# NEW SERIES VVVF (VARIABLE VOLTAGE VARIABLE FREQUENCY) TRANSISTOR INVERTER

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## I. INTRODUCTION

The use of Inverter fed induction motor as variable speed drive systems for labor-saving, energy-saving, and rationalization of facilities has increased rapidly in recent years. This has been accompanied by a steady diversification of the demands of the market for such typical drive equipment as inverters. To meet these needs, Fuji Electric has focussed its attention on the superior performances power transistor as an inverter device and has completed the FRENIC 5000 Series of transistor iverters for induction motor drive. The commercialization of the new series centered about filling out of the model line and expansion of system capacity and sinusoidal PWM (pulse width modulation) control is introduced.

## II. NEW SERIES VARIABLE VOLTAGE VARIABLE FREQUENCY TRANSISTOR INVERTER FRENIC 5000 SERIES

### 1. Features

The FRENIC 5000 Series are high efficiency, high performance, simple to handle transistor inverters specially developed to flexibly meet diverse loads through Fuji Electric's abundant power transistor, converter, and motor application technology. It has the following features:

1) Abundant models and capacities

The FRENIC 5000 Series consists of the following four models, each having its own field of applications:

(1) FRENIC 5000S

The FRENIC 5000S was developed for high-quality speed control of specially designed induction motors (with tacho. geverator). It has an ASR control function and uses a sinusoidal PWM control system. It has the same superior control performances as DC machines and is suitable for various process line control, including NC machine tools. Capacities are 5-60 kVA.

(2) FRENIC 5000G

The FRENIC 5000G is applicable to general variable speed drive of standard induction motors. Capacities are 1.5-60 kVA. A sinusoidal PWM control system is used.

(3) FRENIC 5000P

The FRENIC 5000P is designed for standard induction motor fans, blowers, and pumps energy-saving applications. Capacities are 10-70 kVA. A sinusoidal PWM control system is used.

(4) FVR

The FVR was especially developed as a small easy to use low-level FRENIC 5000P system for small standard induction motor fan and pumps variable speed drive. Capacities are 1.5-10 kVA.

2) High efficiency and performance

A transistor is used as the power device. An auxiliary commutating circuit, like that of a thyristor system, is unnecessary and a small, high efficiency, excellent speed response inverter is realized. Since a sinusoidal PWM control system is employed, the motor current approximates a sine wave and the lower harmonics current is reduces substantially and the motor efficiency is high. *Fig. 1* shows the motor voltage and current waveforms of the sinusoidal PWM control system.

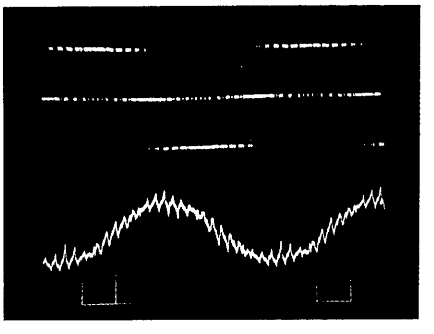



*Fig. 1* Waveforms of motor voltage and current

3) Excellent protection function and high reliability

The unique Fuji Electric protection system that effectively uses the fast response and wide safe operating area of Fuji Electric power transistors is employed and high operating reliability is secured.

4) Abundant options

Abundant options that permit full use of the features

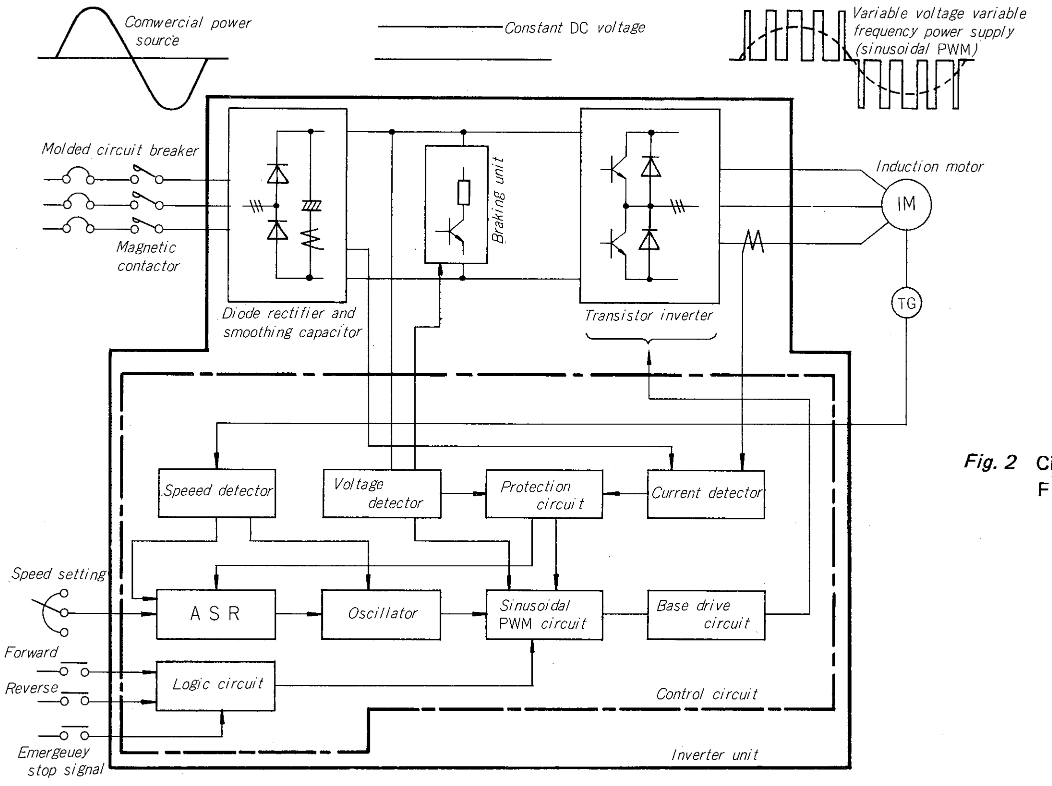



*Fig. 2* Circuit composition of FRENIC 5000S

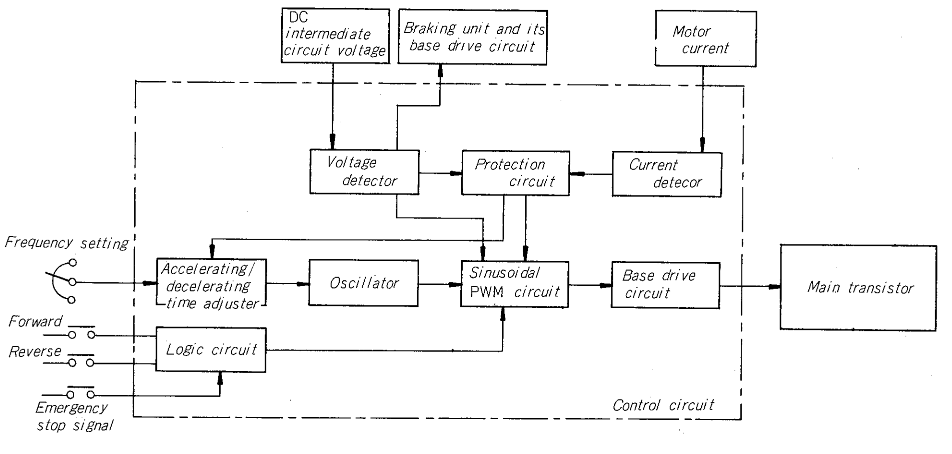



*Fig. 3* Control circuit composition of FRENIC 5000G

of each system and the construction of a versatile variable speed drive system are available.

## 2. Circuit construction and operation

Induction motor speed control systems by FRENIC 5000 Series are grouped into slip control systems and primary frequency control systems. The S series use the former and the G, P, and FVR series use the latter system.

1) FRENIC 5000S

*Fig. 2* shows the control block diagram of the FRENIC 5000S. DC machine level speed control is the objective of this circuit and a slip frequency control system with a speed feedback loop is used. The voltage control system is a sinusoidal PWM control system.

2) FRENIC 5000G

*Fig. 3* shows the FRENIC 5000G control block diagram. The main circuit composition is the same as that of the FRNIC 5000S of *Fig. 2*. The voltage control system is a sinusoidal PWM control system. The output characteristics (highest frequency, voltage/frequency, etc.) can be freely selected from the pattern shown in *Fig. 4*. in *Fig. 4*, ① is applicable to a constant torque load, ② is applicable to a square-law reduced torque load, and ① + ③ are applicable to a constant torque + constant power load.

The basic frequency can be selected as 50 Hz or 60 Hz. Six voltage/frequency patterns can be selected. Besides the usual overvoltage and overcurrent protection circuits, a sudden deceleration overvoltage suppresion circuit, momentary power interruption protection circuit, overload stalling prevention circuit, and other protection circuits are provided and a circuit composition strong against severe operation and with few restrictions on its application is employed. *Fig. 5* shows the typical operating oscillograms. Excellent operating characters have been obtained by means of the

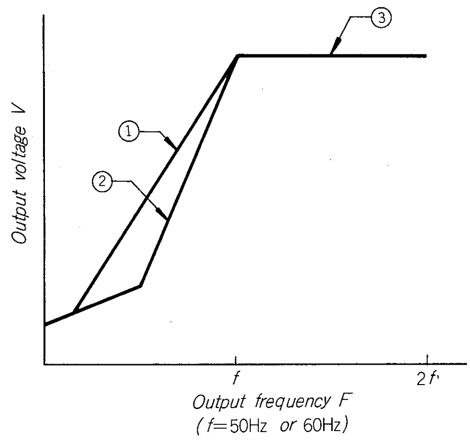



*Fig. 4* V/F characteristics of inverter output

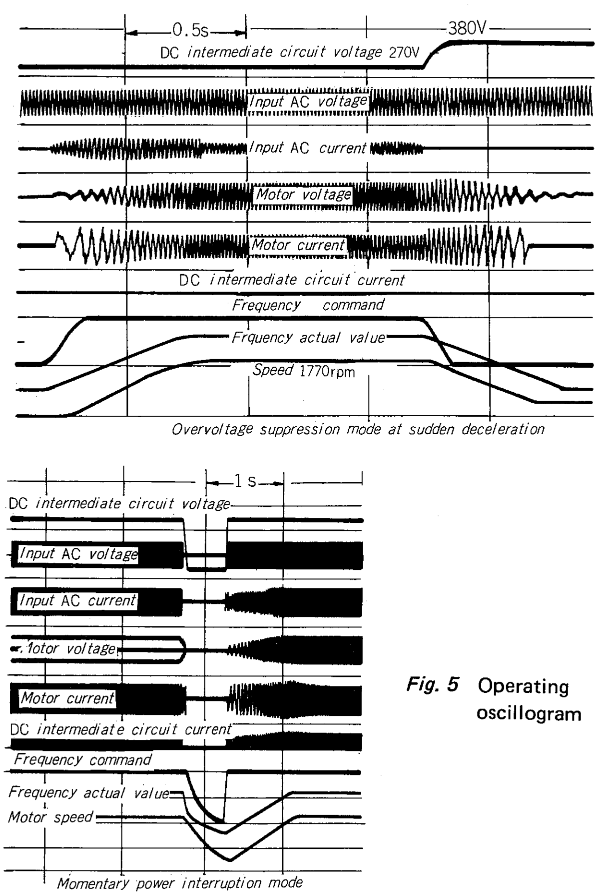



*Fig. 5* Operating oscillogram

sudden deceleration overvoltage suppresion and momentary power interruption protection circuits.

3) FRENIC 5000P

The circuit composition of the FRENIC 5000P is basically the same as that of the FRENIC 5000G except that it has no forward/reverse logic circuit and braking unit and the number of output voltage/frequency patterns is small.

4) FVR

The FVR has the minimum functions needed for fan and pump drive and an extremely simple circuit composition. Use by general users has been taken into account and the same protection circuits as the high-level FRENIC 5000P system have been provided to ensure safe operation in all uses.

### 3. Standard specificaitons

*Table 1* lists the standard specifications of the FRENIC 5000 Series. Each series has its own special features to meet diverse user needs.

### 4. Construction

*Fig. 6* is an exterior view of the unit. This unit has a compact construction which accomodates the converter, inverter, control power supply, control printed circuit board, etc. as a single unit. Incorporation in the user's plan is possible by simply connecting power supply circuit breaker and magnetic contactor. The construction has been simplified by installing the main circuit components to a unitized cooler by modulatization or insulation construcition refinements. This reduces the volume to 80% that of standard Fuji Electric products. The control printed circuit board is designed so it is not adversely static electrically or magnetically from the main circuit and can be serviced and inspected from the front.

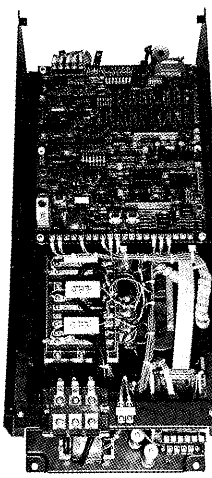


*Fig. 6* Exterior view of FRENIC 5000 unit (20kVA)

## III. APPLICATION TO VARIOUS SYSTEMS

The FRENIC 5000 Series can be used in a wide range of applications. Typical applications are described below.

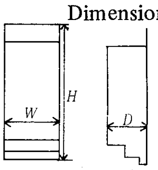
### 1. Application to energy-saving apparatus

As is well known, faus, blowers, and pumps, are frequently used in electric motor applied equipment. About 60% of induction motors are used with fans, blowers, and pumps, which consume about 40% of the energy. Since most of them are square-law reducing torque (cube power loads), a greater energy savings can be obtained by using speed control flow adjustment than by using conventional damper and valve adjustment. Several examples of the energy saving effect of fans, blowers, and pumps will be described by using the models in *Fig. 7* and *Fig. 8*.

Summarizing the data needed to study the energy-saving effect:

*Table 1* Standard specifications of FRENIC 5000 Series

| Item | | FRENIC 5000S | FRENIC 5000G | FRENIC 5000P | FVR |
|---|---|---|---|---|---|
| Input voltage | | 3-phase, 200/220 V (allowable voltage variation 180~253 V), 50/60 Hz ±5% | | | 3-phase, 200/220 V ±10% 50/60 Hz ±5% |
| Output | Rated capacity (kVA) | 5, 9, 13.5, 17.5, 21 30, 40, 50, 60 | 1.5, 3, 5, 9, 13.5, 17.5, 21, 30, 40, 50, 60 | 10, 15, 20, 24, 37, 47, 57, 70 | 1.5, 3, 5, 7.5, 10 |
| | Rated voltage (V) | 3-phase, 200 V ±5% (at 200 V or greater input power supply voltage) | | | |
| | Rated frequency (Hz) | 150 | 50, 60, 100, 120 (240) | 50, 60 | 60 |
| | Frequency control range | 1 : 100 (constant torque control 1 : 10, 5~50 Hz) | 1 : 20 (constant torque control 1 : 10) | 1 : 3 (square-law reducing torque) | 1 : 3 (square-law reducing torque) |
| | Frequency accuracy (25 °C ±10 °C) | Speed precision ±1% | ±0.5% | ±0.5% | ±1% |
| | Voltage-frequency characteristics | – | Switchable among 6 kinds (See *Fig. 4.* (1), (2), (1)+(3), *f* = 50 Hz and 60 Hz. However, (1) only for *f* = 100 Hz, 120 Hz) | Switchable among 4 kinds (See *Fig. 4.* (1), (2), *f* = 50 Hz and 60 Hz) | One kind (V/F fixed) |
| | Overcurrent capacity | 150% of rated current for 1 min. | 150% of rated current for 1 min. | 120% of rated current for 1 min. | 120% of rated current for 1 min. |
| Inverter control system | | Sinusolidal PWM (Pulse Width Modulation) control VVVF (variable voltage variable frequency control) inverter. | | | Square wave PWM control VVVF inverter. |
| Conversion efficiency | | 95% or greater (at rated output) | | | |
| Standard operating system | | Reversible, braking | Reversible, no braking (braking is available as an option) | Nonreversible, no braking | Nonreversible, no braking |
| Options | | Long-term accelerating/decelerating speed controller, I/V converter, PID controller, ratio setter, comparator/D/A converter | I/V converter, PI controller, braking unit | I/V converter, PI controller | Acceleration setter, signal controller, deviation detector |

| Construction Dimensions | Capacity (kVA) | FRENIC 5000S, G/FRENIC 5000 P | | | | | | | | | 1.5 | 3 | 5 | 7.5, 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | | 1.5~5/- | 9/10 | 13.5/15 | 17.5/20 | 21/24 | 30/37 | 40/47 | 50/57 | 60/67 | | | | |
| | *W* (mm) | 280 | 280 | 280 | 280 | 280 | 440 | 600 | 600 | 600 | 280 | 280 | 280 | 280 |
| | *H* (mm) | 450 | 540 | 600 | 650 | 680 | 700 | 700 | 860 | 990 | 320 | 320 | 320 | 360 |
| | *D* (mm) | 250 | 310 | 310 | 310 | 350 | 350 | 350 | 350 | 350 | 120 | 220 | 260 | 260 |

(1) Fluid mechanical flow-head characteristic (*QH* characteritic at the constant rotating speed at the commercial power supply)
(2) Fluid mechenical flow-power characteristic (*QP* characteristic at the constant rotating speed at the commerical power supply)
(3) Passage resistance curve (actual head and flow when valve fully open, RH curve)
(4) Normal flow
(5) Operating time and power charges units

(1) and (2) are provided by the fan, blower, or pump manufacturer and correspond to the bold line *QP*50 Hz curves in *Fig. 7* and to *QP*50 Hz in *Fig. 8*. Since the flow is proportional to the speed and the head is proportion to the square of the speed, the *QH* characteristic at frequencies other than the commercial power supply can be easily plotted. Because the power is proportional to the cube of the speed, the *QP* characteristic can also be plotted easily. The usage state determines

(3). The actual head corresponds to the pumping water level of the pump and to the tank pressure, when there is a pressure tank. The actual head is generally unrelated to the flow and is constant. The piping resistance, etc. except actual head are proportional to the square of the flow. In the example of *Fig. 7*, *PH*1 simulates a fan, blower, etc. without an actual head, *PH*2 simulates a feed pump, etc. with a large actual head.

(4) is also determined by the usage state, but is made 70% flow in this example.

(5) is the data necessary when deciding the power saving and electric charges reduction.

Since a fan, blower, or pump is operated at the point at which the *QH* and *RH* curves intersect, the power can be found from the value of the *QP* curve at the flow at which

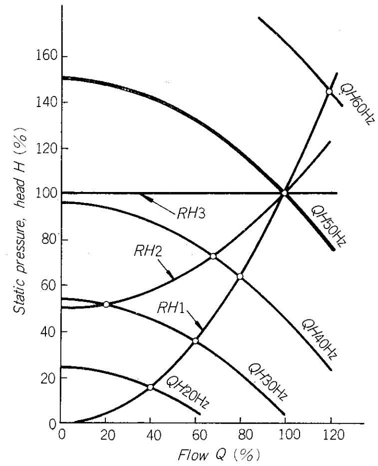



*Fig. 7* Flow-pressure characteristics

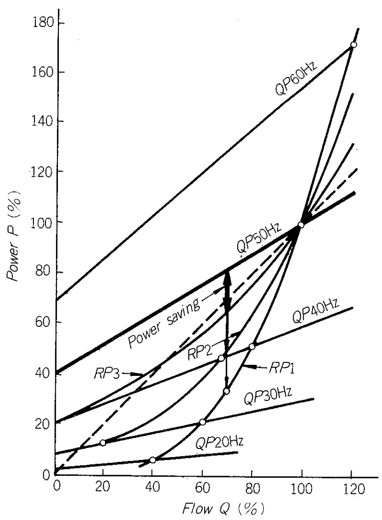



*Fig. 8* Flow-power characteristics

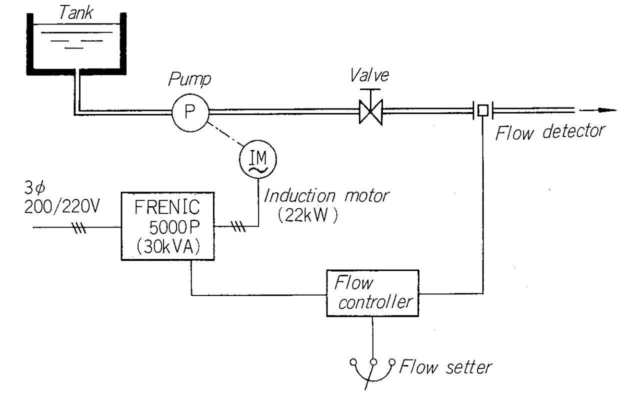
the *QH* and *RH* curves intersect and the *RP* curve of *Fig. 8* is plotted. Since the power damper valve adjustment at a constant commercial powerfrequency is the *QP*50 Hz curve, the spacing be tween the *QP*50 Hz and *RP* curves indicates the power saving. In *Fig. 8*, for example, the power saving is about 55% (*QP* 50Hz-*RP*1) for no actual head (*RH*1) and about 18% (*QP*50 Hz-*RP*3) for a large actual head (*RH*3) and the difference in the energy saving effect with the difference in the actual head is clear.

*Fig. 9* is an example of the FRENIC 5000P used in pump flow control. An annual saving of about ¥2,700,000 in power costs, compared to conventional valve control, is expected.

### 2. Application to machine tools

Because of the demand for constant speed cutting, etc., stepless spindle speed control is indispensable in NC machine tools and the trend is toward the use of inverter induction motor variable speed control as the drive system instead of conventional DC motors because it is maintenance-free.

An example of the FRENIC 5000S used with an NC lathe is introduced below.




*Operating conditions* *Motor* 22kW, 200V *FRENIC* 5000P 30kVA
*Normal flow* 60%~80%, 24 *hours/day*, 330 *days/year*, ¥20/kWh

*Savings* (1) ¥2,700,000/*year compared to valve control*
(2) ¥700,000/*year compared to eddy current coupling*

*Fig. 9* Saving energy of pump system

Because an NC lathe must have the acceleration/deceleration characteristics of a DC machine and must track the speed command value, the speed feedback control type FRENIC 5000S using a tacho generator was used. This reduced the speed fluctuations of the induction motor to less than 1% and provided a fast speed change response. Since it is brushless and maintenance free, there are no restrictions on the motor installaton site, it can be installed below the machine bed or other narrow space, and the machine floor space can be reduced.

- Use with an NC lathe

Motor specifications: Output 11kW/contrinuous, 15kW/30 mins
Speed 1500/4500 rpm
Voltage, poles 200 V, 4P

Inverter: FRENIC 5000S

Specifications: Capacity 20kVA
Speed Control range Constant torque range 150-1500 rpm
Constant power 1500-4500 rpm

Other examples are the effect of multi-drive of the spindles of multi-head milling machines, etc.

## IV. CONCLUSION

The new FRENIC 5000 Series was introduced. Inverter variable speed control is expected to steadily increase and become more diverse in the future. Fuji Electric will continue it efforts to increase the performances, voltage, capacity, and applications of the transistor inverter and beg for users further encouragement and use.