“FRENIC-VG,” a High-Performance Vector-Control Inverter

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ABSTRACT

Inverters for variable speed control of AC machines used in general industry applications mainly use either V/f constant control or vector control. Fuji Electric has developed the “FRENIC-VG,” a new high-performance vector control model, which realizes high precision and high functionality while complying with functional safety standards. It has various outstanding features, including optimized detection circuits, improved speed control precision, speed sensorless vector control, use of multiplex systems, and connection to “E-SX bus.” Application examples include optimal tension control and miniaturization of winder control circuits in wire drawing machines, and high-capacity support, high starting torque, and load adaptive control for cranes.

1. Introduction

Inverters used for the variable-speed control of AC machines in general industrial applications primarily use either V/f constant control or vector control. In applications for which simple variable-speed control and vector accuracy at low speeds are not critical, V/f constant control has evolved as the mainstream control method. On the other hand, vector-control inverters have continued to evolve in response to the desire to control torque as easily in an AC motor as in a DC motor.

Fuji Electric provides a product line of vector-control inverters, and Fuji’s newest series of high-performance vector-control inverters, the “FRENIC-VG,” was launched in 2011. This paper describes the new technology and functions incorporated into the FRENIC-VG, and introduces application examples.

2. Concept and Features

2.1 Concept

Fuji Electric has been providing general-purpose vector-control inverters as products for use primarily by machinery manufacturers and in small and medium-sized plants. In recent years, there has been increasing demand for the higher functionality and precision of machinery and equipment, and for higher plant productivity and the like, and there is a growing need for vector-control inverters capable of performing high-precision detailed control.

Under these circumstances, the trend toward larger capacity drive systems for such machinery and equipment as servo press machines and injection molding machines has advanced, and the support of such machinery and equipment with present-day servo systems would be difficult. On the other hand, in order to prevent personal injury and accidents involving machinery, the concept of risk assessment in functional safety standards is attracting attention, and functional safety standards for inverters have also been increasingly demanded.

To meet these market needs, the FRENIC-VG provides high accuracy, high functionality and capacities of up to 630 kW, and also complies with functional safety standards. Figure 1 shows the appearance of the FRENIC-VG.

2.2 Features

(1) Improved high-speed response

![Fig.1 “FRENIC-VG”](image-url)
The FRENIC-VG speeds up the vector control computation period by adopting a hardware system construction that uses an optimized detecting circuit and high-speed high-resolution analog-to-digital conversion technology for detecting the motor current and voltage, and is also equipped with a microprocessor able to perform high-speed computations.

A speed response of 600 Hz was realized with speed sensor-equipped vector control, enabling application to the aforementioned servo systems, in addition to wire drawing machines, winding machines, printing presses and other applications that require responsiveness, thereby expanding the field of application further (see Table 1).

(2) Improved accuracy of speed control (reduction of rotational fluctuation)

In vector control with speed sensor, pulse signals are received from a speed sensor (PG: pulse generator) attached to the motor, and the actual motor speed is computed from changes in this pulse. However, because the frequency of this pulse decreases as the speed decreases and because the change in pulse rate is small within the control period, the speed could not be computed accurately. As a result, the accuracy of the speed control deteriorated and rotational fluctuation occurred.

With the FRENIC-VG, a new pulse change detection function is provided in a custom LSI and the speed computation algorithm has been improved to enhance the accuracy of speed computation at low speeds.

At low speeds, where changes in the pulse rate are smaller within the control period, the speed is computed according to the time required from one pulse change point until the next change point and from measured values. At very low speeds with a non-varying pulse rate during the control period, the speed is estimated from the previously computed value of the speed. With this method, even without using a high-resolution PG, the speed control performance at low speed is improved and rotational fluctuation is reduced to approximately 1/3rd that of previous models (see Fig. 2).

(3) Vector control without speed sensor

Vector control with a speed sensor provides excellent performance, including high responsiveness and high accuracy, but requires the installation of a PG on the motor, as well as wiring and the like.

Vector control without speed sensor is a control method in which the motor speed is computed from the motor terminal voltage and current and from electrical constants of the motor.

With the FRENIC-VG, in addition to a faster computation period, the motor voltage detecting circuit has been improved so as to enable 3-phase detection, the detection resolution has been improved, the speed control range has been expanded and low speed torque characteristics have been improved (see Fig. 3).

(4) Multiplexed system

Previously, to increase capacity, either a multi-winding motor with split windings was driven using multiple inverters, or a method of coupling the inverter output with reactor was used. With the FRENIC-VG, a direct parallel connection method for directly connecting the inverter outputs in parallel with the motor terminals is realized, thereby eliminating the need for the use of a reactor or a motor with special windings. In this method, the problem of cross current flow between inverters due to an imbalance in output voltage caused by fluctuation of the switching timing of an Insulated Gate Bipolar Transistor (IGBT) was solved using high-speed cross current suppression control.

Table 1 Comparison of speed response

<table>
<thead>
<tr>
<th>Product name</th>
<th>Speed response</th>
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<tbody>
<tr>
<td>FRENIC-VG</td>
<td>600 Hz</td>
</tr>
<tr>
<td>FRENIC5000-VG7 (prior model)</td>
<td>105 Hz</td>
</tr>
<tr>
<td>FRENIC5000-VG5 (model of 2 generations ago)</td>
<td>54 Hz</td>
</tr>
</tbody>
</table>

Fig.2 Suppression of rotational fluctuation

Fig.3 Torque characteristics at low speed
Additionally, in the case where even one of the inverters fails, remaining inverters can operate, and applications to plant equipment and other critical facilities that require redundancy is anticipated (see Fig. 4).

(5) “E-SX bus”

The FRENIC-VG is equipped with a communication option that enables connection to the “E-SX bus” used with Fuji Electric’s “MICREX-SX SPH3000MM” integrated controller.

The E-SX bus realizes faster bus communication (I/O refresh at up to 250 µs) and a new control method that synchronizes the task cycles of devices connected to the bus to improve the overall control performance of the MICREX-SX SPH3000MM. This new bus communication specification synchronizes the data I/O timing with accuracy of ±1 µs.

With the FRENIC-VG, in order to support the E-SX bus, the computational speed of the communication software was increased and the communication LSI was improved. A portion of the feedback control, such as torque and speed control of the motor, can be implemented with the MICREX-SX SPH3000MM, thereby expanding the versatility of the control. Additionally, the MICREX-SXSPH3000MM is capable of synchronously controlling multiple motors through multiple FRENIC-VG inverters, and in the case of a printing press or the like for which multi-axis control is implemented, multiple mechanical mechanisms that had been required in the past can also be simplified.

(6) Support of functional safety

The FRENIC-VG is standardly equipped with an STO function (EN terminal) that complies with the IEC 61800-5-2 standard for functional safety, and the safety functions shown in Table 2 can be added by installing an optional safety function card.

<table>
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<tr>
<th>Level</th>
<th>Function</th>
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<tr>
<td>STO: Safe Torque Off</td>
<td>Shuts down the output, sets motor to free-run state</td>
</tr>
<tr>
<td>SS1: Safe Stop 1</td>
<td>Decelerates motor and shuts down output at specified condition</td>
</tr>
<tr>
<td>SLS: Safely Limited Speed</td>
<td>Prevents motor from rotating faster than specified speed</td>
</tr>
<tr>
<td>SBC: Safe Brake Control</td>
<td>Outputs signals for controlling the motor brake</td>
</tr>
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</table>

Figure 5 shows the configuration of the functional safety system. A commonality of the functional safety system is that there are two systems for each terminal so that reliable operation can continue even if one
of the systems fails. Additionally, the safety function card incorporates redundancy and is equipped with two CPUs, each of which monitors the normal operation of the other CPU. In the case where an error is detected, the output to the motor is shut off.

(7) PC loader, trace back

The FRENIC-VG is equipped with a PC loader and a clock function, and a PC connected through the USB connector on the front of the FRENIC-VG is able to set and reference function codes, and to monitor and trace various types of data during operation.

With the trace back function, the time and date of occurrence of an event, and various operational data immediately before and after the occurrence of an alarm are stored in internal memory. This data can be displayed as a waveform with the PC loader and facilitates cause analysis in the case of an alarm (see Fig. 6).

3. Application Examples

Examples of the application of the FRENIC-VG to a wire drawing machine and a crane are described below.

3.1 Application to wire drawing machines

A wire drawing machine is a type of metalworking machinery that processes thin wire diameters by pulling an iron wire or other wire material with a wind-up pot and passing it through a die. After processing is complete, the wire can be wound with a winding machine. Speed control as well as tension control of a winding machine is important for a wire drawing machine.

(1) Overview of wire drawing machines

In the case where the wire diameter will be subjected to a large amount of processing, because the wire would break if processed in all at once, the processing is carried out with multiple wire drawing machines to narrow the diameter gradually. In some cases, the wire is processed continuously using about ten wire drawing machines. Additionally, a dancer roll is provided between each wire drawing machine so that wire tension is not a cause of interference. Dancer rolls are able to move vertically (or horizontally according to the configuration of the machine), and provide slack with the appropriate tension between each wire drawing machine. However, because thick wires and the like cannot easily be placed into a wire drawing machine, straight wire drawing machines that do not use dancer rolls between the wire drawing machines are also needed.

(2) System configuration

Figure 7 shows an example system configuration of straight wire drawing machines. The main components of a wire drawing machine are the die for processing the wire, and the wind-up pot for pulling the wire. Depending on the amount of processing to be carried out on the wire, multiple wire drawing machines may be used with the wire being wound onto a winding machine in the final stage. In the case where a traverse winding device is attached to the winding machine, disturbances due to operation of the traverse winding device can cause tension fluctuations to occur in the winding machine. Providing a dancer roll between the master wire drawing machine and winding machines prevents interference between the master wire drawing machine and the winding machine.

(a) Control of a wire drawing machine

The master wire drawing machine implements speed control with line speed commands output from a soft start/stop circuit based on speed commands from a line speed setting device. The soft start/stop circuit adds a time gradient to the acceleration and deceleration.

A tension calculation circuit detects the tension with torque signals from each inverter, and implements control so that the tension balance between wire drawing machines is stable, and applies the appropriate tension to the wire. The speed correcting circuit...
3.2 Application to cranes

As the size of cranes used at manufacturing plants, harbor ports and the like increases, the capacity of the installed drive systems is also increasing. Also, in the event that an inverter fails, early recovery is required.

(1) Overview of cranes

Tension between the winding machine and the master wire drawing machine is controlled with a dancer roll. Changes in speed due to fluctuations in the winding diameter are corrected by a winding diameter calculation circuit. Also, the winding diameter is computed for the current winding diameter according to line speed commands and the actual speed of the winding machine motor (detected with a PG).

3) Benefits of using the FRENIC-VG

Benefits of the FRENIC-VG are described for the case when used in conjunction with a straight wire drawing machine.

(a) Realization of optimal tension

The torque accuracy and torque ripple required for tension control have been improved compared to the previous model, and the use of an E-SX bus enables faster communication of the control signals from a PLC. As a result, tension can be controlled appropriately for the wire material, wire breakage and slack and the like is reduced, and stable operation is possible even at faster line speeds. Additionally, because rotational fluctuation at low speeds can be mitigated, cases in which the wire is narrow but the winding diameter ratio (minimum winding diameter: maximum winding diameter) is large can also be supported.

(b) Miniaturization of the braking circuit for winding machines

When a traverse-equipped winding device is attached to a winding machine, disturbances occur, and the operation periodically changes to a braking mode in which regenerative energy is produced. The FRENIC-VG is standardly equipped with a DC common bus terminal to which DC circuits for the inverters for winding machines and wire drawing machines are connected, enabling regenerative energy of the winding machine to be processed with the wire drawing machine. As a result, the winding machines can be miniaturized without a braking circuit. Additionally, a braking circuit (a driving circuit for the braking resistor) for emergency stopping such as in the case of wire breakage is also equipped as a standard feature (200 V and 55 kW or less, or 400 V and 160 kW of less).

Cranes are configured from a main hoisting mechanism for raising and lowering a suspended load, a hoist traverse mechanism for moving the hoisting mechanism horizontally, a travel mechanism for moving the crane itself forward and backward, and a derricking mechanism for raising and lowering the boom.

2) Crane system configuration

The mechanical configuration of a quayside crane used for loading and unloading containers to and from a container ship at a harbor port is described below. Approximately one-half of the operating patterns for the main hoisting mechanism are the braking mode. Also, a pulse width modulation (PWM) converter is provided in the power supply to handle harmonic current.

(a) Inverter for main hoisting mechanism

With the main hoisting mechanism that raises and lowers a container or other load, because main hoisting and travel operations are not performed simultaneously, the main hoist motor and the travel motor are switched to implement control. When driving the main hoisting motor, because holding torque and starting torque are required in order to raise and lower a container, operation is carried out by vector control with speed sensor. The main hoisting mechanism rarely operates at rated capacity, and often operates with a load that is lighter than the rated load. Thus, load adaptive control is used in a speed range corresponding to the load, and the operational efficiency is improved.

(b) Inverter for hoist traverse mechanism

The traverse mechanism that moves horizontally in the lateral direction may operate simultaneously with the main hoisting mechanism, and is therefore operated by vector control with speed sensor since traverse speed responsiveness is also required.

(c) Inverter for derricking mechanism

The derricking mechanism that raises and lowers the boom around a cantilever or other attachment does not operate simultaneously with the travel mechanism, and is therefore controlled with the same motor switching control as the main hoisting mechanism. Also, because the derricking speed is slow, vector control without speed sensor is used in some cases.

(d) Inverter for travel mechanism

In order to drive multiple small-capacity motors simultaneously, the travel mechanism is operated with V/f control.

3) Benefits of using the FRENIC-VG

(a) The normal driving inverter and the backup inverter have been combined to achieve lower cost of the electrical equipment

The main hoisting mechanism achieves lower cost of the electrical equipment by employing the direct parallel connection of the FRENIC-VG so that a single-winding motor can be used. Moreover, driv-
(b) Support for large capacity motors

Large capacity motors can be driven by connecting multiple inverters via the direct parallel connection.

(c) High starting torque

The FRENIC-VG inverters have an overload capability of 200% -3 s and can handle the high torque often required when cranes are started.

(d) Load adaptive control

In the case of a load that is lighter than the rated load, load adaptive control is performed for the main hoisting mechanism to increase automatically the allowable elevating speed limit value beyond its value for rated loads. The load is detected with a load estimating calculation based on the torque current at startup. With the improved torque ripple and responsiveness of the FRENIC-VG compared to prior models, more accurate load estimating calculations, higher allowable elevating speed limit values, and improved operating efficiency can be achieved.

(e) Functional improvement of brake release and applying sequence calculation

A function has been added to permit individual adjustment of the releasing and applying sides during the processing sequence at the time of a brake release/engagement sequence. As a result, the brake adjustment time can be shortened and load swaying can be reduced further.

4. Postscript

The main features and application examples of the newly commercialized “FRENIC-VG” of high-performance vector-control inverters have been introduced.

A lineup of DC power distribution stacking inverters, which are necessary primarily in large-scale plants, is planned to expand the application fields of the FRENIC-VG further. Technical issues such as high-capacity motor driving and redundancy at large-scale plants are solved with the direction parallel connection method.

Fuji Electric will continue to expand the functionality of the FRENIC-VG of inverters and will work to expand their fields of applications to servo systems, large-scale plants and the like.
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