Inverter Application Development

Yutaka Shoji,
Hajime Saito,
Yasumasa Miyamoto,
Yoshihisa Nagata

Keywords Multi-level inverter, PWM, Medium-voltage inverter, Torque response, High frequency, Mechanical diagnosis, Fault prediction

Abstract

Given the rising interest on the climate change, the market demands for greenhouse gas reduction and energy saving are recently increasing. By using an inverter, if variable speed operation is applied to the facilities of variable torque loads such as fans and pumps in a fixed speed operation, we can expect the substantial energy saving.

In industrial facilities, requirements of higher accuracy, faster response, and a higher speed are increasing. If inverters with advanced functions are adopted, mechanical capability can be maximized for our customers. In addition, when Information and Communication Technology (ICT) is introduced to mechanical facility diagnosis where such diagnosis formerly relied upon experience and instinct of skilled engineers, maintenance cost reduction and optimization can be attained. If internal information of inverters is utilized as the basic data for mechanical facility diagnosis, it then becomes possible to establish a system that does not require any expensive external sensors.

1 Preface

In recent years, inverters have become an indispensable system due to the demand for energy conservation and improved control accuracy of industrial machinery. In addition, the increasing performance of computers has made large-scale analysis more accessible, and Information and Communication Technology (ICT) has been applied to equipment.

There is a growing demand for systems that use ICT to detect equipment failures before they occur. In this paper, we introduce the products and technologies from our inverter line-ups that comply with the International Electrotechnical Commission (IEC) standards and meet various market requirements, such as advanced control performance and utilizing ICT with the facility.

2 Introduction of Inverter Products

2.1 High-Performance Low-Voltage Vector Inverter, THYFREC VT350 (“VT350” hereafter)

We commercialized VT350 in 2019. This product is a successor model of the high-performance low-voltage vector inverter, THYFREC VT310 (“VT310” hereafter), applied to general industries like iron and steel industries. Table 1 shows specifications for VT350 control.

2.1.1 High Performance for Torque Control

Fig. 1 shows a comparison of torque accuracy and Fig. 2 shows a comparison of torque control response. VT350 is equipped with a unit that can detect an inverter output voltage. As a result, the torque accuracy is improved by approximately 40% compared with the conventional model VT310 and torque control response improved by about 60%.

2.1.2 Safe Torque Off (STO) Function

In the conventional method, a magnetic contactor was installed in between inverters and the motor, in order to stop the motor safely in case of a failure. Such a system adopted a function to open the circuit upon the reception of an emergency stop signal. In VT350, this emergency stop signal is received at the inverter unit main body so that a standard function (IEC 60204-1 Stop Category 0) makes a safe stoppage of the motor by forcibly interrupting the gate signal that is used to drive the power module.

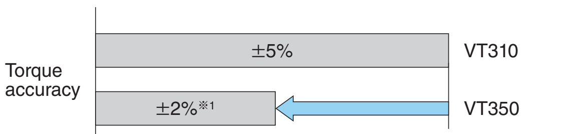
2.1.3 Load Balance Control Function for Multiple Motors

In response to the operation of a large-scale

Table 1 Specifications for VT350 Control

This product is applicable to the torque control accuracy of ±2% (when provided with a voltage detection unit), torque control application of 1200 rad/s, constant output range of 1:5, motor capacity of 65 kW for 200 V class, and motor capacity of 630 kW for 400 V class(in the case of overload durability at 120% for 1 minute).

			Vector control with IM speed sensor	Vector control with PM sensor
Frequency control		Control system	Totally digital control of approximated sinusoidal PWM	
		Carrier frequency	Mono-sound mode: 4.0, 6.0, 8.0 kHz	
		Output frequency resolution	0.01 Hz	
		Frequency setting resolution	0.01 Hz (digital) 0.03% (analog) at the maximum frequency	
		Frequency accuracy	±0.01% (digital) at 25 ± 10℃ ±0.1% (analog) at 25 ± 10℃	
Elapsed load		Voltage/frequency characteristics	Arbitrary setting at 150〜9999 min^{-1} (240 Hz Max.)	
		Auto-tuning	Automatic measurement of motor constants and automatic adjustment of various parameters A basic system not to make the motor run, or an extension system to make the motor run, is available.	Encoder phase adjustment Magnetic pole position prediction Automatic measurement of motor constants (with motor revolution)
		Output frequency	0〜240 Hz	
	Speed control	Control range	1:1000	
		Constant output range	Up to 1:5	Up to 1.15
		Control accuracy (Fmax ≧ 50 Hz)	±0.01%	
		Control response	300 Hz	



※1. This VT350 performance is in case of the voltage detection unit model.

Fig. 1 Comparison of Torque Accuracy

Torque accuracy is compared between VT310 (conventional model) and VT350.

facility, a maximum of four VT350 units can be connected through an optical communication network (maximum transmission speed of 20 Mbps) in order to control the load balance of motors. **Fig. 3** shows a diagram of speed commands vs. torque current detection characteristic. Between the two inverters, torque currents are almost identical.

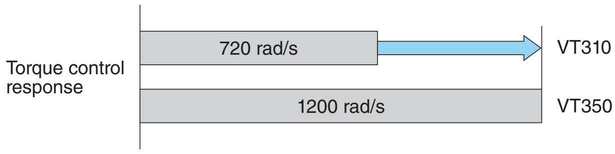


Fig. 2 Comparison of Torque Control Response

Torque control response is compared between VT310 (conventional model) and VT350.

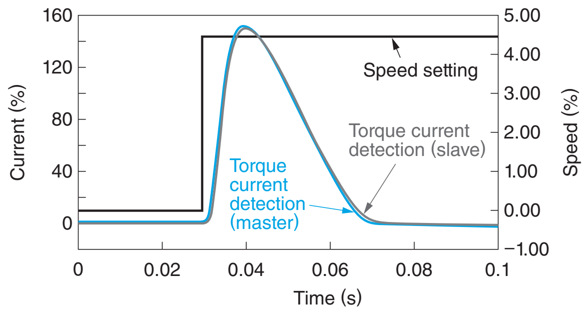


Fig. 3 Diagram of Speed Commands vs. Torque Current Detection Characteristic

This shows the difference between speed commands vs. each torque current detection when two VT350 units are connected in the master-slave method. In the master-slave case, the current detection graph is almost identical.

2.1.4 Large-Capacity Output by Parallel Unit System

An output capacity of a single low-voltage inverter unit is determined based on a restrictive condition of the maximum current specified for the built-in power device. For the VT350, the capacity can be increased up to 630 kW at the highest by connecting multiple units in parallel.

2.1.5 Improvement on Ease of Maintenance

Fig. 4 shows a connection diagram of a control source supply unit. By connecting a control source supply unit, the inverter parameters can be displayed even after the main circuit power source is turned off. This function is convenient because we can perform maintenance work on the inverters even during a scheduled power outage in the plant. Even though the main power source is disconnected due to a failure, we can check the inverter's characteristics.

2.2 IEC Standards-Compliant Direct Medium-Voltage Inverter, THYFREC VT730S ("VT730S" hereafter)

Since 2005, we have been supplying medium-voltage serial-cell multiplex inverters and have large supply records. Our direct medium-voltage type inverter series has acquired a good market review in Japan. In order to expand market shares in countries and areas other than Japan, we developed in 2011 VT730S that conform to IEC Standards. To meet the requirements of overseas customers, we manufacture both 3 kV and 6 kV products. Each unit is composed of an input transformer and 9 inverters for the 3 kV class and an input transformer and 18 inverters for the 6 kV class. **Table 2** shows the product specifications of VT730S. Features of these products are as follows:

(1) Standard specifications of inverters conform to IEC Standards.

(2) Efficiency is 97% or above and power factor is 0.95 or above.

(3) Voltage distortion is restricted by the multi-level Pulse Width Modulation (PWM) system.

(4) A great reduction of harmonics is realized by the 36-phase rectification method (6 kV circuit).

(5) A single unit can clear the harmonic measure guidelines conforming to the IEEE 519-1992.

This time, to meet the requirements of customers abroad, a single unit voltage of VT730S was raised from 640 V to 690 V so that the total number of cell units in 6 kV circuit can be reduced, and medium-voltage inverters applicable to 10 kV circuits have been commercialized. **Fig. 5** shows a circuit diagram of a single cell unit.

2.2.1 Reduction of 6 kV Class Cell Units

In a conventional 6 kV circuit, the inverter system was composed of 18 single-phase cell units (6-tier stacks per phase). In the new inverter sys-

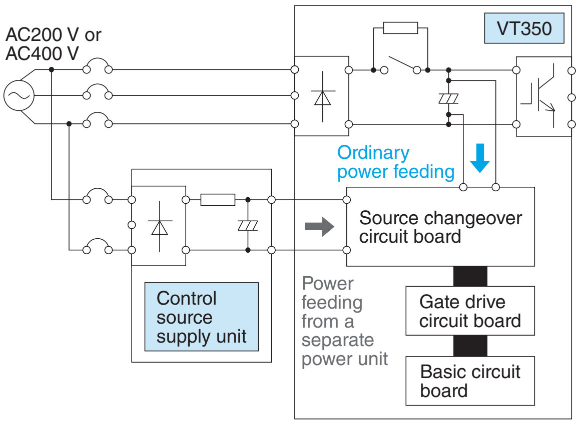


Fig. 4 **Connection Diagram of Control Source Supply Unit**

A connection diagram of the control source supply unit is shown.

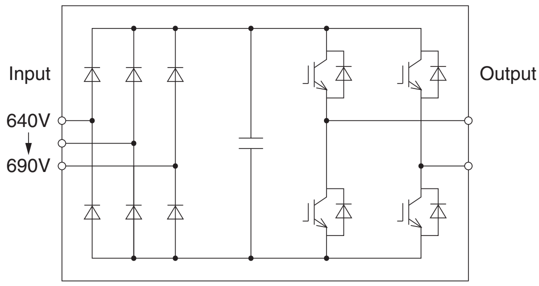


Fig. 5 **Circuit Diagram of Single Cell Unit**

A circuit diagram of the cell inverter and an extended voltage are shown.

Table 2 **Product Specifications of VT730S**

This product is applicable to a maximum of motor capacity 1250 kW for a 3 kV system and 2500 kW for a 6 kV system. (Assuming that overload durability is 120% for 1 minute.)

Series		3 kV system					6 kV system						
Type (VT730S-□□□)		235L	335L	475L	950L	1250L	330H	500H	710H	1000H	1500H	2000H	2500H
Standard overload	Rated capacity (kVA)※1	332	457	634	1217	1520	446	663	914	1269	1909	2435	3041
	Rated current (A)※2	58	80	111	213	266	39	58	80	111	167	213	266
	Applicable motor (kW)※3	235	335	475	950	1250	330	500	710	1000	1500	2000	2500
	Overload durability	120% for 1 minute											
Heavy overload	Rated capacity (kVA)※1	263	366	503	972	1212	354	526	732	1006	1520	1943	2423
	Rated current (A)※2	46	64	88	170	212	31	46	64	88	133	170	212
	Applicable motor (kW)※3	190	270	380	750	950	250	390	560	750	1200	1570	2000
	Overload durability	150% for 1 minute											
Power source	Main circuit	3000/3300 V ± 10% 50/60 Hz ± 5%					6000/6600 V ± 10% 50/60 Hz ± 5%						
	Control circuit	200/200 V ± 10% 50/60 Hz ± 5% (Standard) or 400/440 V ± 10% 50/60 Hz ± 5% (Optional)											
Output	Rated output voltage (V)	3000/3300					6000/6600						
	Output frequency range	Arbitrary setting within the range of 0～120 Hz											

Notes:
※1. The output capacity is shown when output voltage is 3300 V or 6600 V.
※2. All effective values including harmonics are shown.
※3. This table is applicable to our Standard 4-pole cage-rotor type induction motors when the output voltage is 3300 V or 6600 V.

tem, a single-phase cell unit is set at 690 V and a total of 15 cell units (5-tier stacks per phase) can secure a 6 kV output. This time, we newly developed cells that are applicable to 4000 kW and the maximum capacity was also expanded. **Fig. 6** shows a circuit diagram of 5-tier cells and **Table 3** shows 6 kV capacity series. By decreasing the cell units, the secondary winding of the multi-winding input transformer and the number of parts were reduced.

2.2.2 THYFREC VT731S (“VT731S” hereafter) Applicable to 10 kV

To address overseas 10 kV system voltages, we developed VT731S that is composed of 24 higher-voltage single-phase cell units (8-tier stacks per phase). To assure a 10 kV line voltage using a single-phase cell unit voltage of 640 V, it was necessary for the former system to employ 9 single-phase cell units per phase. Since the single-phase cell unit voltage is raised to 690 V, a line voltage of 10 kV can be secured with 8 units per phase. **Fig. 7** shows a circuit diagram of 8-tier cells and **Table 4** shows 10 kV capacity series.

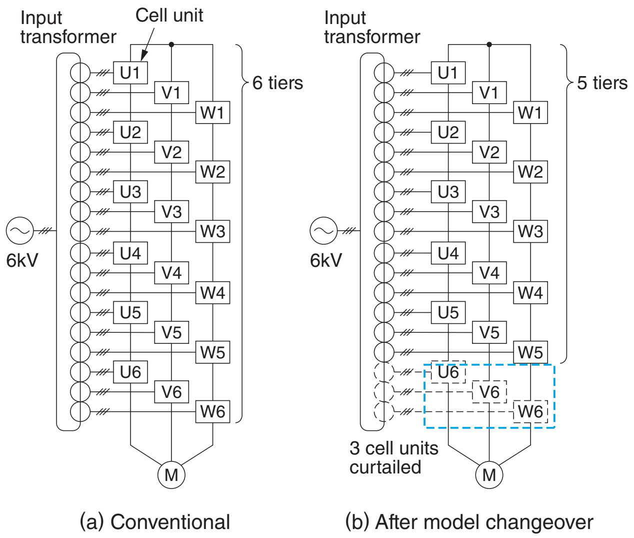


Fig. 6 Circuit Diagram of 5-Tier Cells

With 5 single-phase cell inverters per phase, the number of input transformer secondary windings is also 5 per phase. A cell voltage of 690 V and a line voltage of approximately 6000 V are secured.

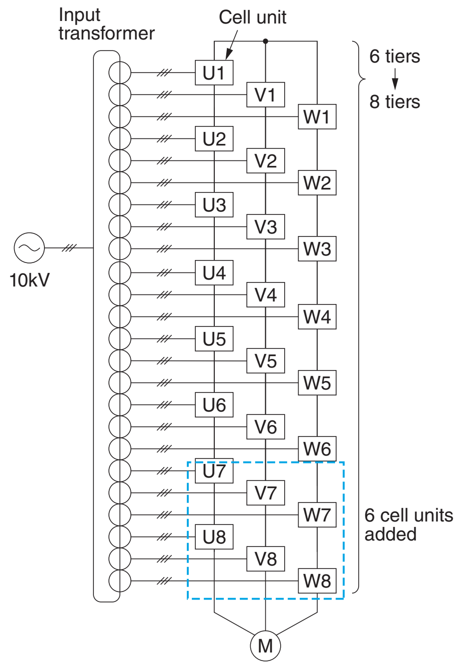


Fig. 7 Circuit Diagram of 8-Tier Cells

With 8 single-phase cell inverters per phase, the number of input transformer secondary windings is also 8 per phase. A cell voltage of 690 V and a line voltage of approximately 10,000 V are secured.

Table 3 6 kV Capacity Series

With single-phase cell inverters in 5-tier stacks per phase, the specified output capacity is secured, which capacity is equivalent to 6-tier stacks of a conventional model.

Item	Specifications						
Type (VT730S-□□□□)	500HE	800HE	1000HE	1600HE	2000HE	2500HE	4000HE
Applicable motor (kW)※1	500	800	1000	1600	2000	2500	4000
Overload durability	120% for 1 minute						

Note: ※1. Rated output voltage: 6000 V

Table 4 10 kV Capacity Series

Capacities of the VT731S applicable to 10 kV are shown.

Item	Specifications							
Type (VT731S-□□□□)	500T	800T	1250T	1600T	2500T	3150T	4000T	6300T
Applicable motor (kW)	500	800	1250	1600	2500	3150	4000	6300
Overload durability	120% for 1 minute							

Table 5 Product Specifications of VT240S

This table is applicable up to an output frequency of 800 Hz.

Item	Specifications
Voltage	400 V system
Capacity	~475 kW
Output frequency	~800 Hz※1
Carrier frequency	8 kHz fixed

Note: ※1. When exporting inverters with output frequency of 600 Hz or above from Japan, proceedings are required by submitting a written application for export control permission according to the relevant law of Japan.

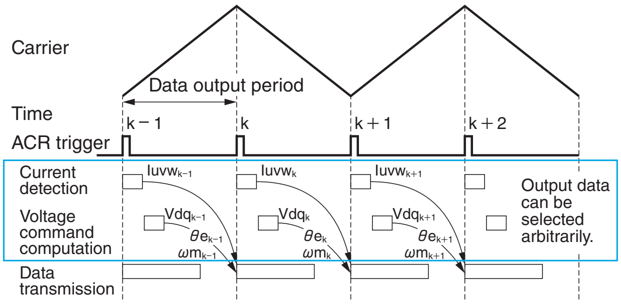


Fig. 8 Schematic Diagram for Data Sampling

Sampling of data within inverters is carried out at a PWM pace of the inverter. The sampling items can be set arbitrarily.

3 High-Frequency Inverters

3.1 Outline of High-Frequency Inverters

Thanks to the recent advancement of motor designs and manufacturing technologies, the industry realized higher motor speeds. Through the higher motor speed, we can improve the output density for the motor. Formerly, it was necessary to add a device, like speed increasing gears to increase the motor speed. Currently, however, machinery can be directly driven by a motor that runs at a high speed. This arrangement can greatly improve the total efficiency of a facility. To keep up with higher speed market demand, we developed a high-frequency low-voltage general-purpose inverter, THYFREC VT240S ("VT240S" hereafter).

3.2 Low-Voltage General-Purpose Inverter, VT240S, with Higher Frequency

We have supplied many VT240S at home and abroad. For this VT240S Series, we additionally developed high-frequency models to realize high speed revolutions for high-speed permanent magnet synchronous motors (high-speed PM motors). This type of motor is frequently adopted mainly for aeration blowers in sewage treatment processes at sewage treatment plants, food-related factories, and paper mills. It greatly helps the compact design of the facility and is energy saving. Table 5 shows product specifications of VT240S.

4 Power Electronic Printed Circuit Boards of Interface for Internet of Things (IoT)

With the progress of ICT / IoT, there is active research on machine failure sign diagnosis technology that detects signs before machine failure occurs. This technology consists of three major technical elements.

(1) Machine condition measurement technology

(2) Machine learning and statistical approach by which normal status is learned to identify an abnormal status

(3) Model-based analysis technology such as physical model base and a digital twin

In particular, measurement technology is an important technology that forms the basis of the machine failure sign diagnosis technology, but expensive sensing devices (image, vibration, sound, temperature, humidity, current voltage, etc.) are required to obtain highly accurate data. Due to the challenge of cost-effectiveness consideration, it could not be introduced.

As a technology to solve this problem, we developed a power electronics IoT interface printed circuit board that can output an inverter's internal information at a high speed. By adding these Printed Circuit Boards (PCBs) to our conventional inverters, inverter control information of the main control PCB can be sampled in a PWM-level period (in the order of microseconds). Fig. 8 shows a schematic diagram for the data sampling. The output data can be gathered through a Personal Computer (PC) or a Programmable Logic Controller (PLC) connected to the Ethernet. By this technology, the basic data of a mechanical fault sign can be gathered based on internal information of the inverter.

5 Postscript

This paper introduced our unique products out of our inverter lineups and the data collection system for fault sign diagnosis. While a decrease in skilled field-service engineers performing the facility maintenance service is predicted, we believe that an inverter-based facility status measuring system can contribute in building an inexpensive equipment failure sign diagnosis system.

Going forward, we will continue to meet our customers' requests and make every effort to commercialize highly functional products.

・Ethernet is the registered trademark of Fuji Xerox Co., Ltd.
・All product and company names mentioned in this paper are the trademarks and/or service marks of their respective owners.