinusoidal-wave voltage, and as shown in *Fig. 6* (a), distortions were produced in the rotating flux vector. By this, torque ripples were produced, and when the electric equipment were combined with mechanical system, gear noise and current unstable phenomena produced during the light load operation presented often a considerable problem.

In the flux control sinusoidal PWM system adopted by this inverter series, the problem was solved by compensating the dead time due to the transistor switching, through use of flux loop (AϕR) and by controlling the rotation flux vector to an ideal circular form as shown in *Fig. 6* (b).

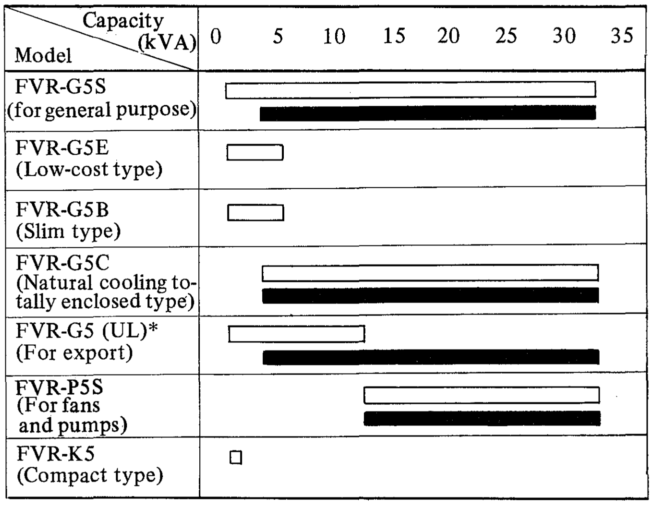
The features of this series is in that, by adding current control function and frequency compensating function to this flux control, overcurrent tripping, often produced at starting, is prevented. Furthermore, in order to reduce electromagnetic noises of electric motors, an automatic regulation of flux volume and optimization of transistor switching frequency are effectuated.

Table 3 shows the capacity parameters of this series. FRENIC 5000G5 has the rating of overcurrent capacity of

Table 3 FRENIC 5000G5/P5 capacity series

Applicable motors (kW)	Inverter capacity (kVA)			
	200 V Series		400 V Series	
	FRENIC 5000G5	FRENIC 5000P5	FRENIC 5000G5	FRENIC 5000P5
30	44	44	44	44
37	55	53	56	56
45	67	67	66	66
55	84	78	84	84
75	104	104	104	104
90	132	132	132	132
110		153	153	153
132			175	175
160			221	221
200			282	282
220			335	335
280				400

Table 4 FVR series capacity line



*UL CSA standards homologation expected on Dec, 1988.

200 V 400 V

150%, one minute, for constant torque load; while FRENIC 5000 P5 is for the load having the square reduction torque characteristics, being provided with overcurrent capacity of 120%, one minute.

It is expected to increase the use of inverters of this series in a wider field of application of loads where acceleration and deceleration with high torque are necessary as in the case of press machines and transport carriages, etc. through the adoption of the flux control system.

Also, for expanding the field of application to general industries, increasing of inverter capacity through adoption of multi-connected system was attempted, and at the same time, as for the control technology, a full digitalization was aimed; a system of higher performance as the torque control function, etc was sought for in order to attain a control system that is as good as that of vector control, and in order to make it possible to cope smoothly with the FA issue, we believe that it is our urgent task to improve the simple interface function for the system construction with a programmable controller.

(2) Small-capacity all-digital transistor inverter (FVR-G5S/P5S)

The use of this series is also divided, roughly, into two categores: one aiming at energy saving mentioned before, and another aiming at labor saving and automatization in machine tools and transport machines. The two main categories are: FVR-P5S Series (Overcurrent capacity of 120% for one minute) produced for answering the needs not requiring so much accelerating/decelerating capabilities as the case of the use of the former mentioned above; and another as the use of the latter, those answering the needs requiring excellent accelerating/decelerating capabilities, namely FVR-G5 (overcurrent capacity of 150% for one minute).

Also available in the FVR-GR Series, are the several versions such as FV-G5E Series, a sort of junior economy type of the former, whose functions are much simplified; then, miniaturized for mounting on panels, space-saving FVR-G5B Series; FVR-G5C Series, the natural cooling totaly enclosed type in due consideration of dust prevvention; and finally, FVR-G5 (UL) Series for export in a perfect conformity with the UL and CSA Standards. And, as the lowest ranking in hierarchy of the system structure, we have the newly developed FVR-K5 Series. This is a series of products aiming at the maximum efficiency in miniaturization of shape and reduction in weight and price, having the minimum varieties, but solid fundamental functions and performance so that this makes an ideal products for a simple and variable-speed operation. *Table 4* shows the capacities of FVR Series now in manufacture.

As the fundamental features common to FVR Series we can cite: (1) capacity of securing more than 200% of starting torque, (2) natural cooling totally enclosed structure, (3) simplified handling and operation, and realization of full digitalization for avoiding errors due to temperature drift and secular changes and (4) availability of various types of cards permitting an easy realization of specialized functions through plug-in type option cards. In the following, their details are described.

In order to enhance the starting torque value, it is indispensable to operate the machine always with slip frequency smaller than that of predetermined value. Thus, if, at the time of starting acceleration, the output current is feared to surpass the maximum rated value, a stall control that would retain the slip frequency constant, will come into effect by stopping the rise of command frequency. Further, by approaching the output current waveform of low-frequency region to sinusoidal one, fundamental-wave efficiency, effective for securing the starting torque, is enhanced.

As for the natural cooling totally enclosed construction, an aluminum die cast monocoque structure is adopted, giving a role of a heat sink to the totally enclosed case in order to radiate the switching loss of power transistor. Thus, the requirements for increase of cooling surface and

Table 5 OPC series list

Model	Function	Application
OPC-01	Synchronous operation	Synchronization of belt conveyors
OPC-02	Relay interface	Relay sequence control
OPC-03	Constant-torque operation	Winding machine and press
OPC-04	Digital interface	Combination with NC machines
OPC-05	Analog meter drive	Analog frequency meter
OPC-06	Constant-speed operation	Grinder, extruder
OPC-07	Bypass transfer	Bypass back up
OPC-09	Remote control	Panel control when installed in the panel
OPC-10	Remote indication	Panel dispaly when installed in the panel

cost reduction are met simultaneously.

For the full digitalization, with an aim of eliminating the drift and secular change which are inherent to the conventional analog system and, at the same time, for improving the maneuverability, all switching and adjustment by conventional switches and volumes are eliminated, consequently, setting of operational pattern constants is now possible through a mere depression of touch key from the inverter face.

As for the functional option, OPC series option cards shown in *Table 5* are available and contribute considerably to the expansion of field of application for this inverter.

Present needs for small-capacity general purpose inverters are diversified: there are many needs requiring high speed response and high stopping precision being equal to servomechanism, at the same time, also there are many demand compacting of the size, reduction of weight and price. Therefore, from now, we FUJI ELECTRIC will endeavor for coping with the actual demand of the market polarized into the following three cores: the exclusive and general purpose series that can attain miniaturization and reduction of weight and price of the series of products destined for certain specific machines; the multifunctional series incorporating the interface function of higher hierarchy programmable controller; and high-precision speed and torque control series destined to specialized applications.

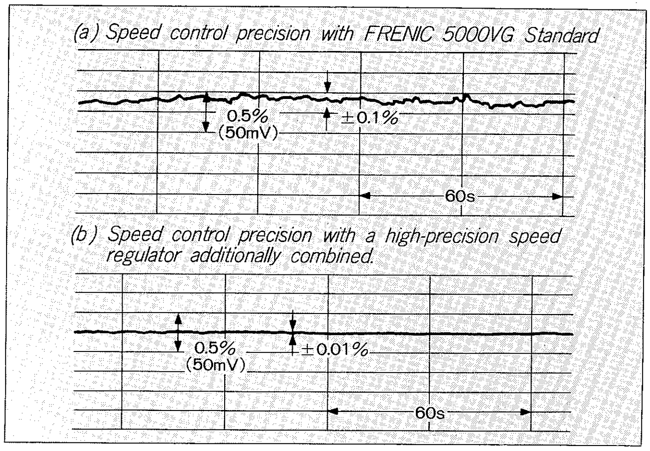
2.4 General-industry use vector control PWM transistor inverter (FRENIC 5000 VG)

This series of inverters are used being combined with exclusive-use totally enclosed forced ventilation induction motor, mainly as stand-along type AC variable-speed drive equipment in the fields of almost all sectors of industries as metallurgic, textile, paper-making and chemical industries as well as in the fields of cargo machines and machine tools. *Table 6* shows the standard specifications of this series. Increase in capacities is obtained through use of parallel inverter system in case of the squirrel-cage induction motor rate and at the sametime this inverter series are combined being 400 V, 220–400 kW.

Table 6 FRENIC 5000VG standard specification

Item	Specification
Capacity	200 V series: 3.7～75 kW, 400 V series: 3.7～40 kW
Main circuit system	Voltage source PWM transistor inverter
Control system	Sinusoidal wave PWM speed control with minor
Speed precision	±0.25%/25°C±10°C
Overload torque	150%, 1 minute
Control system	Resistive discharge

Fig. 7 Examples of application of high-precision speed regulator



Features of FRENIC 5000VG are: (1) Transient response characteristics are excellent, (2) high speed control precision, (3) wide speed control range and (4) complete availability of optional functions. So that the applicable field is wide.

As for the transient response, as the vector control system is adopted all through the variable-speed range, the frequency response characteirstics as hight as max. 70 rad./s are obtained. For obtaining the speed control precision, a high-precision speed regulator can be provided as an option, and by using this, a precision as high as ±0.01% can be obtained. *Fig. 7* shows the results obtained in the use in a paper machine.

The speed control range is, within the rated torque range, 1:100; and when constant output range is included it is as wide as 1:240 for 3.7～22 kW, for 30～45 kW, it is 1:200 and for 55～75 kW, it is 1:160. so that no decrease in output power will occur even in the high-speed range, and for all-control range, a motor output of 150%, one minute can be obtained. The standard specification of the electric motor is: 4 poles and the base rotating speed being 1,500 rpm. However, they can be applied also to squirrel cage type induction motors of other poles.

For expanding the field of application, various optional functions are available and, in particular, through use of an interface unit of exclusive use for higher-hierarchy programmable controller, it is possible to build up a control network with this series products.

From now on, FUJI ELECTRIC will endeavor for improvement of high-speed response characteristics, introduction of high-precision torque control, consolidating of data way function to higher hierarchy system, and completion of RAS function, as well as, at the same time, for improving the economicity and maintenability.

3. GTO THYRISTOR INVERTER (FRENIC 4000F/G)

This is a new series of Industrial use viarable voltage veriable frequency inverters using GTO thyristors. As this series inverters can obtain higher maximum frequency than those of thyristor invertesr, they are particularly suitable for variable speed drives of, for example, an ultra high-speed, large-capacity and high-pression pumps and blowers. *Table 7* shows the standard specification of this series.

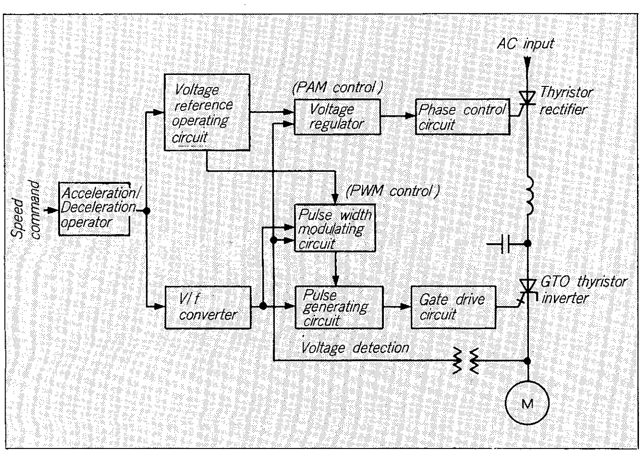
The control system is constant V/f control system using PWM and PAM simulataneously, whose control block diagram is show in *Fig. 8*. In the low-speed range, PWM control is carried out suppressing the torque ripple of the electric motor, and in the high-speed range, one-pulse operation is effectuated, exerting PAM control.

The main circuit is arranged into standardized stack construction. *Fig. 9* shows the GTO thyristor stack circuit diagram and *Fig. 10,* its outer view. This stack constitutes inverter's two arms of positive side and negative side, and by combining 3 stages, a six-pulse 650 kVA inverter is constituted. By multi-connecting this single unit, the system can be applied to the capacity range of several thousands of kVA from 650 kVA on.

Table 7 FRENIC 4000F/G standard specifications

Item		Specifications
Input voltage		AC810 V
Output voltage		AC750 V
Output capacity		More than 650 kVA (capacity expansible parallelizing and multiplexing)
Output frequency		max. 300 Hz (PAM control)
Rating		100% continuous, 150%, one minute
Operating mode		1 quadrant (4 quadrants possible, as an option)
Control system		PWM, PAM jointly used constant V/f control
Control range		1:20
Control precision		Frequency ±0.5%
Ambient conditions	Installation place	Indoors, altitude less than 1,000 m.
	Temperature	−10 to +40°C
	Humidity	20～95%, RH. No dewing.
Housing panel		Self-standing enclosed type
Cooling		Forced ventilation

Fig. 8 FRENIC 4000F/G control block diagram



4. ALL DIGITAL CURRENT SOURCE THYRISTOR INVERTER (FRENIC 2000VM)

FRENIC 2000VM is an all digital vector controlled current source thyristor inverter, and with the series aiming at higher functionality and higher performance through solidifying of high-precision, high speed response, dataway function and RAS functions, it makes an ideal medium and large capacities variable speed drive equipment.

The standard specifications of FRENIC 2000VM are shown in *Table 8* and its features are as follows.

As the equipment adopts the 16-bit master CPU carrying out the main control, and the multi-processor system through a slave CPU that takes up the duty of controlling the converter side and inverter side, a complex vector operation can be done with high speed. *Fig. 11* shows the outerview of the control unit.

In order to carry out compensation to the operating error due to secondary windings resistance change of the squirrel-cage induction motor, the equipment effectuates

Fig. 9 GTO thyristor stack circuit diagram

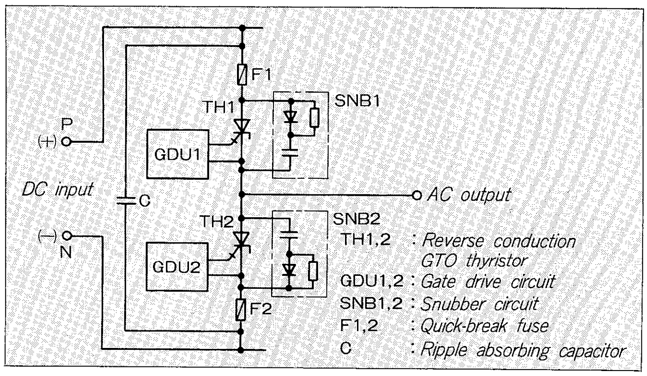


Fig. 10 GTO thyristor stack

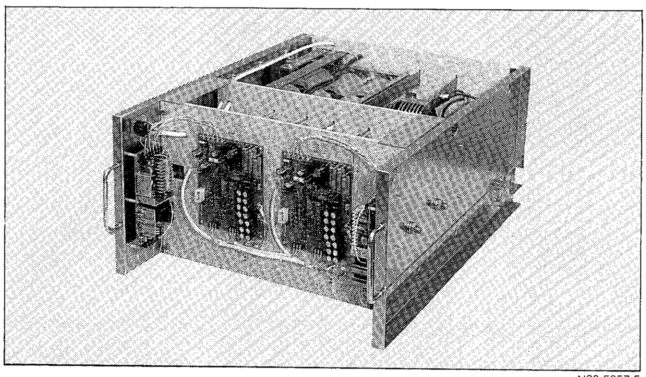


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Table 8 FRENIC 2000VM standard specifications

Item		Specifications
Input source		3ϕ 200/220 V 50/60 Hz 3ϕ 400/440 V 50/60 Hz
Source variation		±10% (voltage), ±5% (frequency)
Rated capacity		7.5 ~ 910 kVA
Maximum output frequency		120 Hz (7.5 ~ 240 kVA) 60 Hz (250 ~ 910 kVA)
Overload capacity		150%, one minute
Control system		Speed control + vector control
Speed control range		1:100
Speed precision		±0.01%
Control response		30 rad/s
Field control range		1:1.5
Operating system		4 quadrants
Ambient condition	Installation place	Indoors, altitude less than 1,000 m
	Ambient temperature	–10 to +40°C
	Humidity	20 ~ 95% RH (No dewing)
Housing panel		Self-standing enclosed type
Cooling system		Forced ventilation

Fig. 11 FRENIC 2000VM, outer view of control unit

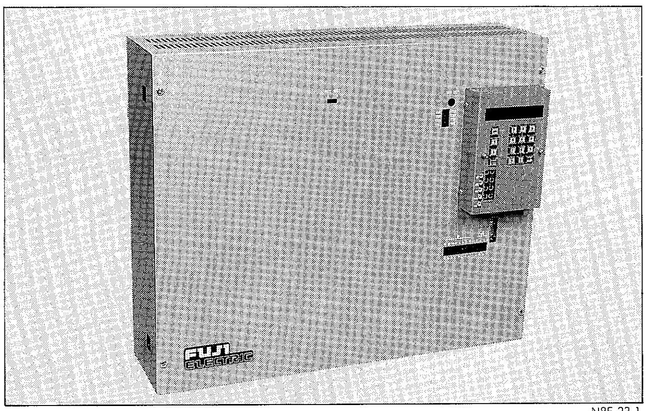
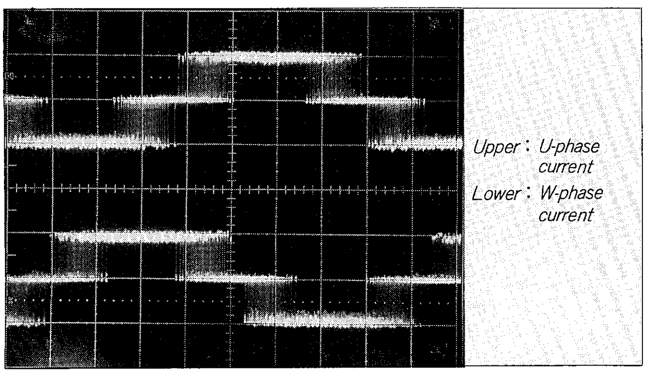


Fig. 12 Current PWM waveforms



highly accurate flux operation in all the speed control range by adopting both voltage and current models that analogize the flux from terminal voltage and current of the electric motor in the medium and high speed range, and in the ultra low speed range, by adding the compensation by thermal sensor.

For the low speed range where the torque ripple presents problems, current PWM control through software processing of the exclusive-use slave CPU is effectuated, in order to reduce the torque ripples. *Fig. 12* shows the current PWM waveform during that operation.

Provided with self-diagnostic function which detects and processes various sorts of failure modes, the machine can, at the time of producing some failure, localize the cause of failure, order of its producing, and as it memorizes the control data of before and after the production of the failure, it can trace back the cause using the exclusive-use loader. Through solidification of these RAS functions, maintainability is being improved.

Various status signals are received and sent to and from the higher hierarchy programmable controller through the inverter-side DDC interface unit, the signals including the set value of various parameters, operation command and control equipment status.

5. DATA WAY SYSTEM BETWEEN PROGRAMMABLE CONTROLLER AND INVERTER

As for data transmitting system between inverter and programmable controller (MICREX-E, F), the system can be roughly classified into two categories depending on the scale of the plant applied. That is, for the large-scale plants having a large quantity of informations, the system is linked to the higher-hierarchy controller through DDC only interface and transmission line. *Fig. 13* shows the system configuration. As it can be seen from the Fig., to the transmission link, besides the MICREX, other man-machine interface (PMS) can be connected, for example, the failure informations are linked to PMS through the Data Way, and as various inverters can be centrally monitored at one place, the maintainability can be improved in great strides.

From the MICREX side, sequence control signal, various reference on speed and torque, as well as parameter set values as P.I. constants are given. On the other hand, from the inverter side, status signals of the equipment and other signals necessary for main control on MICREX sides are sent back.

Fig. 13 Large-scale plant transmission system

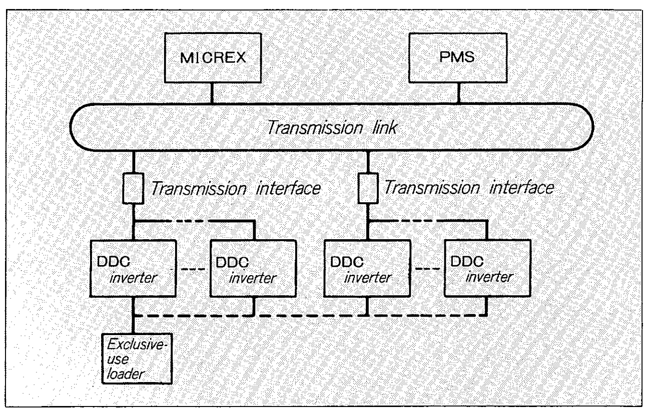
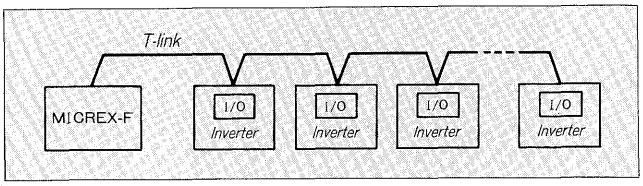


Fig. 14 Small-scale plant transmission system



The exclusive-use loaders are used for setting DDC equipment parameters and RAS function display.

In the transmission system by T-ling applied to small-scale plants, and exclusive-use remote I/O provided with functions as digital input/output and analog output is installed to have a linkage with MICREX-F.
From MICREX-F, the system is based on individual transfer in a level of each I/O unit, and as the T-link connection is not made through a loop, but through cascade connection, additional installation of inverters is relatively easily done, so that as there is no need for making it an exclusive-use data way, the system configuration are made simple. *Fig. 14* shows this system configuration.

6. CONCLUSION

We have here described the outline of the motor drive system that FUJI ELECTRIC is at present trying to consolidate as a standard series. FUJI ELECTRIC has also standard series in vector controll inverters for machine tools only, high-frequency transistor inverters and current source V/f control thyristor inverters. But they are out of scope of this paper.

In order that the series should retain always the fresh level, from both technical and economic point of view, a constant effort for improvement and development would be necessary from now on for the already serialized inverters as the standard series. The precious opinions and advice from consumers are indispensable for improvement and development of these standardized series products. We, authours, wish to end this paper by thanking readers in advance for their kind suggestions and guidance for the future as they had granted us in the past.