Changes for the Better

MITSUBISHI ELECTRIC

FATEC

INVERTER SCHOOL TEXT

INVERTER PRACTICAL COURSE

(FR-A800)

● SAFETY PRECAUTIONS ●

(Always read these instructions before use.)

When designing a system, always read the relevant manuals and give sufficient consideration to safety.
While training, pay full attention to the following points and handle the equipment correctly.

[Precautions during Training]

⚠WARNING

- Do not touch the terminals while the power is ON to prevent electric shock.
- When opening the safety cover, turn the power OFF or conduct a sufficient safety check before operation.
- Keep hands away from moving parts.

⚠CAUTION

- Follow the instructor's directions during training.
- Do not remove the units from a demonstration machine or change the wiring without permission. Doing so may cause a failure, malfunction, injury and/or fire.
- When the demonstration machine emits an abnormal odor or noise, stop the machine by pressing the "power supply switch" or "emergency switch".
- When an error occurs, notify the instructor immediately.

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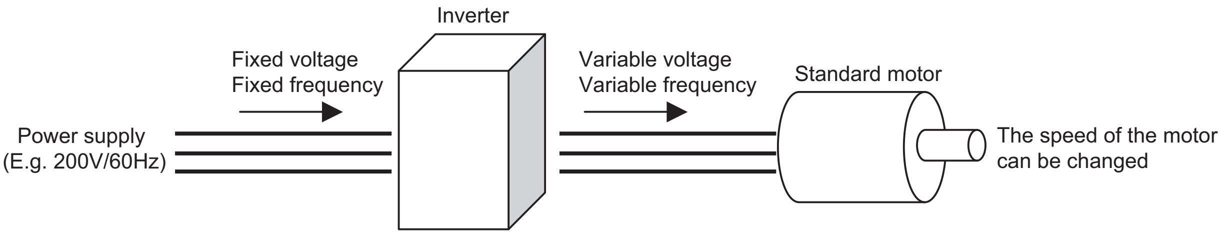
Chapter 1 BASICS OF INVERTERS

1.1 What Is An Inverter?

An inverter is equipment that "freely changes the speed of a standard motor."
Industrial and residential power supply (AC) is different in each country and is fixed at either 200V/50Hz, 200V/60Hz, 100V/60Hz, or 100V/50Hz. With a power supply of a fixed voltage and frequency, the motor can be rotated only at a single speed. However, an inverter can change voltage and frequency freely, enabling the speed of a standard motor to be changed.
Using their ability to freely change a standard motor's speed, inverters are commonly used to control fan's air volume and conveyor speed.



1.2 Advantages of Inverter Operation

Inverter operation offers the following advantages.

- Inverters can freely change the speed of standard motors. They can be also connected to the installed motors.
- Inverters can drive standard motors at a set speed regardless the power supply frequency.
- Inverters can save energy (electricity).
- Inverters can improve productivity by changing the motor speed to match the application.
- Inverters can perform smooth start and stop operations by reducing the starting current of standard motors.
- Inverters support automated factory systems, such as automatic operation and synchronized operation of several machines.


FR-A800 series


FR-E700 series

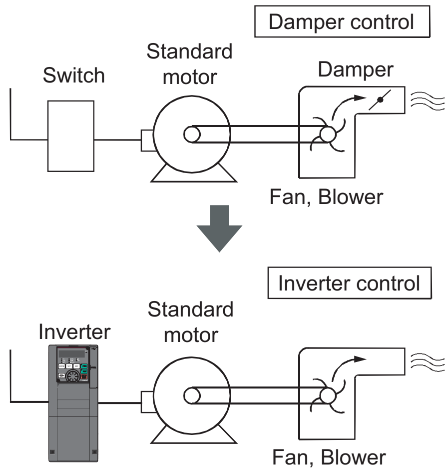
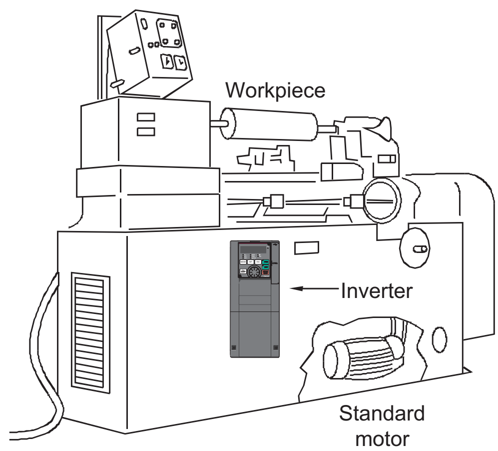
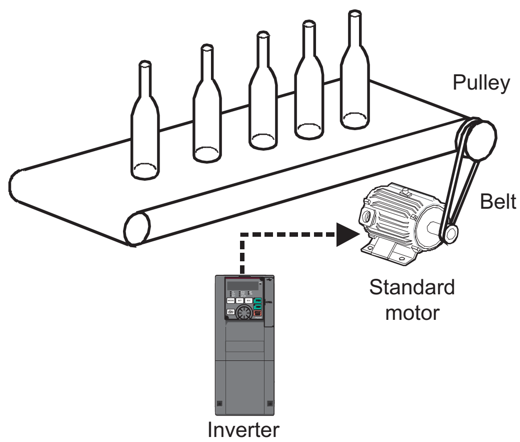

FR-F700P series

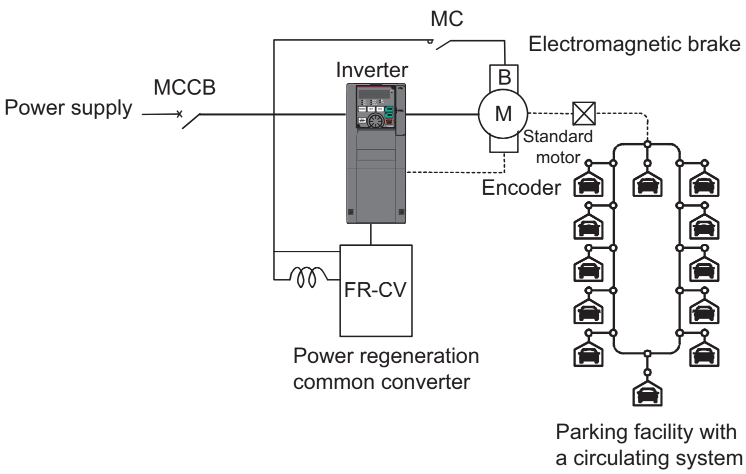
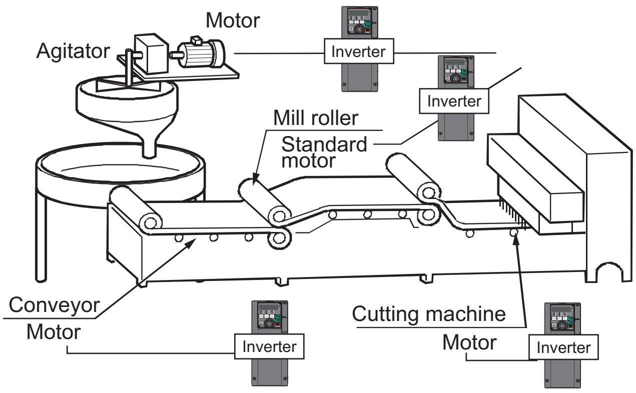
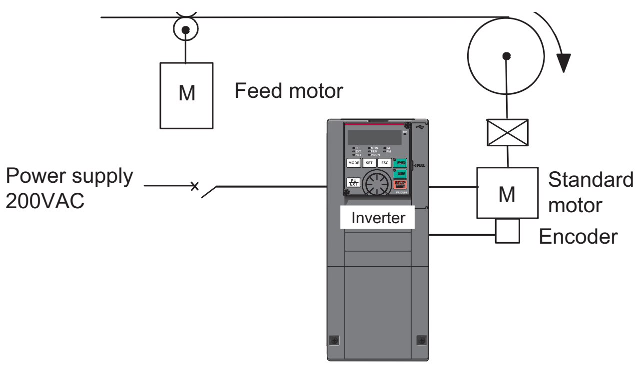

FR-F700PJ series


FR-D700 series

1.3 Inverter Application Examples

Inverters are used in various fields.

<table>
<tr><th>Features</th><th>Application examples</th></tr>
<tr><td>Inverters realize energy saving and automation.
•Useful for air flow control (flow amount control)
•Automatic control over air flow (pressure or flow amount)
•Necessary amount can be changed according to seasons and day/night.</td><td>•Pump
•Fan, blower
•Ventilation fan
•Cooling tower
•Drying machine
(Furnace fan)

</td></tr>
<tr><td>Higher machine efficiency and downsizing of machines
•Conventionally, pulleys etc. were used to change the rotation speed of a main spindle to match the size of the workpiece. Using inverters simplifies the speed changing mechanism, allowing machines to be downsized.
•Machining conditions can be changed easily for optimal performance.</td><td>•Drive for a main spindle of a machine tool
•Table of a machine tool
•Spindle stock feed
•Drive for a cutter
•Rice mill

</td></tr>
<tr><td>Higher machine efficiency, specified position stop, automatic operation
•The operation efficiency can be improved and carts can be stopped at the specified position.
•The conveyor speed can be changed to the most suitable value for every workpiece.
•The soft start and stop prevents products from falling down and wobbling.
•Shocks to machines are absorbed and acceleration and deceleration without shocks are realized.</td><td>•Cart
•Belt conveyor
•Wood working machine
•Weighing machine
•Packaging machine

</td></tr>
</table>

<table>
<tr><th>Features</th><th>Application examples</th></tr>
<tr><td>Specified position stop, automatic operation
•Carts can be stopped at the specified position.
•Multilevel car parking towers with a circulating system may need a large starting torque depending on the imbalance of the automobiles parked. Vector control is suitable for such application.
A negative load may be generated depending on the number of automobiles parked, requiring a large brake torque. In such cases, use an inverter with the power regeneration common converter FR-CV (optional) to construct an efficient driving system.</td><td>•Multilevel car parking tower
•Automated warehouse
•Cargo elevator
•Conveyor

</td></tr>
<tr><td>Vector control or sensorless vector control enables generation of high starting torque and minimum speed fluctuation.
•Accurate control over extrusion pressure according to the material extruded.
•Even for loads that change (increase) their viscosity as speed decreases, operations continue without torque shortages occurring.</td><td>•Extruder
•Molding machine
•Wiredrawing machine
•Agitator
•Roller driving
•Testing machine

</td></tr>
<tr><td>Controlling torque with vector control
•Winding/unwinding torque can be controlled with vector control.</td><td>•Various winding
•Unwinding line

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</table>

1.4 Specifications of Mitsubishi Electric Inverters

1.4.1 Comparison table

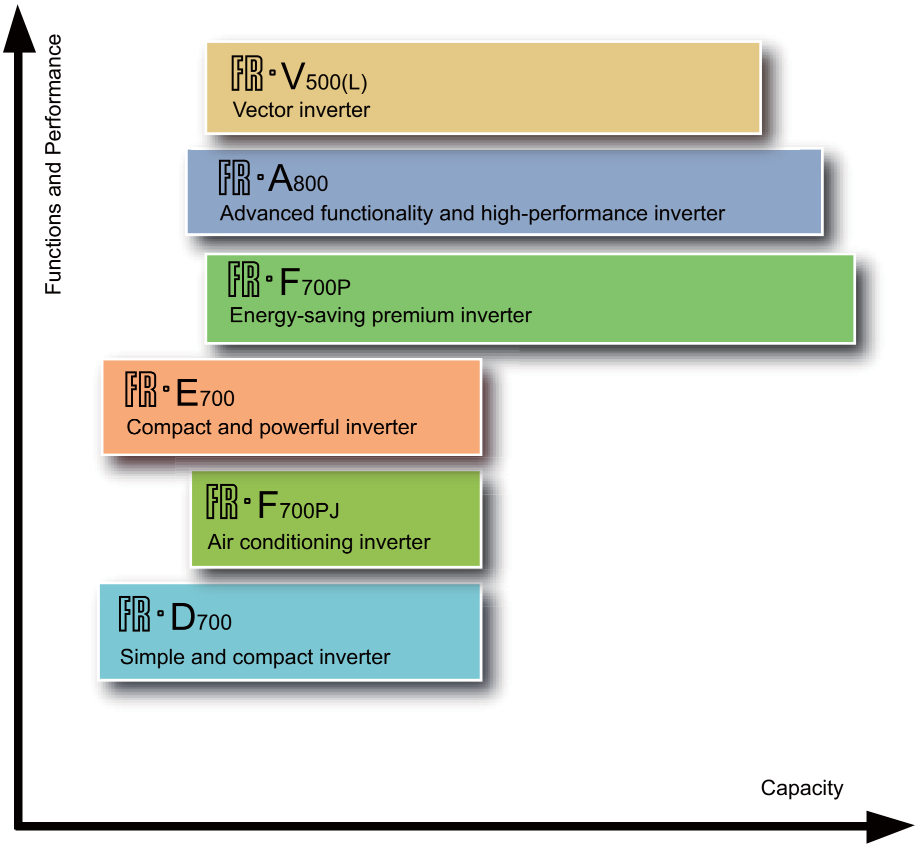
Item		Inverter model					
		FR-D700	FR-F700PJ	FR-E700	FR-F700P	FR-A800	FR-V500 (L)
Model features		Compact, economical, standard function	Compact, economical, energy saving, standard function	Compact, high-functionality	For fans and pumps, energy saving, high-functionality	High-performance, high-functionality	High-performance, high-functionality
Power supply specification		3ϕ 200/400V 1ϕ 100/200V	3ϕ 200V 3ϕ 400V	3ϕ 200/400V 1ϕ 100/200V	3ϕ 200V 3ϕ 400V	3ϕ 200V 3ϕ 400V	3ϕ 200V 3ϕ 400V
Capacity		0.1 to 15kW	0.4 to 15kW	0.1 to 15kW	0.75 to 560kW	200V class 0.4K to 90K 400V class 0.4K to 500K	1.5 to 250kW
Control method		V/F control, General-purpose magnetic flux control, Optimum excitation control are available	V/F control, General-purpose, vector control Optimum excitation control, IPM motor control are available	V/F control, General-purpose vector control, Advanced magnetic flux vector control, Optimum excitation control are available	V/F control, Simple magnetic flux vector control, Optimum excitation control, IPM motor control are available	V/F control, Advanced magnetic flux vector control, Real sensorless vector control, vector control (FR-A8AP) PM sensorless vector control are available	Vector control, V/F control are available
Low noise		○	○	○	○	○	○
Reset/output stop		△ Selectable	△ Selectable	○	○	○	△ Output stop is selectable
Multi-speed		15 speeds	15 speeds	15 speeds	15 speeds	15 speeds	15 speeds
Brake resistor	Built-in	—	—	—	—	○(7.5K or lower)	○5.5K or lower
	Options	○0.4K or higher	○	○0.4K or higher	—	○ (200V class 22K or lower 400V class 55K or lower)	○15K or lower
Brake unit connection		○	○	○	○	○	○
Speed command		0 to 5V, 10V 4 to 20mA DC	0 to 5V,10V 4 to 20mA DC	0 to 5V,10V 4 to 20mA DC	0 to 5V,10V ±5V, ±10V 4 to 20mA DC	0 to 5V,10V ±5V, ±10V 4 to 20mA DC	0 to 5V,10V ±10V DC
Fault output		1 changeover contact	1 changeover contact	1 changeover contact	1 changeover contact × 2	1 changeover contact × 2	1 changeover contact
Output signal		1 type	1 type	2 types	5 types	5 types	3 types
Automatic restart after instantaneous power failure		○	○	○	○	○	○
Torque at low speed		1Hz 150%	1Hz 120%	0.5Hz 200% (3.7K or lower)	3Hz 120%	0.3Hz 200% (3.7K or lower)	0r/min 100% continuous
Stall prevention		○	○	○	○	○	○(V/F control)
Fast-response current limit		○	○	○	○	○	○
Installation ratio to 0.75kW		31	31 (Without Filterpack)	31	100	—	—
Price ratio to 0.75kW		50	53 (Without Filterpack)	61	95	—	—

○: Available △: Available with some limitations —: Not available

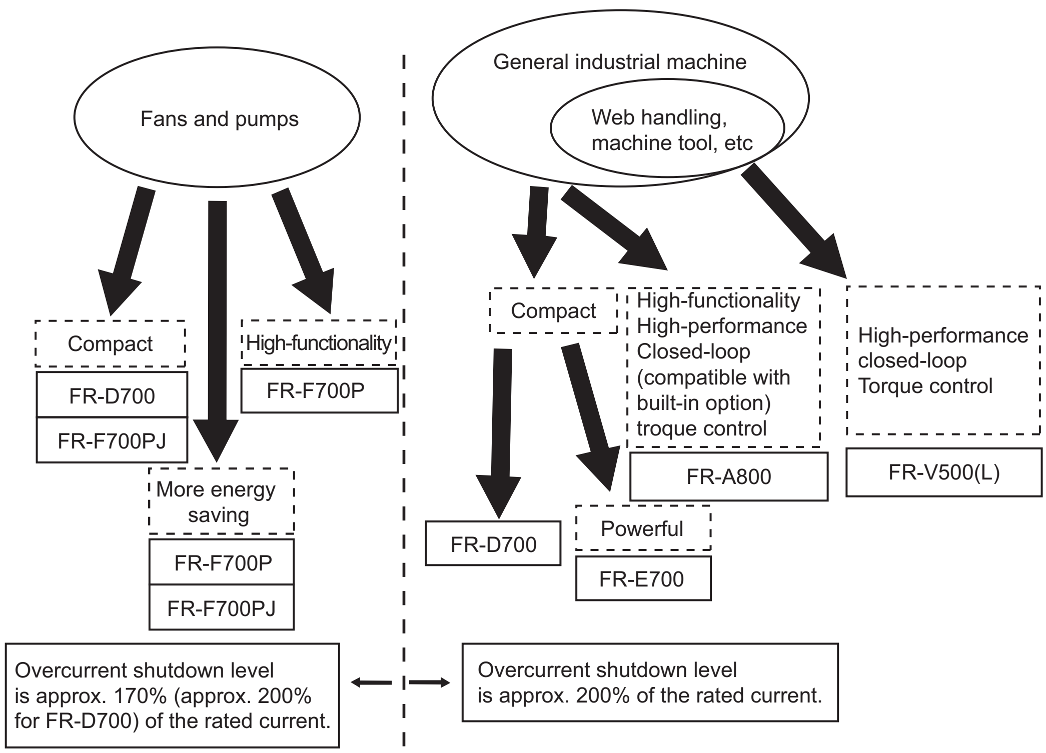
Item		Inverter model					
		FR-D700	FR-F700PJ	FR-E700	FR-F700P	FR-A800	FR-V500 (L)
EC Directives	EMC Directive	△ (With dedicated noise filter)	△ (With dedicated noise filter)	△ (With dedicated noise filter)	○(With embedded noise filter)	○ (With embedded noise filter)	△ (With dedicated noise filter)
	Low Voltage Directive	○	○	○	○	○	○
UL standard		○	○	○	○	○	○
cUL standard		○	○	○	○	○	○
Selection point		Compact and standard performance.	Compact. Suitable for reduced noise control of fans and pumps. Supports IPM motors (MM-EF).	Suitable for operations requiring certain functions such as multi-speed setting and motor braking.	Suitable for reduced noise control of fans and pumps. Supports IPM motors (MM-EFS, MM-EF).	Suitable for operations requiring high start torque and no-trip operations. Also suitable for most operation including uncertain operating conditions.	Suitable for operations requiring high torque, high accuracy and high response level.
Main applications		Carrier, pulley, starter, air conditioner, fan, pump	Air conditioner, fan, pump	Industrial machine, variable transmission, carrier, pulley, starter, conveyor	Air conditioner, fan, pump	Carrier, machine tool, industrial machine, lift, winding machine	Lift, winding machine carrier,

○: Available △: Available with some limitations —: Not available

1.4.2 Inverter line-up



1.4.3 Applicable series for each industry



1.4.4 Introduction of the inverter series

For fans and pumps

FR-F700P

Three-phase 200V class	0.75K to 110K
Three-phase 400V class	0.75K to 560K

- Drives both the general-purpose motors and IPM motors. When it drives an IPM motor (MM-EFS), which has permanent magnets embedded in its rotor, further energy savings and higher efficiency are achieved.
- This inverter is suitable for fans and pumps, and has a variety of functions: optimum excitation control, variable torque acceleration/deceleration patterns, PID control, commercial power supply switching, adjustable 5 points V/F, continuous operation at an instantaneous power failure, regeneration avoidance function, etc.
- Extended service life of parts comes with the service life diagnose function as standard.
- Compatible with various plug-in options.
  Compatible with networks, such as LONWORKS and CC-Link, via plug-in options.

FR-F700PJ

Three-phase 200V class	0.4K to 15K
Three-phase 400V class	0.4K to 15K

- Drives both the general-purpose motors and IPM motors. When it drives an IPM motor (MM-EFS), which has permanent magnets embedded in its rotor, further energy savings and higher efficiency are achieved.
- Filterpack, which contains a power factor improving DC reactor, common mode choke, and capacitive filter, is available. (Filterpack complies with the Architectural Standard Specifications (Electric Installation) (2009) supervised by the Ministry of Land, Infrastructure, Transport and Tourism.)
- Spring clamp terminals provide high reliability and easy wiring.

**MM-EFS (55kW or lower)
MM-THE4 (75kW or higher)**

Three-phase 200V class	0.75kW to 75kW
Three-phase 400V class	0.75kW to 160kW

- This is an IPM motor, which has permanent magnets embedded in its rotor. It is more efficient than an induction motor.
- Compared with the "MM-EF series", the motor loss (iron loss and primary copper loss) is further reduced, thus achieving higher efficiency. This motor satisfies the highest efficiency standard IE4 (super premium efficiency).

General industrial applications

(Compact and high functionality inverter.
Suitable for goods transfer, conveyor, food packaging, and standard machine tools, etc.)

FR-E700

Single-phase 100V class	0.1K to 0.75K	Three-phase 200V class	0.1K to 15K
Single-phase 200V class	0.1K to 2.2K	Three-phase 400V class	0.4K to 15K

- 0.5Hz 200% torque (0.1K to 3.7K) can be generated under Advanced magnetic flux vector control.
- The setting dial has non-slip treatment. Turn the setting dial quickly to jump the displayed numbers. Turn it slowly to display the number one by one.
- Compatible with various plug-in options.
  The inverter is compatible with networks such as CC-Link, PROFIBUS-DP, DeviceNet, via plug-in options.

General industrial applications

(Compact standard inverter. Suitable for goods transfer, conveyor, food packaging, fans and pumps, etc.)

FR-D700

Single-phase 100V class	0.1K to 0.75K	Three-phase 200V class	0.1K to 15K
Single-phase 200V class	0.1K to 2.2K	Three-phase 400V class	0.4K to 15K

- Spring clamp terminals provide high reliability and easy wiring.
- It features the safety stop function and complies with safety standards at a low cost.
- 1Hz 150% torque can be generated under General-purpose magnetic flux and with the auto tuning function.
- The setting dial has non-slip treatment. Turn the setting dial quickly to jump the displayed numbers. Turn it slowly to display the number one by one.

General industrial applications

(High-functionality high-performance inverter. Suitable for lift, web line control, machine tools, etc.)

FR-A800

Three-phase 200V class	0.4K to 90K
Three-phase 400V class	0.4K to 500K

- The inverter can be used with PM (magnet) motors due to the addition of PM sensorless vector control. PM motors from other manufacturers can also be operated with the auto tuning function.
- A variety of useful functions such as USB memory connection and PLC function are available.
- Full-scale vector control can be performed on a motor with encoder. (The plug-in option or FR-A8AP is required.)
- Compatible with various plug-in options.
  Also compatible with networks such as CC-Link and SSCNETIII/H, via plug-in options.

FR-V500(L)

Three-phase 200V class	1.5K to 55K, 75K
Three-phase 400V class	1.5K to 55K, 75K to 250K

- Vector control can be performed on a dedicated motor to achieve high performance and fast response.
- The magnetic flux inside a motor can be calculated accurately to improve the torque accuracy.
- No adjustment is required for the speed control gain/position loop gain.
- Compatible with SSCNET communication via a plug-in option.

Chapter 2 MOTOR CHARACTERISTICS AT INVERTER DRIVE

This chapter describes the basic characteristics that are of importance when selecting motor capacity and when operating a standard motor by inverter.
Motor characteristics differ when operating by commercial power supply, and when operating by inverter. It is important that the user understands these differences.

POINTS for understanding !

1. Relationship between motor speed, current and torque
2. V/F (Voltage/frequency ratio) pattern and motor basic characteristics
3. Difference of motor characteristics when operating by commercial power supply, and when operating by inverter.
   Torque, current, temperature, etc.
4. Concept of torque boost

2.1 Motor Classification

Although there are many methods to classify motors, the motors can be classified into the following types when distinguished by the principle and structure. Within these motor types, the motor driven by the inverter is a standard motor.
In addition, there is an energy-saving drive high-efficiency magnetic motor (IPM) for further energy saving.

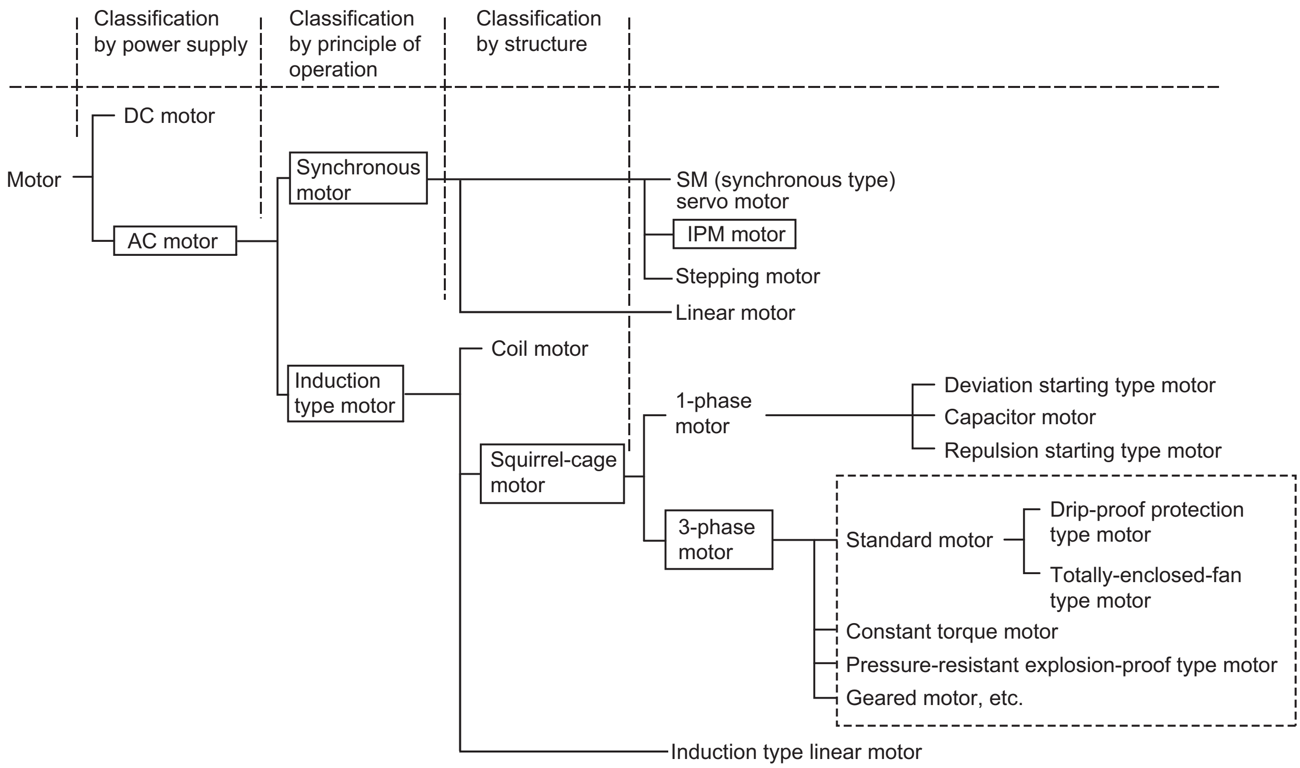


Table 2.1

Motor types		Model	Capacity	Structure/ specification	Application
Induction type motor	Standard motor	SB-JR	0.4 to 55kW	Drip-proof protection type	Numerous speed controls can be performed in combination with the inverter.
		SF-PR	0.75 to 55kW	Totally-enclosed-fan type	
		SF-HR	0.2 to 55kW		
		SF-JR	0.2 to 55kW		
	Constant torque motor	SF-HRCA	0.2 to 55kW	Totally-enclosed-fan type	Most suitable for the applications that continuously operate with the rated torque at low speed.
		SF-JRC	0.4 to 37kW		
		SF-JRC-FV	45kW	Totally-enclosed strong cooling type	
		SF-V5RU	1.5 to 55kW	Totally-enclosed strong cooling type	Equipped with an encoder. Dedicated to vector control inverters.
		SF-THY	75 to 250kW		
	Pressure-resistant explosion-proof type motor	XE-NE	0.2, 0.4kW	Pressure-resistant explosion-proof type	Used in environments with flammable gas, mist, etc. Approved by the Ministry of Health, Labor and Welfare.
		XF-NE	0.75 to 7.5kW		
		XF-E	11 to 45kW		
		XF-TH	55 to 110kW		
		XE-NECA-2/1	0.4kW		
		XF-NECA-2/1	0.75 to 7.5kW		
		XF-ECA-2/1	11 to 37kW		
	Geared motor	GM-S	0.1 to 2.2kW	For constant load	Large torque can be obtained at low speed. Used in various industries such as transport machinery and food processing.
		GM-D	0.4 to 7.5kW	For middle load	
		GM-LJ	11 to 37kW		
		GM-PJ	3.7 to 55kW	For constant load or middle load	
		GM-J2	25 to 90kW	For constant load	
Synchronous motor	IPM motor	MM-EF	0.4 to 110kW	Totally-enclosed-fan type	More efficient than the induction type motor. High reliability is obtained with sensorless operation. High-speed type is also available.
		MM-EFS MM-THE4	0.75 to 160kW	Totally-enclosed-fan type, Totally-enclosed strong cooling type	
		MM-CF	0.4 to 7.0kW	Totally-enclosed self-cooling	
		MM-BF	0.4 to 3.7kW		

Motor types	Rated output range (kW) 0.01 0.1 1 10 100	Maximum motor speed (r/min) 100 1000	Variable speed range (with inverter) 1 : □ 10 100 1000	Encoder	Availability of torque control	Positioning accuracy (guide) (mm) 1/1000 1/100 1/10 1 10
Standard motor				Without	Not available*	Use the limit switch.
Standard motor (with encoder)				With	Not available*	
Vector inverter dedicated motor				With	Available	
IPM motor				Without	Not available	Use the limit switch.

※ Available for FR-A800 series.

Useful information

General-purpose inverters can handle standard motors, but they also create limitations in some applications. Main limitations of inverter driving are torque and temperature.
It is difficult to control motor temperatures from the inverter, therefore measures should be taken from the motor.
The constant-torque motor (dedicated motor) is designed to continuously run with a constant torque at low speed, effectively controlling the temperature rise in a motor.

Remark

The temperature rise during low-speed operation under Advanced magnetic flux vector control, General-purpose magnetic flux, and Real sensorless vector control is low compared with the temperature rise under V/F control.
Refer to "the standard motor (continuous operation) characteristics" indicated in catalogs.

2.2 Structure of Motor

Since the standard motor is robust and has a simple structure, it can be used in various environments such as outdoor, underwater and explosive atmosphere.
The motor types can be classified by structure: the totally-enclosed fan-cooled type and the drip-proof protection type. The structure example of the totally-enclosed fan-cooled type is shown in Fig.2.1. The structure can be divided into two parts: the fixed part and rotary part. The fixed part and rotary part are comprised of mechanical parts and electrical parts respectively. The external fan connected to the shaft is designed for cooling the heat generation of the motor itself.
When the low-speed operation is performed by the inverter, the motor speed becomes slower and the cooling effect by the external fan decreases. To keep the rise of the motor temperature within the specified value, it is necessary to suppress the permissible load torque.

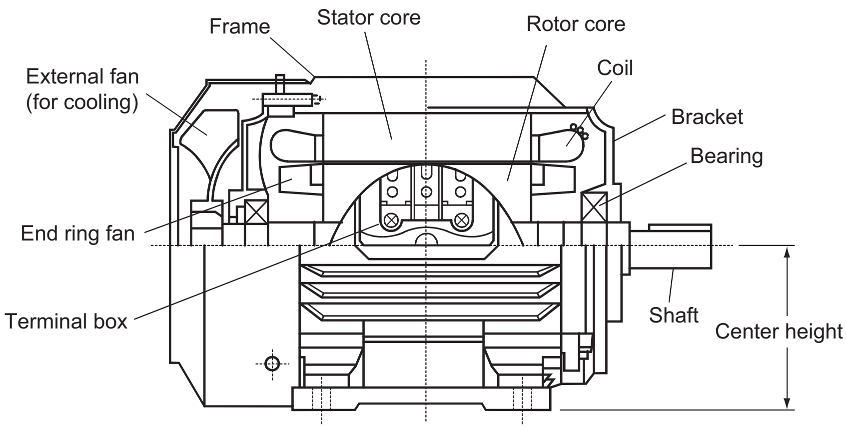


Fig.2.1 Structure example of totally-enclosed fan-cooled type motor

2.2.1 Standard motor (induction type)

The cross section view of the standard motor (induction type) is shown on the right.
It consists of stator core, stator coil, gap and rotor core. The current is applied to the coil, and the rotating magnetic field is generated. Inverter-dedicated vector-controlled motor, which theoretically has the same characteristic with DC machine, divides the current flowing through the stator coil into the field-magnets-generating current (field magnet current) and the torque generating current (torque current) that crosses the field magnet current, and electrically controls both.
In addition, the vector inverter dedicated motor is widely used because of its constant torque control from low speed to high speed and good response.

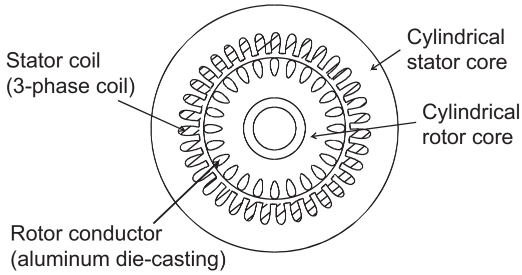


Fig.2.2 Cross section of 3-phase motor (induction type)

2.2.2 IPM motor (synchronous type)

The rotor of the IPM motor (synchronous type) has permanent magnets embedded, and the stator consists of the coil where the current is applied. The cross section view is shown in Fig.2.3.
The current flow to the rotor (secondary side) is blocked, therefore no loss occurs at the secondary side. This makes an IPM motor more efficient than an induction motor. (Refer to page 78.)

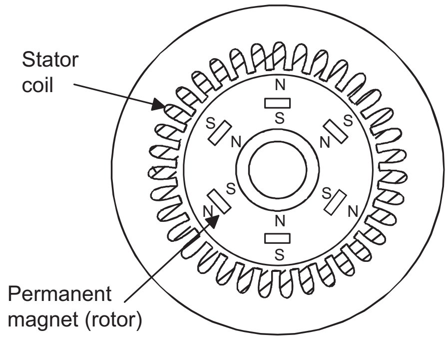


Fig.2.3 Cross section of IPM motor

2.2.3 Heat-resistant classes and temperature rise

Various insulants with high heat resistance are used for general-purpose motors due to the significant development of insulating materials to be used.
Currently, there are five types of heat-resistant classes for motors. Of these, E, B, and F are standard types. F and H are used for harsh environment such as high-temperature and heavy-load operations.

Heat-resistant class and maximum temperature rise are specified in Table 2.2. The surrounding air temperatures of motors are assumed to be 40°C. For use in a surrounding air temperature of 40°C or higher, deduct 40°C from the surrounding air temperature, then deduct the obtained value from the temperature rise limit in Table 2.2.

Table 2.2 Heat-resistant class and temperature rise limit

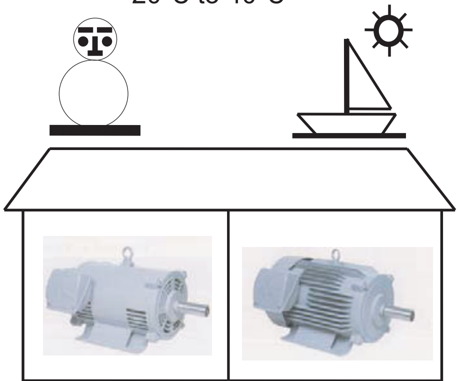
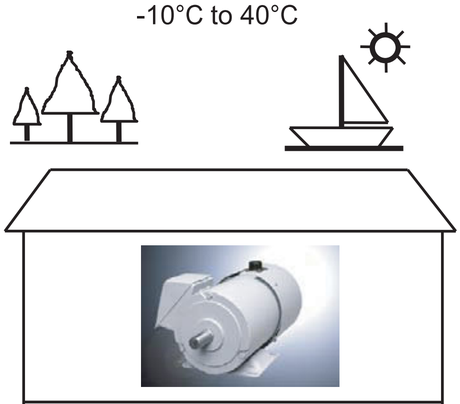
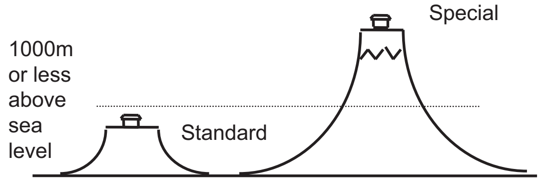
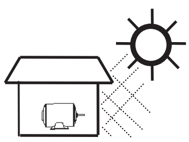
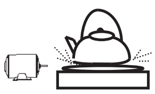
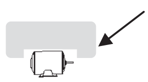
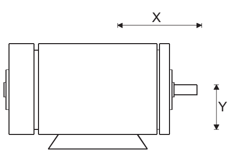
Heat-resistant class	Temperature rise limit
A	60K
E	75K
B	80K
F	105K
H	125K

* The temperature rise of insulants is measured in a resistance method.

2.3 Installation

2.3.1 Installation environment

The motor driven with a general-purpose inverter is a standard motor which does not generally operate with feedback control.
On the contrary, the standard motor driven with a vector inverter requires feedback control and has a built-in encoder (sensor) behind the for detecting speed. A semiconductor and electronic components are installed in the encoder.
The lifetimes of coil insulating material, bearings, and bearing grease inside the motor, as well as the operating environment have limitations. The motors are designed to operate under the following environmental conditions.

Environment	General-purpose inverter motor	Vector inverter dedicated motor
Surrounding air temperature	-20°C to 40°C 	-10°C to 40°C 
Ambient humidity	Drip-proof protection type motor: 85% RH or less, No water droplets Totally-enclosed fan-cooled type motor: 95% RH or less, No water droplets Squirrel-cage induction motor	Totally-enclosed fan-cooled type motor Squirrel-cage induction motor 90% RH or less, No water droplets
Altitude		The installation altitude of a motor is 1000m or less above sea level. If the atmospheric pressure is low, the heat dissipation gets worse. The motor temperature, insulation, grease life, etc. during the operation cannot be guaranteed if the altitude is over 1000m, specialized measures are required.
Ambience	 Indoor, no direct sunlight (excluding outdoor, totally-closed fan-cooled motor)  No flammable gas	 • No oil mist • No corrosive gas • No dust and dirt
Vibration resistance		Restrictions of the vibration passed on to the motor during the operation Both X and Y directions 4.9m/s^2 or less

2.3.2 Outer sheath form of motor

An outer sheath form for motor must be selected according to the installation condition and environment. Selecting an inappropriate motor may cause problems or shorten the motor life. The outer sheath forms (protection forms) are generally categorized in accordance with the Japanese standard JIS or the international standard IEC. The classifications by JIS and IEC are below.

Categorization by JIS and IEC
Symbols for the protection types of motors are indicated by putting the first and second reference numbers corresponding to the following table, after IP.

Example) IP 6 5

- 5: Second reference number
- 6: First reference number

First reference number: Grade for protection from solid foreign matter entrance

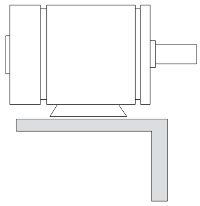
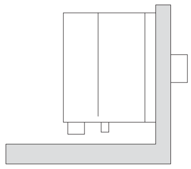
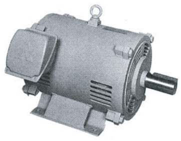
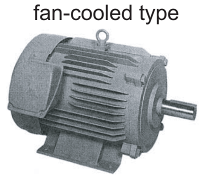
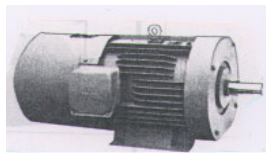
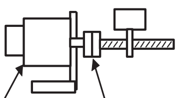
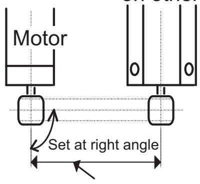
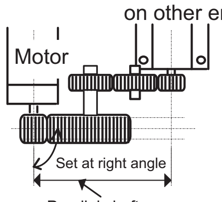
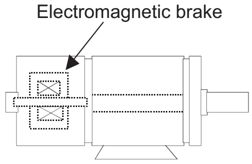
0	Unprotected	3	Protection from the entrance of solid foreign matter of diameter 2.5mm or more such as an edge of tool or a wire	6	Absolute dust-proof structure, totally free from the entrance of powder dust
1	Protection from the entrance of solid foreign matter of 50mm or more such as a hand	4	Protection from the entrance of solid foreign matter of diameter 1.0mm or more such as a cable or a flake		
2	Protection from the entrance of solid foreign matter of diameter 12mm or more such as a one-yen coin	5	Protection from powder dust, no entrance of powder dust that disturbs normal operation		

Second reference number: Grade for protection from water entrance

0	Unprotected	3	Protection against the water spray within the range of 60 degrees from the perpendicular	6	Protection against strong jet water as ocean waves, no water immersion which disturbs normal operation
1	Protection against the dripping that vertically drops such as condensed water	4	Protection against the splash from all directions	7	No water immersion which disturbs normal operation even if submerged in 150mm to 1m
2	Protection against the dripping within the range of 15 degrees from the perpendicular	5	Protection against the jet water from all directions	8	Usable in water, usable for a long time below water

2.3.3 Mechanical specifications of main motors

Generally, for general-purpose inverters and vector inverter standard motors, leg installed type (with legs) motors are relatively common.
The following outlines the main mechanical specifications of these motors.

Installation method: Leg installed type; Flange installed type	Leg installed type 		Flange installed type 
Cooling method: Open type (Standard type); Totally-enclosed fan-cooled type (Suitable for adverse environment with dust, dirt, humidity, etc.); Separate-cooling type (Adopted with large capacity in a forced cooling system)	Open type 	Totally-enclosed fan-cooled type 	Separate-cooling type 
Power transmission: Direct connection driving; Belt driving; Gear driving	Direct connection driving 	Belt driving 	Gear driving 
Electromagnetic brake: Safety brake (Excitation open brake); Non-safety brake (Excitation brake)	Electromagnetic brake 		

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2.4 Basic Characteristics

2.4.1 Torque and current curves

Fig.2.4 shows the torque and current characteristics at direct power ON of a standard motor.

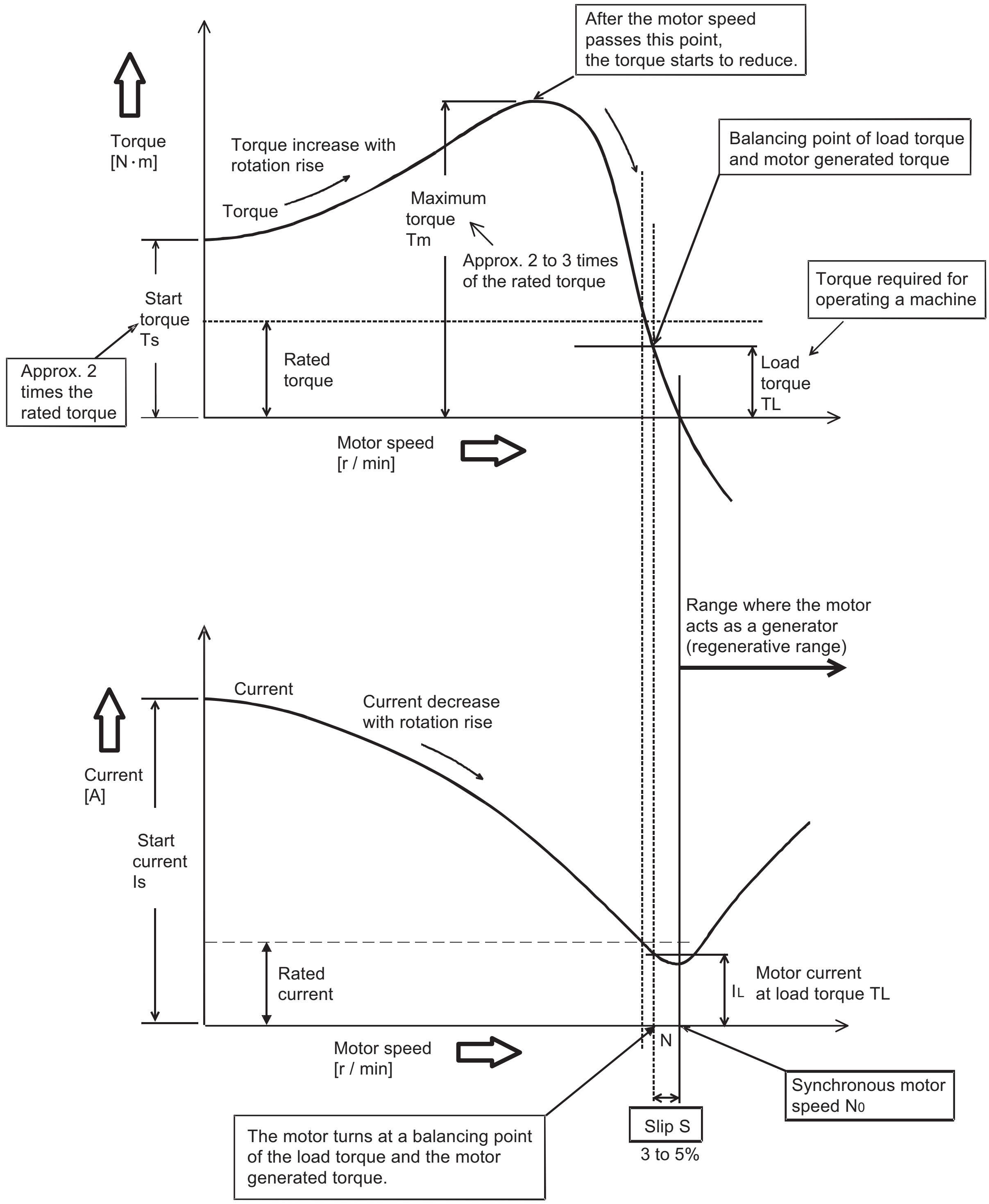

Fig.2.4 Relationship of a standard motor speed, current and torque

2.4.2 Motor speed

The motor speed is determined by the number of poles and the magnitude of the power supply frequency to be applied in addition to the load torque. This is represented by the following formula.

$$\text{Motor speed N} = \boxed{\frac{120 \times \text{Frequency f [Hz]}}{\text{Pole number P}}} \times \boxed{(1\text{-S})} \quad \text{[r/min]} \quad \cdots\cdots\cdots\cdots \quad (2.1)$$

Determined by the specification of the motor.

Determined by the load specification (load torque).

This magnitude is called Synchronous speed N_0.

To change the motor speed, it is only necessary to change the power supply frequency to be applied to the motor or the number of poles as understood from the Formula (2.1). In addition to this, there is a method to change the applied voltage of the motor.

To change the frequency. . . . . Inverter
To change the number of poles. . . . . Pole number conversion motor
To change the voltage . . . . Primary voltage control (PS motor)
To change the slip . . . . Coil-type motor

The variable speed motor (Mitsubishi Electric AS motor) of the eddy current joint system has an electric joint of the eddy current system between the output shaft and the drive motor, and the drive motor always rotates at the rated speed. Since the motor speed of the output shaft is slipped at the joint part, it is similar to the system to change the slip S.

2.4.3 Slip

When a load is applied, the motor speed becomes mismatched with (or reduced from) the synchronous speed in Section 2.4.1. The indicated degree of the gap with the synchronous speed is called "Slip".
"Slip" is derived by Formula (2.1) as shown below.

$$\text{Slip S} = \frac{\text{Synchronous speed } N_0 - \text{Motor speed N}}{\text{Synchronous speed } N_0} \times 100\ [\%] \quad \cdots\cdots\cdots\cdots \quad (2.2)$$

(1) At a start (the motor speed is 0), the "slip" is 100%. (Normally it is indicated as "Slip 1".) When the frequency is gradually increased with the inverter (called the frequency start), the "slip" is several percent.

(2) For operation at the rated torque, the "slip" is generally 3 to 5%. When the load torque increases (overload), the "slip" and the motor current also increase.

(3) When the slip becomes a minus value, it means that the motor speed has exceeded the synchronous speed ($N>N_0$).

☒ Useful information

The torque generated from the standard motor is not fixed. Even if motor capacity is large, if the load is small, the motor generated torque also becomes smaller proportional to the load. The motor generated torque constantly varies according to the load torque. The motor speed also varies according to the load fluctuation.

2.4.4 Motor current

As shown in Fig.2.4, the faster the motor speed (i.e. the larger slip) is, the larger the current flows. When the current at slip 0 is the no load current, it may be approximately 50% of the rated current with a small capacity standard motor. Also for the minus torque (regenerative brake area), the larger the (absolute value of) slip is, the larger the regenerative current becomes.

2.4.5 Motor speed fluctuation and motor load current

The standard motor speed is determined by the relationship between the load torque T_L and the motor generated torque as shown in Fig.2.4.

(1) When the load torque varies (constant motor torque)

As the load torque increases, the motor speed (N_2) slows down, and as the load torque decreases, the motor speed (N_1) becomes faster. (The larger the load torque is, the larger the motor current becomes.)

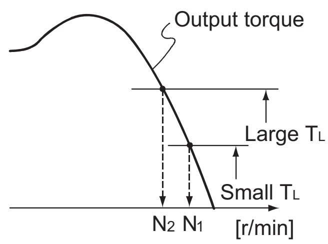

Fig.2.5 Load fluctuation and motor speed

(2) When the motor applied voltage (power supply voltage) changes (constant load torque)

Since the motor torque is proportional to the square of the voltage to be applied, the motor speed also changes when the voltage changes. When the voltage increases, the current decreases.

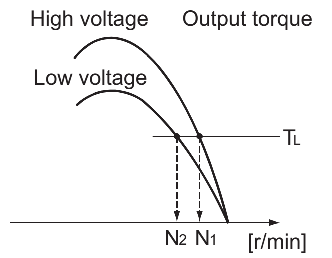

Fig.2.6 Voltage fluctuation and motor speed

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2.4.6 Rated motor torque

The "power" generated by the standard motor is called torque. Normally a "power" is represented as [N] in a linear operation. For the motor, however, "power" is generated by turning the shaft. Therefore, the expression of "power" will be "Power in the rotational operation" = torque [N·m].
The value of the rated motor torque can be calculated by Formula (2.3).

$$\text{Rated torque } T_M = 9550 \times \frac{\text{Rated motor output P [kW]}}{\text{Rated motor speed N [r/min]}} \text{ [N·m]} \quad \cdots\cdots (2.3)$$

Rated output and rated speed are indicated on the motor's rating plate and test reports.

(Note) The "rated motor speed" is a motor speed at the rated motor torque when the rated voltage and frequency are applied.

Example

What is the rated torque T_M of 3.7kW 4P rated motor at rated speed 1730 [r/min]?

$$\text{Rated torque } T_M = 9550 \times \frac{3.7}{1730} = 20.4 \text{ [N·m]}$$

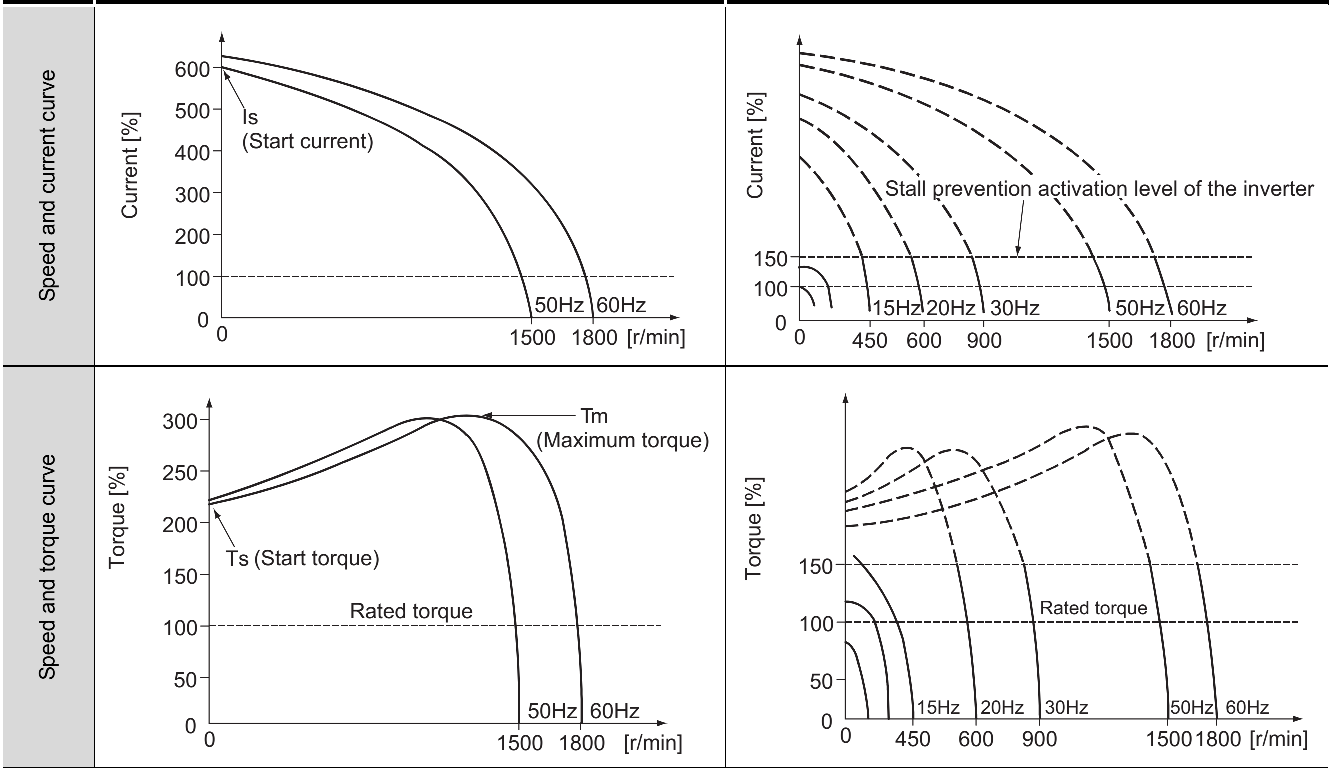
During the inverter operation, the calculation of the rated torque is not affected even if the synchronous speed N_0 is used.
For precise calculations, use the rated motor speed.

Useful information

The rated motor torque is not a torque generated from the motor. It is a load torque which is permissible in the continuous operation at the rated motor speed.

2.5 Torque and Current Characteristics at Inverter Drive

The motor torque and current characteristics in the commercial operation and the inverter operation are compared as shown in Fig.2.7. [%] indicates the ratio to the rated torque and rated current. (Example: For four poles)



	Commercial operation	Inverter operation
Characteristics	•The start torque (Ts) and start current (Is) are both large. •The motor speed is fixed by the power supply frequency.	•The operation starts from the low frequency to suppress the start current, and the start torque is small. •The motor speed can be set as desired regardless of the power supply frequency.

Fig.2.7 Motor current and torque characteristics comparison (when the inverter is performing V/F control)

Approximate characteristic values when a standard motor is used with the commercial operation

(1) Start current	Is = 600 to 700 [%]
(2) Start torque	Ts = 150 to 250 [%]
(3) Maximum torque	T_M = 200 to 300 [%]
(4) Slip at the rated load	S = 3 to 5 [%]

2.6 Operating Standard Motor with Inverter

2.6.1 Difference between the rated torque at 50Hz and 60Hz

For use anywhere in Japan, the standard motor is designed with three common rated specifications: 200V 50Hz, 200V 60Hz, and 220V 60Hz. The comparison of the rated current, rated motor speed and rated torque to each power supply specification for the commercial power supply operation with SF-JR 3.7kW 4P is shown in Table 2.3.

Table 2.3 Comparison of 3 commonly used ratings

Power supply	Rated current [A]	Rated motor speed [r/min]	Rated torque [N·m]
200V 50Hz	14.6	1420	24.9
200V 60Hz	14.2	1710	20.7
220V 60Hz	13.4	1730	20.4

When the rated current at each power supply rating is assumed to be $I_{200/50}$, $I_{200/60}$, and $I_{220/60}$ respectively ($I_{400/50}$, $I_{400/60}$, and $I_{440/60}$ for a 400V power supply), the following relationship exists and the current will be the maximum at 50Hz.

$I_{200/50} > I_{200/60} > I_{220/60}$ ($I_{400/50} > I_{400/60} > I_{440/60}$)

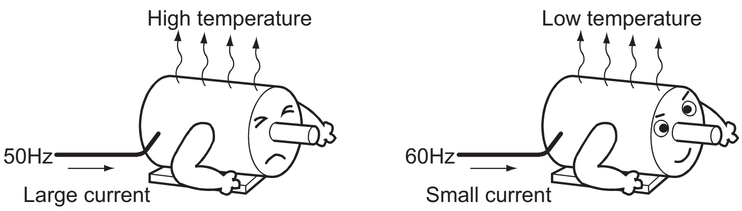
As seen from Formula (2.3) in Section 2.4.6, the magnitude of the motor rated torque differs at 50Hz and 60Hz.

$$\text{Torque at 50Hz } T_M = 9550 \times \frac{P\,[\text{kW}]}{N\,[\text{r/min}]} = 9550 \times \frac{P}{1500} = 6.37 \times P$$

Increased by 20%

$$\text{Torque at 60Hz } T_M = 9550 \times \frac{P\,[\text{kW}]}{N\,[\text{r/min}]} = 9550 \times \frac{P}{1800} = 5.31 \times P$$

The motor current as well as the torque (power) is large at 50Hz, and the rise of motor temperature is also higher compared to 60Hz.



2.6.2 Singularity in the inverter operation

As compared to the commercial operation, the inverter operation has the "increase of motor current". Since the waveform of the voltage to be applied to the standard motor is not the sine wave but a wave pattern with distortion, the motor current at the rated torque increases by approximately 5% compared to that with the commercial power supply. Consequently, the motor temperature will be also higher than that with the commercial power supply. A problem may occur when using 50Hz with little margin for the specified temperature.
This is why "Reduce the load torque to 85% at 50Hz" is indicated for the continuous operation in the catalog or instruction manual of the inverter.
Since there is enough margin for the specified temperature at 60Hz, even if the current increases, the temperature stays within the specified value.

Note Here, "at 50Hz" should not be considered the magnitude of the power supply frequency but "when the rated torque calculated with 50Hz is output".

2.6.3 For the voltage change when the speed is changed by the inverter

The standard motor speed can be changed by changing only the frequency as shown in Formula (2.1).
However, if the output frequency is set to 50Hz or less with the constant voltage (e.g. 200V), the motor magnetic flux increases (or is saturated), and the increased current causes the motor to be overheated and then burned out.
To prevent this, it is necessary to make the magnetic flux constant. Since the magnetic flux is proportional to the voltage and inversely proportional to the frequency as shown in Formula (2.4), this problem can be resolved by applying a voltage to a motor which satisfies this relationship.

$$\text{Magnetic flux} \propto \frac{\text{Voltage V}}{\text{Frequency f}} = \text{Constant} \cdots\cdots \quad (2.4)$$

In the case that the speed is set to a half (60Hz to 30Hz), V/f is as shown below.

$$\frac{V}{f} = \frac{220\ [V]}{60\ [Hz]} = \frac{110\ [V]^{*}}{30\ [Hz]} = \text{Constant}$$

* Increased more for the voltage drop compensation inside the motor in practice.

As above, the rise of the motor temperature can be avoided by changing the voltage. However, it is important to consider the torque status.

2.6.4 Motor generated torque

The relationship between the motor applied voltage (V), the frequency (f) and the torque is represented by Formula (2.5).

$$\text{Torque } T = K \times \frac{V}{f} \times I \quad \cdots\cdots (2.5)$$

K: Constant I: Current

(1) If the V/F ratio and current are constant, the torque is constant.

(2) When the voltage (V) is constant and only the frequency (f) varies, the torque is inversely proportional to the frequency if the motor current is constant.

- The relationship between the voltage and the torque to the change of frequency described as above is shown in Fig.2.8. The relationship between the output voltage and output frequency of the inverter is called "V/F pattern". This is an important factor to control the motor.

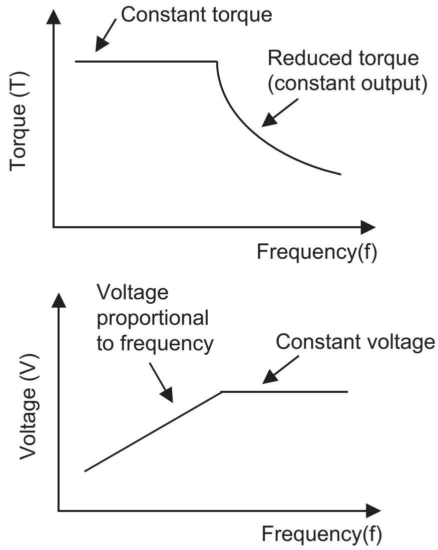


Fig.2.8 Constant torque and constant output range

2.6.5 Operation which exceeds 50Hz or 60Hz

The inverter output voltage cannot output more than the power supply voltage, therefore the output voltage is constant for frequency that exceeds 50Hz or 60Hz. (Base frequency···Refer to the following figure.)
Since only the frequency is changed, the torque is reduced inversely proportional to the frequency if the motor current value is constant as shown in Formula (2.5). This area is called "constant output" range.

Useful information

Base frequency
This frequency represents the frequency at the rated torque of the motor.
Since the standard motor is designed for use at either 50Hz or 60Hz, set the base frequency either 50Hz or 60Hz.
Considering the rise of the motor temperature in Section 2.6.2, it is recommended to use the motor set at 60Hz regardless of the power supply frequency. For a machine of which motor rated torque is designed at 50Hz, setting 60Hz as the base frequency is also applicable if the load current at 50Hz is below the motor rated current at 60Hz.

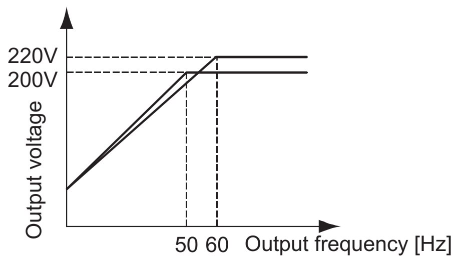


Fig.2.9 V/F pattern and base frequency

2.7 Standard Motor Output Characteristics in Inverter Operation

The output characteristics for the combination of the standard motor (4 poles) and an inverter of the same capacity is as shown below.

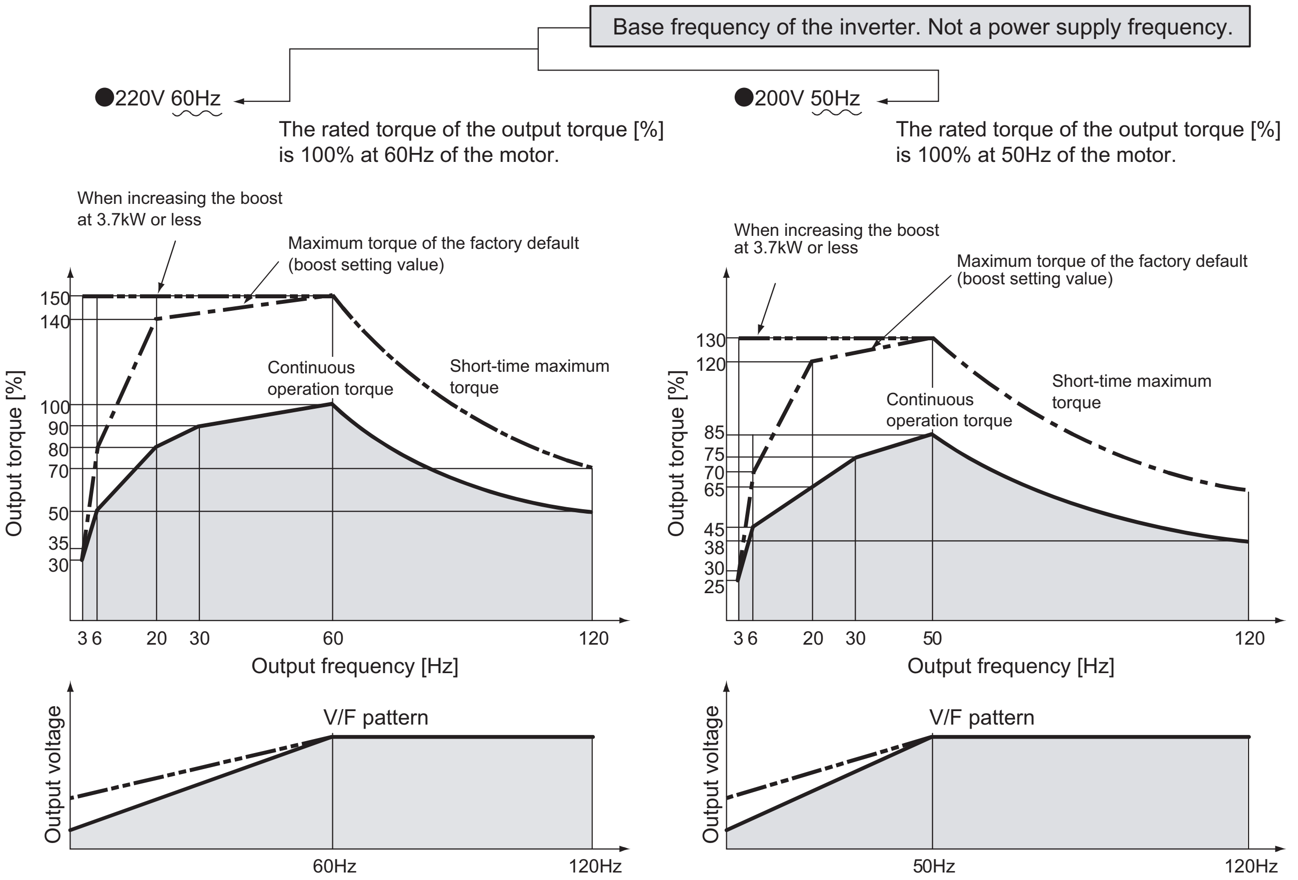


Fig.2.10 Output characteristics of a standard motor (in V/F control)

(1) The continuous operation torque is a permissible load torque which is regulated by the rise of the motor temperature. It is not the maximum value of the motor generated torque.

(2) The short-time maximum torque is the maximum torque generated by the motor within the overload current rating (150%) of the inverter. Therefore, if the capacity of the inverter is increased, the maximum torque becomes larger.
The short-time of the short-time maximum torque is the overload current permissible energization time and within one minute.
*Inverter-dedicated constant-torque motor can continuously generate 100% torque even in the low-speed operation.

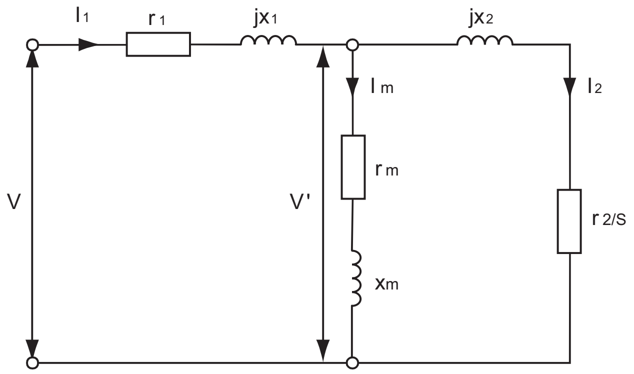
Useful information

Standard motors can run as high as 120Hz at maximum. However, the operatable frequency range is limited according to the motor size. For example, 4-pole 132-frame motor or smaller (SF-JR7.5kW or lower) can run at up to 120Hz. Motors of 160 and 180 frames (11kW to 30kW) can run at up to 100Hz. Motors of 200 and 225 frames (37kW to 55kW) can run at up to 65Hz. This limitation is imposed by the permissible speed of the bearing and the motor structure strength.

2.8 V/F Pattern and Torque Boost

2.8.1 Fundamental equivalent circuit of motor

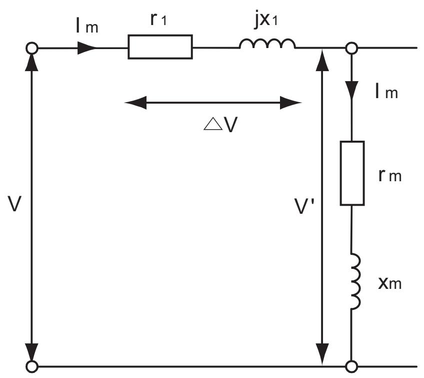
In order to understand torque boost, first the fundamental equivalent circuit of motor is described. Fig.2.11 is an equivalent circuit which is generally used for a motor.



V: Primary voltage
V': Primary induced voltage
I_1: Primary current
I_2: Secondary current (primary converted value)
r_1: Primary resistance
r_2: Secondary resistance (primary converted value)
r_m: Iron loss resistance
x_m: Excitation reactance
x_1: Primary magnetic leakage reactance
x_2: Secondary leakage reactance
S: Slip

Fig.2.11 Equivalent circuit of motor

The equivalent circuit of a motor operating without a load, and with the circuit open on the secondary side is shown in Fig.2.12.



Im: Excitation current

Fig.2.12 Equivalent circuit (secondary open without load)

Voltage equation is shown in Formula (2.6).

$V' = V - (-jI_m)(r_1 + jx_1)$ .... (2.6)

If it is replaced with ΔV = (-jIm)(r1 + jx1), the formula can be simplified as shown in Formula (2.7).

$V' = V - \Delta V$ .... (2.7)

The motor generated torque is affected by the primary resistance and primary leak reactance inside the motor or the voltage drop caused by the cable impedance of the motor wiring.

2.8.2 Torque boost

The output voltage of the inverter must be V/F = Constant at the base frequency or lower as shown in Section 2.6.3 (Fig.2.13). However, the primary coil of the motor includes the amounts of resistance and reactance (collectively called impedance) as shown in the equivalent circuit of Fig.2.11, and the torque generated by the motor decreases due to the voltage drop caused by the impedance.
A standard motor is designed with a coil in consideration for the amount of the voltage drop at 50Hz or 60Hz.
When a standard motor is operated with an inverter, the voltage varies in proportion to the change of the output frequency f. Especially the voltage drop is large in the low-frequency range with low voltage, and the motor generated torque is extremely small compared to the one with the commercial power supply. Therefore, the decrease of the motor output torque is suppressed in the low-frequency range by increasing the voltage in the amount of ΔV in Formula (2.7) to balance with the voltage drop.
As shown in Fig.2.14, the compensation of the voltage in the amount of ΔV is called torque boost.

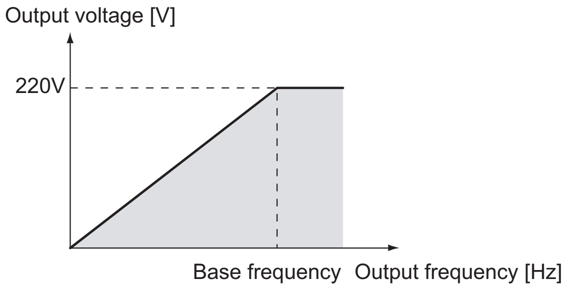


Fig.2.13 V/F pattern of standard motor (without torque boost)

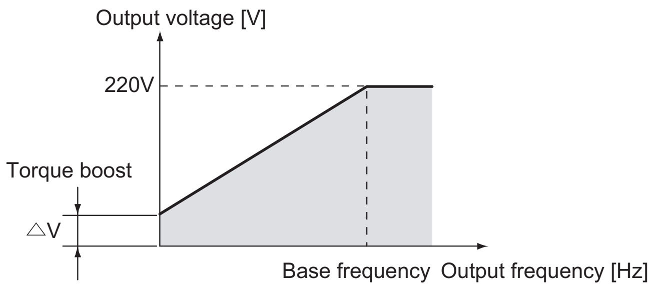


Fig.2.14 V/F pattern of standard motor (with torque boost)

The manual torque boost is as shown in Fig.2.15.

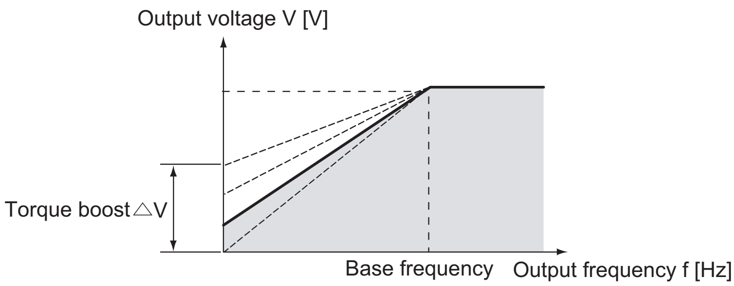


Fig.2.15 Torque boost

The increase of the voltage is constant by the output frequency f. (It is not relevant to the motor current.)

2.8.3 Torque boost setting

When the large start torque or acceleration torque is necessary, the motor torque of about 100 to 150% can be generated in the low frequency area by adjusting the torque boost.

(1) The standard torque boost (factory setting) is adjusted to the characteristics of the standard motor.
(For a specialized motor where the motor coil specifications are different, it may be better to adjust the torque boost.)

(2) If the torque boost is increased too much under light load, the current becomes very large and the inverter may trip due to the overcurrent.

(3) For constant operation under light load, motor efficiency is improved by reducing the torque boost. (Refer to Section 2.9 Reduced-torque load pattern.)

(4) Likewise, the torque boost adjustment is effective against the voltage drop due to the cable between the standard motor and the inverter.

The relationship between the motor torque and the current when the voltage is increased by the torque boost is shown in Fig.2.16.
Since the inverter drive provides the stall prevention function (limiting at 150% of the rated current), the maximum value of the start torque is determined within the current range.
Setting the torque boost setting too high will cause the output current to exceed the stall prevention activation level and trigger the overcurrent protection function.

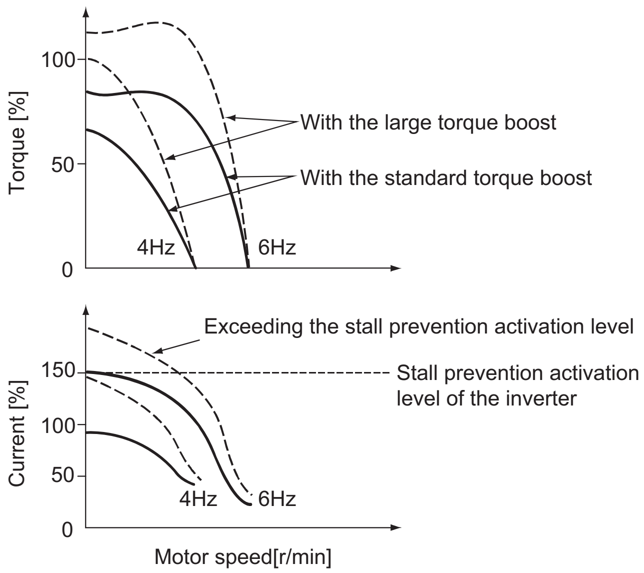


Fig.2.16 Example of motor torque and current at a start

When the torque boost setting value is increased, the change of the current for each load condition is as described below.

1) For the light load…… Since the magnetic flux of the motor iron core is saturated, the current increases and the overcurrent protection function can be activated more easily.

2) For the heavy load… With the torque boost, the amount of the voltage drop caused by the motor's primary coil and cable is compensated, and the large motor torque is generated. This reduces the motor slip, and the current decreases compared to that for the light load.

☒ Useful information

The inverter dedicated constant torque motor is a motor specially designed for the continuous use with 100% torque at low speed. When the motor must be used under light load, the motor current may exceed the rated motor current in the low-frequency range. Therefore, use the motor with reduced torque boost.

Example
How does the motor current change if the torque boost setting value of the inverter is increased? Although it differs depending on the load condition (light load or heavy load), the motor current increases by increasing the torque boost and the large start torque is generated. During the acceleration under heavy load, the motor slip decreases when the torque is increased. As a result, the average current during the acceleration can be suppressed. Setting the value too high activates the overcurrent protection function because the motor current at start exceeds the stall prevention activation level.

2.9 Load Torque Types and V/F Patterns

The load torque characteristics vary depending on applications. The following shows the typical examples and the V/F patterns to be applied.
For the inverter operation, the V/F characteristics according to the load characteristics can be selected.

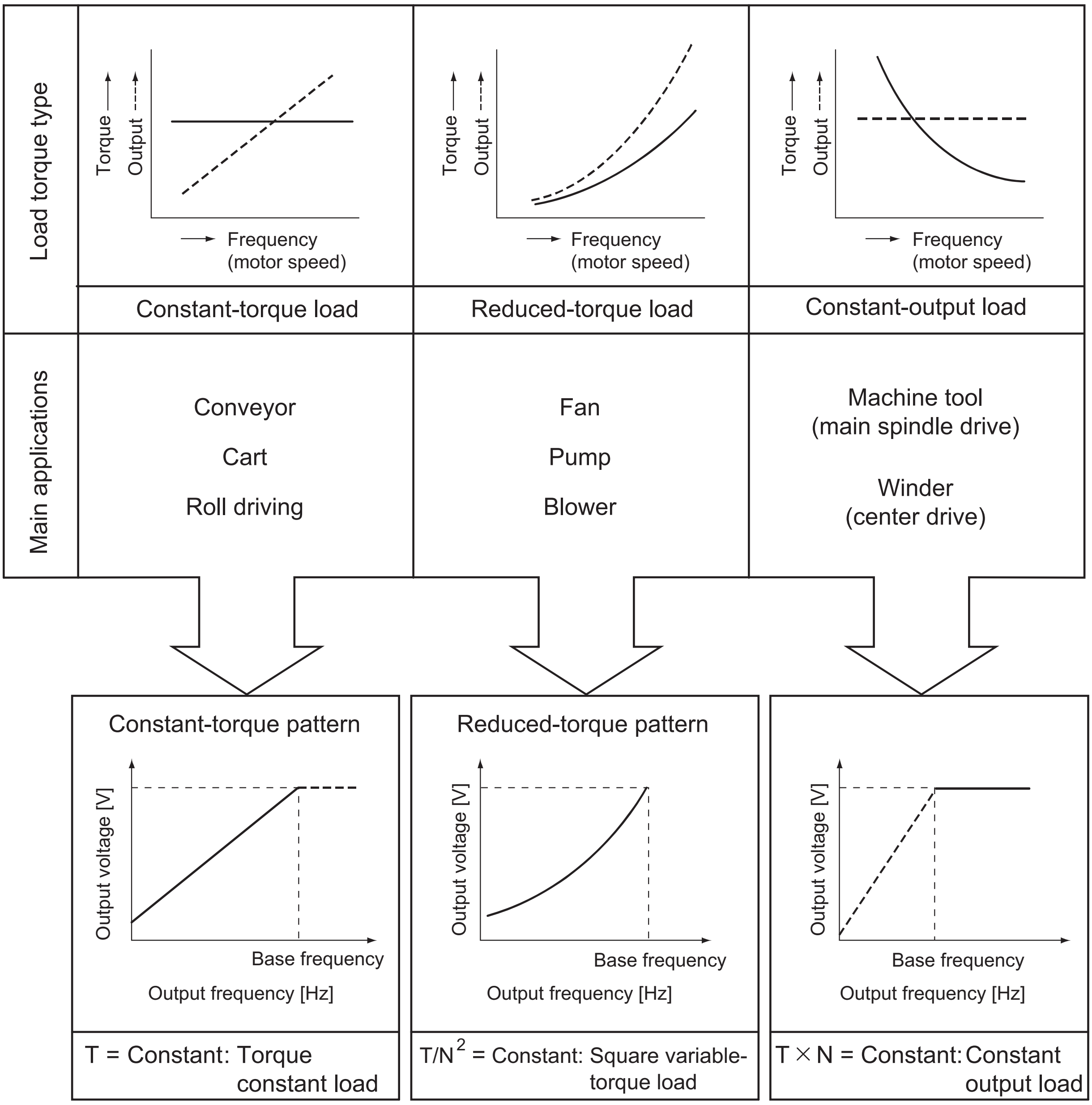


Fig.2.17 Load torque types and V/F patterns

Useful information

When the reduced-torque load is operated, the V/F pattern of the constant torque can be used for the operation. However, the reduced-torque pattern is more efficient, and saves energy. (Refer to page 76 for the details.)

2.10 Acceleration/Deceleration Time and Inertia Moment J

2.10.1 Acceleration/deceleration time

The acceleration/deceleration time differs for commercial operation and inverter operation as shown below.

Acceleration/Deceleration time / Operation	Acceleration time	Deceleration time
Commercial operation	$ta = \dfrac{\text{Entire } J \times N}{9.55 \times \{T_M \times (1.5 \text{ to } 2) - T_L\}}$ [s] N: Rated motor speed [r/min] T_M: Rated motor torque [N·m] T_L: Load torque [N·m]	$td = \dfrac{\text{Entire } J \times N}{9.55 \times T_L}$ [s] N: Rated motor speed [r/min] T_L: Load torque [N·m]
Inverter operation	$ta = \dfrac{\text{Entire } J \times \Delta N}{9.55 \times (T_M \times \alpha - T_L)}$ [s] ΔN: Difference of the motor speed before and after acceleration [r/min] T_L: Maximum load torque [N·m] α: Average acceleration torque coefficient (Approximately 1.1 boost standard)	$td = \dfrac{\text{Entire } J \times \Delta N}{9.55 \times (T_M \times \beta + T_L)}$ [s] ΔN: Difference of the motor speed before and after deceleration [r/min] T_L: Minimum load torque [N·m] β: Average deceleration torque coefficient (Regenerative control torque coefficient)
	Entire J = Motor J_M + Load J_L [kg·m^2]	

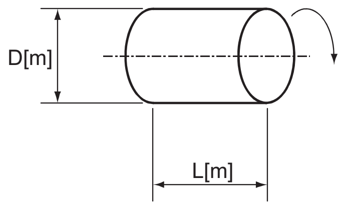
(1) Because of the different average acceleration torque coefficients, the acceleration time is shorter for the commercial operation.

(2) The motor coasts to stop for the commercial operation, whereas the motor stops with the regenerative brake activated for the inverter operation. Therefore, the deceleration (stop) time for the inverter operation is significantly shorter compared to that for the commercial operation. To suddenly stop the motor for the commercial operation, the mechanical brake is used. Alternatively, the DC dynamic brake or the electric brake method by reversed-phase braking is adopted.

2.10.2 Inertia moment J

(1) The inertia moment J is a numerical value of an object's inertia. A heavy object with a large diameter has a large inertia, and a light object has a small inertia.

(2) How to calculate the inertia moment J of a rotator



$$J = \frac{1}{8} \times W \times D^2 = \frac{\pi}{32} \times \rho \times L \times D^4 \text{ [kg·m}^2\text{]}$$

W: Weight [kg]
ρ: Gravity [kg/m^3]

Examples of the gravity	
Aluminum	······ 2.7×10^3
Iron	······ 7.8×10^3
Cast iron	······ 7.2×10^3

(3) For the calculation of the acceleration/deceleration time, the load inertia moment (J_L) must be converted to the motor shaft.
Motor shaft conversion $J = J_L \times i^2$ (i = Deceleration ratio)

(4) The load with large inertia moment J takes time to accelerate or decelerate. Therefore, a large motor torque is required to accelerate or decelerate in a short time.

(5) The conversion formula of the inertia moment J and GD^2 is expressed with the following formula.
J [kg·m^2] = (1/4) $\times$ GD^2 [kgf·m^2]

Chapter 3 INVERTER PRINCIPLES AND ACCELERATION/ DECELERATION CHARACTERISTICS

This chapter describes how the basic circuits in an inverter operate to create variable frequency and variable voltage. These frequency and voltage are output from an inverter to a standard motor to change the motor speed.
An inverter can be thought of as a power supply converter (converts from constant frequency/voltage to variable frequency/voltage) for standard motors. Although an inverter is powered from a commercial power supply, a waveform of the input current is different from that of a sine wave. Furthermore, the output waveform greatly differs from this input waveform. This unique waveform, which is generated due to the operation principle of an inverter, is highly relevant to the choice of a standard motor/peripheral devices and to the measurement of current/voltage. For this reason, it is important to understand how the distinctive waveform correlates to the operation of each circuit in an inverter.

POINTS for understanding !

1. Principle of creating the output waveform (variable voltage/variable frequency)
2. Operation flow from start to stop
3. Concept of the inverter power factor

3.1 Configuration of Inverter

Fig.3.1 shows the configuration of a general-purpose inverter, which uses a commercial power supply (AC 50Hz or 60Hz) to create an AC power supply that generates various, needed frequencies to rotate a motor at various speeds. More precisely, a general-purpose inverter consists of two significant sections, the main circuit and the control circuit. The main circuit is subdivided into the converter part, which converts a current from a commercial power supply to DC and then smoothes pulsation included in the converted DC, and the inverter part, which converts the smoothed DC to AC with variable frequency. The control circuit controls the main circuit.

Basically, a converter refers to a unit that performs forward conversion from AC to DC whereas an inverter refers to a unit that performs reverse conversion from DC to AC. However, with general-purpose inverters, the whole unit including the converter is referred to as an inverter.

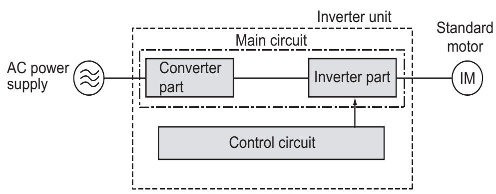


Fig.3.1 Configuration of inverter

As described above, the main circuit part in an inverter consists of two power supply converting units that are largely different from each other in elements and characteristics. The next section describes the individual operation principles of the inverter part and converter part.

3.2 Converter Operation

The converter part consists of the following parts as Fig.3.2 shows:
1) Converter
2) Smoothing capacitor
3) Inrush current control circuit

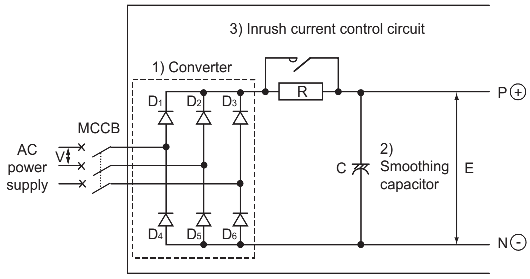


Fig.3.2 Converter part

(1) Principle of converter

A converter is a device to create DC from AC power supply. See the basic principle with the single-phase AC as the simplest example.
Fig. 3.4. shows the example of the method to convert AC to DC by utilizing a resistor for the load in place of a smoothing capacitor.
A diode is used as the element. This diode lets the current flow or not flow depending on the direction to which the voltage is applied as Fig.3.3 shows.

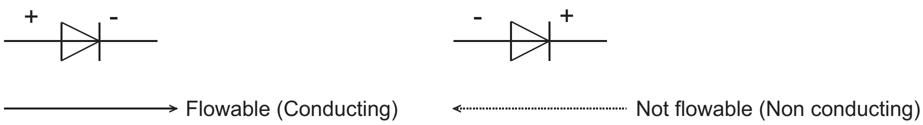


Fig.3.3 Diode

This diode nature allows the following: When the AC voltage is applied between A and B of the circuit shown in Fig.3.4, the voltage is always applied to the load in the same direction shown in Table 3.1.
That is to say, the AC is converted to the DC.
(To convert the AC to the DC is generally called rectification.)

Table 3.1 Voltage applied to the load

AC voltage	AC flowing direction	Voltage applied to load
	Direction of solid line	Same direction
	Direction of dotted line	

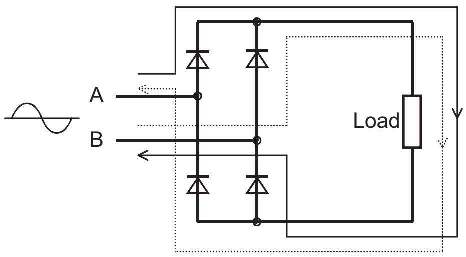


Fig.3.4 Rectifying circuit

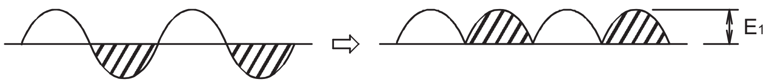


Fig.3.5 (Continuous waveforms of those in Table 3.1)

For the three-phase AC input, combining six diodes to rectify all the waves of the AC power supply allows the output voltage as shown in Fig.3.6.

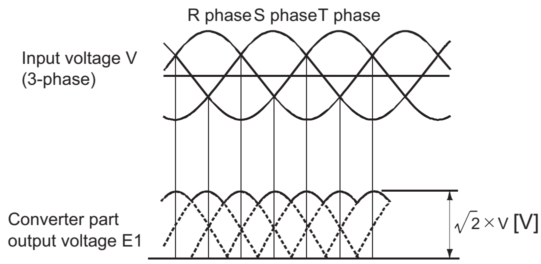


Fig.3.6 Converter part waveform

The principle of rectification is explained with a resistor. However, a smoothing capacitor is actually used for the load. If a smoothing capacitor is used, the input current waveforms are not sine waveforms but distorted waveforms shown in Fig.3.7 since the input current flows only when the AC voltage surpasses the DC voltage.

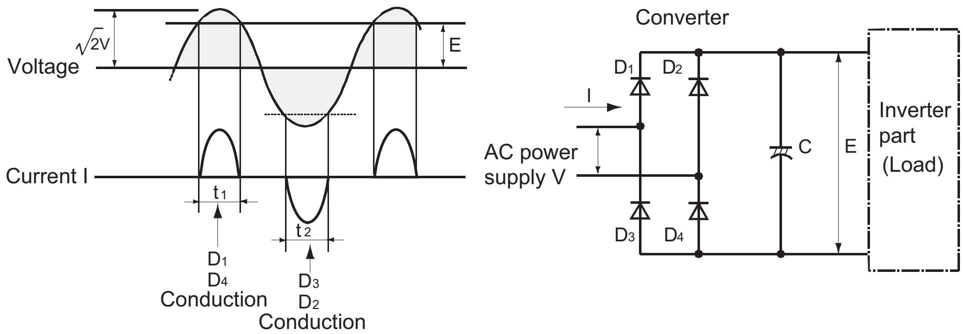


Fig.3.7 Principle of converter

(2) AC input current in normal status (during motor operation)

When three-phase AC inputs are rectified with six diodes as shown in Fig.3.2, these diodes are conducted in the timings shown in Fig.3.8. Input current waveform is distorted in the same manner as for a single-phase power supply.

The diode-rectified waveforms of all the three phases are further smoothed to DC with less pulsation by the smoothing capacitor C.

When the inverter is stopped, the DC voltage can be up to $\sqrt{2}$ times larger (approx. 280VDC with 200VAC) than the AC input voltage.

Note that while an inverter is in operation, the DC voltage slightly fluctuates depending on the output (torque/rotation speed).

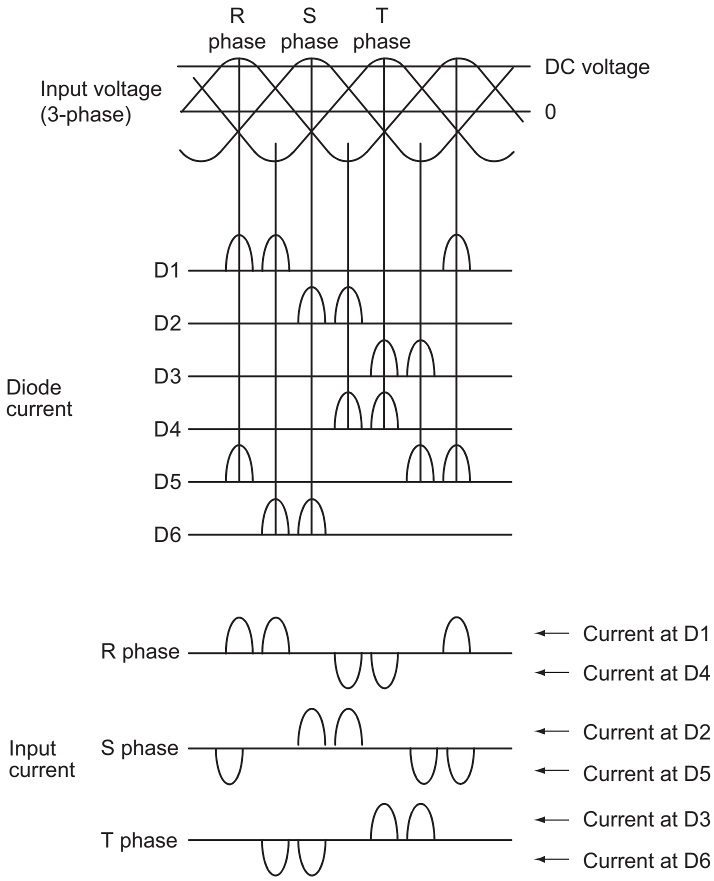


Fig.3.8 Principle of input current

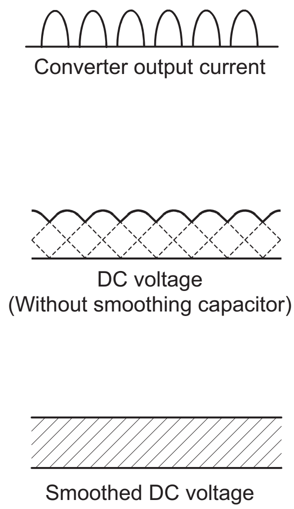


Fig.3.9 DC smoothed waveform

Useful information

When the three-phase AC input voltage becomes imbalanced, the AC input current may become significantly imbalanced.

This is most likely to happen when a light load is used with a large DC bus voltage. A phase may open in an extreme case, however this is not an error of the inverter.

As the three phases of the inverter input current become imbalanced, compare the currents in all the three phases when measuring. To measure the DC bus voltage, measure the inverter terminals P-N with a tester.

Be careful when measuring the DC bus voltage for 400V (200V) inverters. The DC bus voltage can be up to 800VDC (400VDC).

(3) AC input current at power on

When an inverter is powered on, a large inrush current flows for charging a smoothing capacitor. To control the peak value of the inrush current, use the control resistor shown in Fig.3.10.

After the smoothing capacitor is charged, short both ends of the control resistor with a relay, etc.

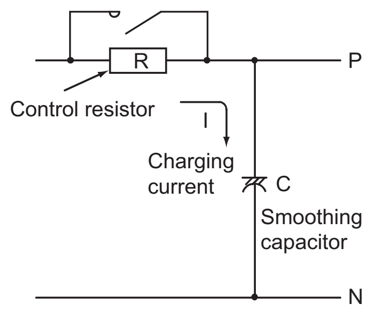


Fig.3.10 Inrush DC control resistor

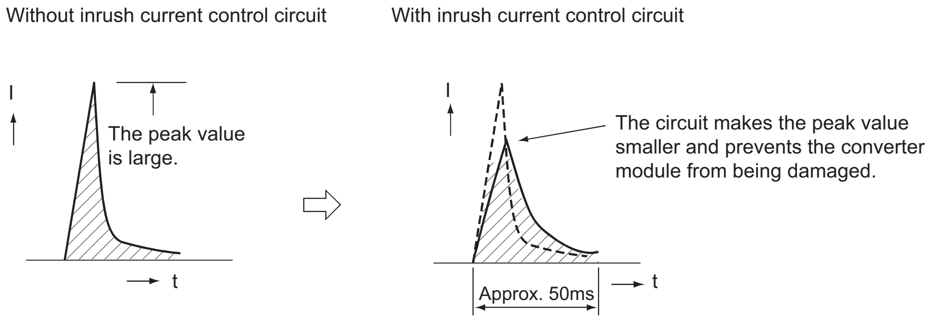


Fig.3.11 Inrush current

Do not switch an inverter between on and off too often with a magnetic contactor (MC), etc. Doing so lets the peak current to flow to the converter every time the inverter is switched, shortening the lives of the diodes. It may also shorten a switching life of the inrush current control circuit, and therefore the number of switching times should be limited within several times a day.

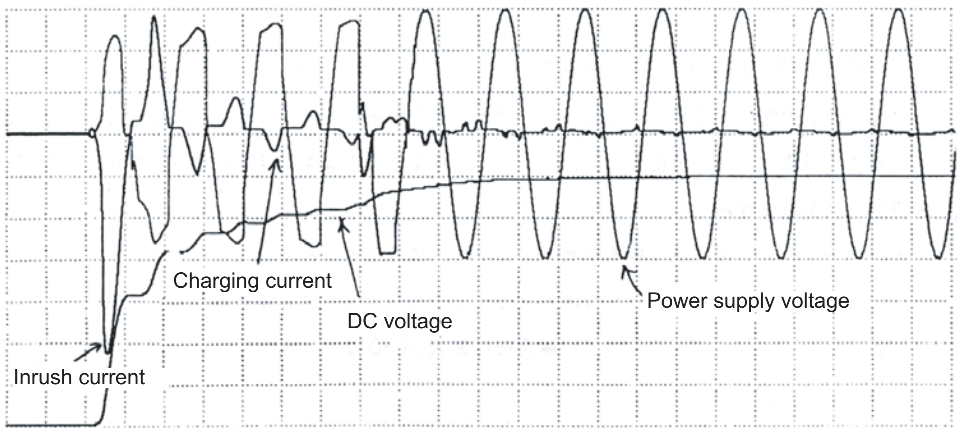


Fig.3.12 Actual measurement example of inverter input current/voltage waveform

3.3 Principle of Inverter

(1) Method to create AC from DC

An inverter is a device to create the AC from the DC power supply. See the basic principle with the single-phase DC as the simplest example.

Fig.3.13 shows the example of the method to convert DC to AC by utilizing a lamp for the load in place of a motor.

If the four switches S1 to S4, which are connected to DC power supply, are alternately turned on/off, AC is created as shown in Fig.3.14.

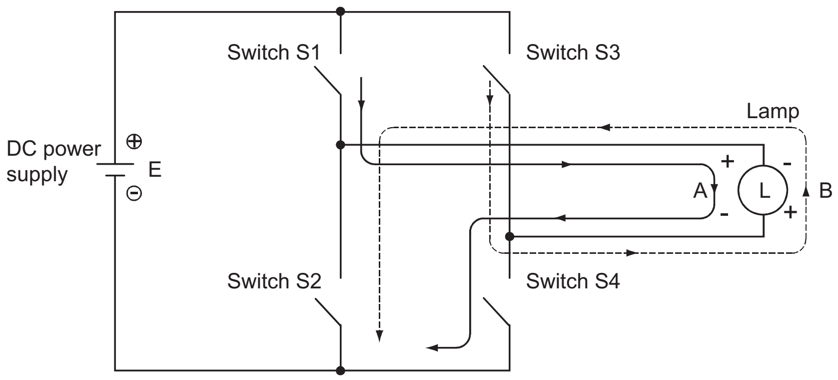


Fig.3.13 Creating AC

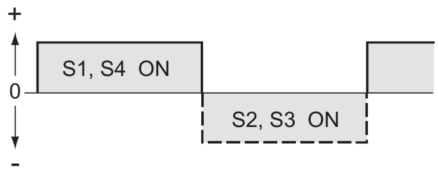


Fig.3.14 Current waveform

- When the switches S1 and S4 are turned on, the current flows in the lamp L in the arrow A direction.
- When the switches S2 and S3 are turned on, the current flows in the lamp L in the arrow B direction.

  Therefore, if the switches are alternately turned on/off with the combinations of the switches S1 and S4 and the switches S2 and S3, AC is created since the direction of the current flowing in the lamp L alters.

(2) Method to change frequency

The frequency is changed by changing the period to turn on and off the switches.

For example, if the switches S1 and S4 are turned on for 0.5 second and S2 and S3 for 0.5 second and this operation is repeated, the AC with one alternation per second, i.e., the AC with a frequency of 1Hz is created.

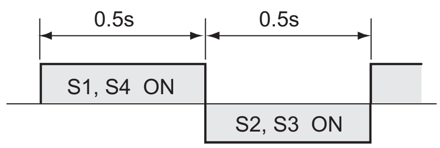


Fig.3.15 1Hz AC waveform

Generally, under the condition that S1/S4 and S2/S3 are turned on for the same period of time and that the total time of one cycle is t_0 seconds, the frequency f can be obtained as follows:

$$f = \frac{1}{t_0} \text{ [Hz]}$$

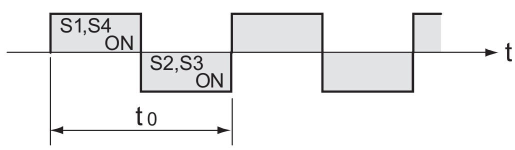


Fig.3.16 Frequency

(3) Methods to change AC voltage

The voltage changes by turning ON and OFF the switches with a shorter period.
For example, if the switches S1 and S4 are turned ON for the half period, the average output voltage is E/2, half of the DC voltage E.
To obtain a higher voltage, turn ON for the longer period. To obtain a lower voltage, turn ON for the shorter period.

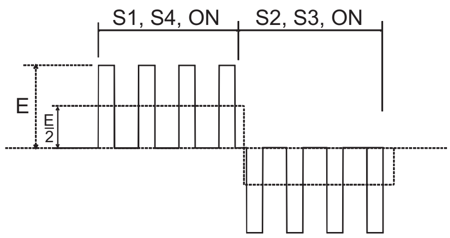


Fig.3.17 Voltage waveform of E/2

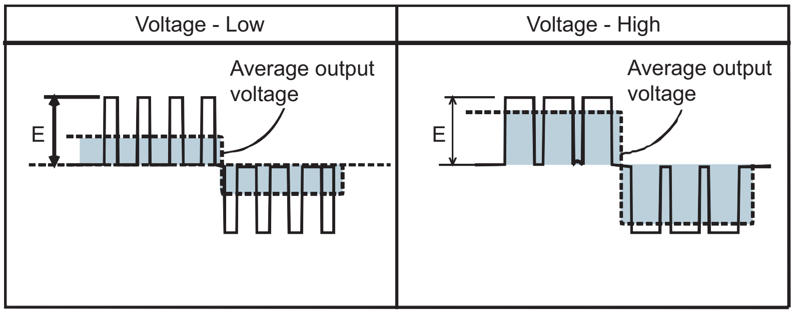


Fig.3.18 Method to change voltage

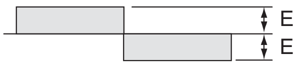
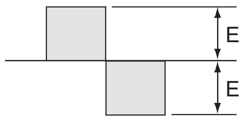
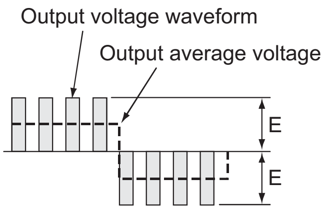
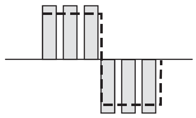
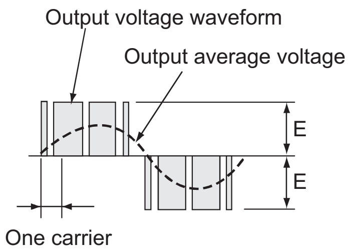
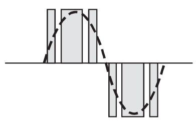
The control system of general-purpose inverters is referred to as "voltage source" system since the inverter part is their voltage source. The voltage source system is subclassified into the following types in accordance with the voltage change method.

- Voltage source ······ System to control the voltage applied to a motor
  - PAM system ····· System to change the DC voltage
  - PWM system ····· System to change the switching pulse width of a transistor
    - Sine wave approximation PWM system ····· System to change the switching pulse width of a transistor so that the shape of an output average voltage waveform approaches the shape of a sine waveform

Differences between these control systems affect the standard motor characteristics (vibration, noise, torque ripple, motor current ripple, torque response level, etc.). (Refer to Table 3.2)

Table 3.2 Control systems for voltage source inverters

(E: DC voltage)

Control system	Output frequency-Low (low voltage)	Output frequency-High (high voltage)	Characteristics
PAM system Pulse Amplitude Modulation			•Low standard motor noises •Low noise •High efficiency •Converter is required for voltage control. •Slow response •Smooth operation not possible at low speed •Rarely used anymore.
PWM system Pulse Width Modulation			•Frequency/voltage control by the inverter part alone •High frequency noises from a standard motor
Sine wave approximation PWM system			•Smooth operation at low speed •Lower cost than PAM •Low-degree high-frequency is less. •High frequency noises from a standard motor

The PWM system is a system that changes the output voltage by generating switching pulses within one cycle and changing the pulse width. The sine wave approximation PWM system is a system that makes the average output voltage the shape of a sine wave by changing the switching pulse width within one carrier. Most of general-purpose inverters use the sine wave approximation PWM system. The number of switching pulses generated per second is referred to as carrier frequency.
With the PWM system, the frequency components of the generated motor vibration and motor noise are proportional to the carrier frequency.
When the carrier frequency is high, the high-carrier frequency PWM control is used. The high carrier frequency is higher than the human audible frequency range (20Hz to 20,000Hz). Therefore the electromagnetic noises are hardly heard from a motor, realizing the low noise rotation. However, transistors used in the inverter part are normally limited for use at approximately up to 2kHz. For this reason, recently IGBTs (Insulated Gate Bipolar Transistor) are used more commonly.
Also, Soft-PWM control is used to suppress the carrier frequency and disperse the motor's magnetic noise components. With this, noise generation is suppressed, and the motor's magnetic noise is reduced.

Useful information

- If a machine generates large vibrations and noises only within a specific motor speed range, the cause may be a resonance with the carrier frequency. With the Mitsubishi Electric general-purpose inverter FR-A800 series, these vibrations and noises may be reduced by changing the carrier frequency pattern (E600(Pr. 72) PWM frequency selection). Also note that doing so changes the motor noise sound.
- Lower noise operation may result in a larger leakage current between the inverter and the motor. Pay attention when selecting an earth leakage current breaker and be careful when earthing (grounding). Noise is also likely to increase.

(4) Three-phase AC

Fig.3.19 shows the basic circuit of a three-phase inverter.

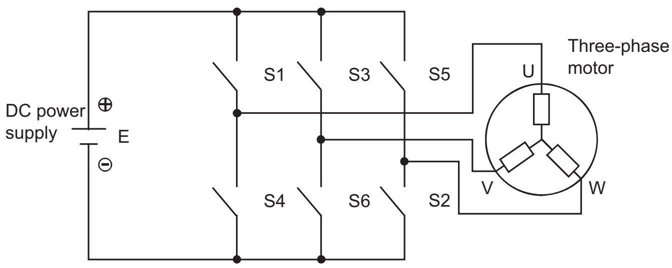


Fig.3.19 Three-phase inverter basic circuit

Turn on/off the switches S1 to S6 in the order shown in Fig.3.20. Doing so obtains pulse waveforms at sections U-V, V-W and W-U in the same cycle, and applies AC voltage in a rectangular waveform to a motor.
Changing the on/off cycles of the switches outputs a needed frequency to a standard motor, and changing the DC voltage E changes the input voltage at the same time.

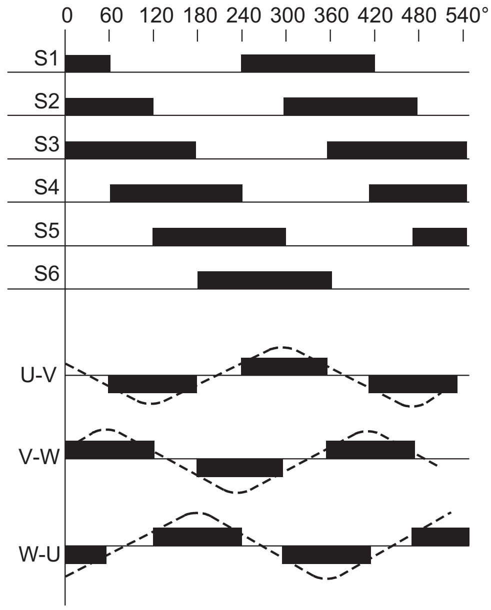


Fig.3.20 Method to create three-phase AC

(5) Configuration of inverter part

Instead of switches, six transistors are used as shown in the configuration of Fig.3.21. The connected motor is a standard motor, and this motor is rotated by turning the transistors on/off alternately.
To change the motor rotation direction, change the order that the transistors are turned on/off.

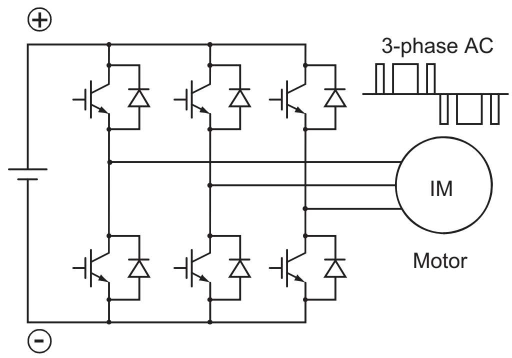


Fig.3.21 Transistor inverter

Useful information

If an AC power supply is applied to the output terminals of the inverter part, an inrush current flows for charging the smoothing capacitor C through the diodes that are connected in parallel with the transistors, as mentioned in Fig.3.11. In this example, control resistors are not installed in the circuit on the transistors side and therefore the diodes of the transistor section will be damaged. Never connect the power supply to the output terminals U, V and W of the inverter.

(6) Role of transistors

A transistor is composed of three terminals, a collector (C), emitter (E) and base (B) (substituted by a gate (G) in IGBT.). The line C-E is not conducted (switched off) when a base signal is off, and conducted (switched on) when a current is applied to the base. In other words, transistors function as the switch S (ON-OFF) with faster operation.

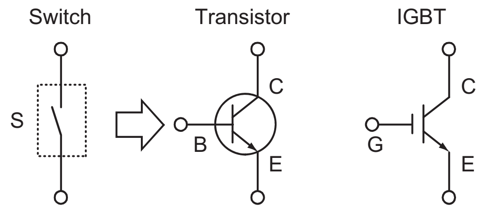


Fig.3.22 Transistor

To turn off this base signal (substituted by a gate signal in IGBT.) is referred to as "transistor base shut-off", which appears in the explanation for the protective function of the inverter. When the transistor base shut-off is performed, the six transistors are turned off simultaneously, disconnecting the inverter from the motor. In other words, the motor coasts to stop.

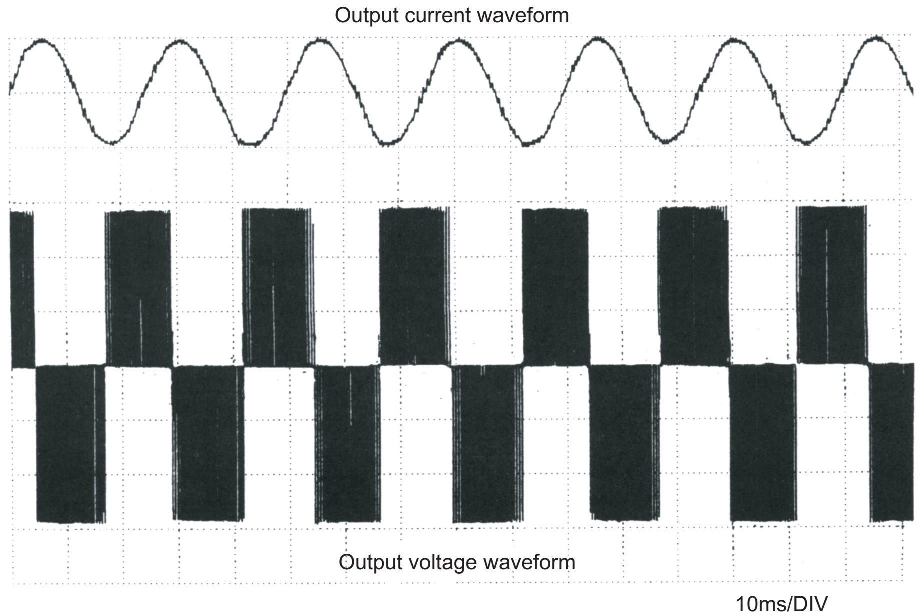


Fig.3.23 Measurement example of the inverter FR-A800 series output current/voltage waveform (at 40Hz)

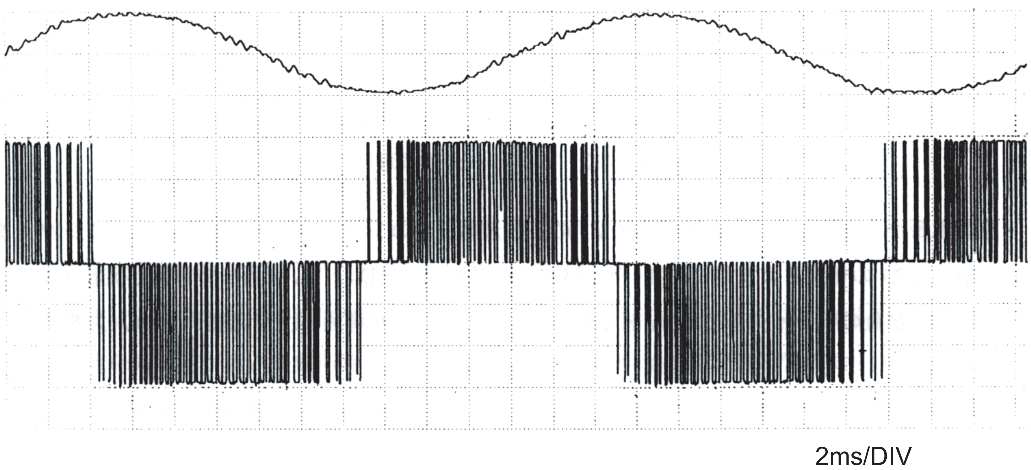
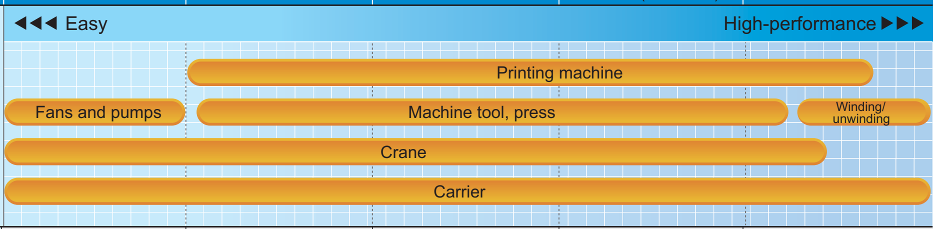


Fig.3.24 Measurement example of the inverter FR-A800 series output current/voltage waveform (500% of Fig 3.23) (at carrier frequency 2kHz)

3.4 Inverter Control Systems and Auto Tuning Function

Inverters offer several control methods.
FR-A800 series inverters offer five different control methods to support a wide range of applications.
The following sections are described mainly based on FR-A800 series parameters.



	V/F	Advanced magnetic flux vector	Real sensorless vector	PM sensorless Vector (PM motor)	Vector（FR-A8AP）
Speed control	○	○	○	○ (zero speed control, servo lock, high frequency superposition control)	○ (zero speed control, servo lock)
Torque control	×	×	○	×	○
Position control	×	×	×	○ (high frequency superposition control)	○
Speed control range	1 : 10 (6 to 60Hz : power driving)	1 : 120 (0.5 to 60Hz : power driving)	1 : 200 (0.3 to 60Hz : power driving)	1 : 1000 (high frequency superposition control) 1 : 10 (current synchronization operation)	1:1500 (1 to 1500r/min: Both driving/regeneration)
Speed response	10 to 20rad/s	20 to 30rad/s	314rad/s(50Hz)	200rad/s(32Hz)	816rad/s(130Hz)
Applied motor	standard motor (without encoder)	standard motor (without encoder)	standard motor (without encoder)	PM motor (without PLG)	standard motor (with encoder) Vector control dedicated motor

3.4.1 V/F control

With conventional general-purpose inverters, when f (frequency) is changed, V (output voltage) is changed in the constant ratio (V/f) as shown by the dotted line in the figure below.
For this reason, this system is called V/F control.

In this system, the voltage that is actually valid decreases due to a voltage drop in the wiring or the primary coil of a motor, and a sufficient amount of torque cannot be output.
The slower the speed is, the more this phenomenon takes effect.
(Low-speed torque becomes insufficient.)

Therefore, the amount of voltage drop estimated in advance is set higher (torque boost *) as indicated with the solid line in the figure to cover the shortage of the torque at low speed.

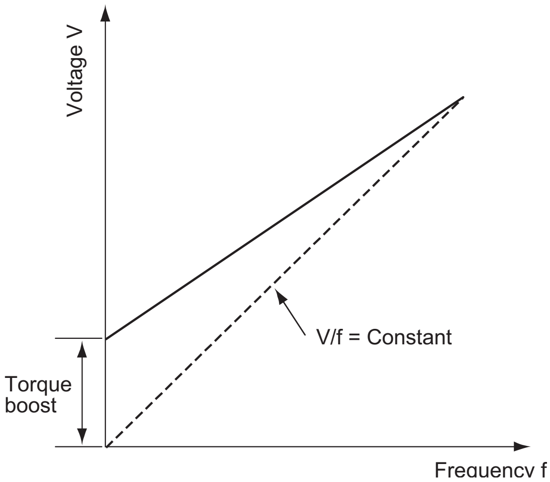


Fig.3.25 V/F control

* As described in Section 2.8.3, when the torque boost is increased too much, the sufficient torque is provided securely. However, it may cause overcurrent to be generated, and the inverter is likely to have an OCT (overcurrent) trip.

To solve this, there are other control systems available such as the Real sensorless vector control or Advanced magnetic flux vector control.

3.4.2 General-purpose magnetic flux vector control E800 D700 F700PJ

This control divides the inverter output current into an excitation current and a torque current by vector calculation and compensates frequency and voltage so that a current corresponding with the load torque can flow. By this, the low-speed torque can be improved and a high torque of 200% can be obtained at 6Hz (with 3.7kW or lower).
Even if the motor constant becomes somewhat unstable (due to use with other manufacturer's motors), large, stable low speed torque can be provided without any special settings of a motor constant or tuning. This feature realizes wide versatility.

- Based on the output frequency and each current phase to the output voltage, this control divides the inverter output current (motor current) into an excitation current (a current necessary to generate a magnetic flux) and a torque current (a current proportional to the load torque) by vector calculation.
(Refer to the figure on the right.)

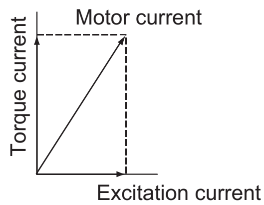


Fig.3.26 General-purpose magnetic flux vector control

- When a standard motor's current is changed due to the load fluctuation, the amount of a voltage drop on the primary side of the motor (including the wiring) is changed. This affects the amount of the excitation current.
The amount of the voltage drop is calculated from the standard motor and primary wiring constants and the magnitude of the torque current. By this, the output voltage from the inverter is compensated (increased or decreased) so that the primary magnetic flux of the standard motor stays constant.
- General-purpose magnetic flux vector control can be performed by setting the motor capacity, number of motor poles, and control method. The motor ratings (Mitsubishi Electric motor) are already stored in the inverter.

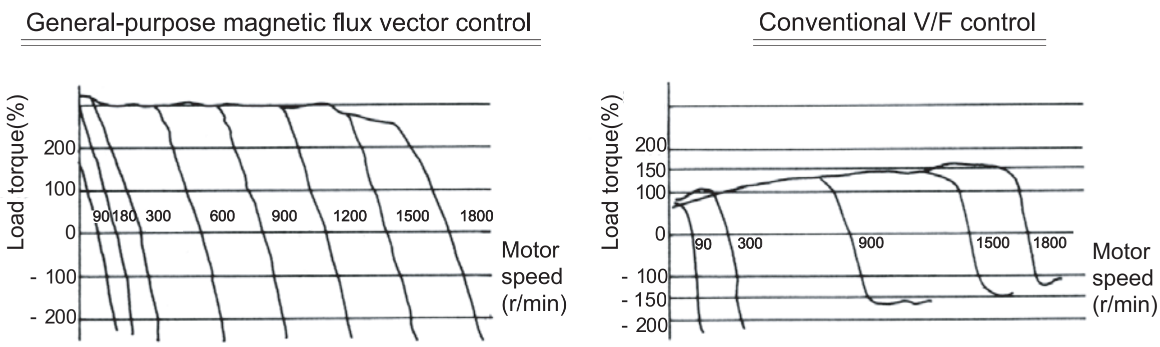


Fig.3.27 Example of speed-torque characteristics during General-purpose magnetic flux vector control of the standard motor 0.75kW4P

3.4.3 Advanced magnetic flux vector control

A800 E700

This control divides the inverter output current into an excitation current and a torque current by vector calculation compensates frequency and voltage so that a current corresponding with the load torque can flow. By this, the low-speed torque and speed control range can be improved, and a high torque of 150% can be obtained at 0.5Hz.

- Based on the output frequency and each current phase to the output voltage, this control divides the inverter output current (motor current) into an excitation current (a current necessary to generate a magnetic flux) and a torque current (a current proportional to the load torque) by vector calculation. (Refer to the figure on the right.)

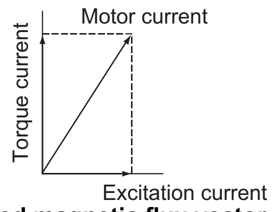


Fig.3.28 Advanced magnetic flux vector control

- The actual motor speed is estimated based on the torque current, and the output frequency is compensated (increased or decreased) so that this estimated speed becomes the preset speed. <<Slip compensation>>
- When a motor current is changed due to the load fluctuation, the amount of a voltage drop on the primary side of the standard motor (including the wiring) is changed. This affects the amount of the excitation current.
  The amount of the voltage drop is calculated from the standard motor and primary wiring constants and the magnitude of the torque current. By this, the output voltage from the inverter is compensated (increased or decreased) so that the primary magnetic flux of the standard motor stays constant.

★ The portions highlighted in gray are the features added to the General-purpose magnetic flux vector control. These additional features allow a large torque to be generated at lower speed. Also, the auto tuning function allows an inverter to measure and store the motor circuit constant. With this feature, the inverter can perform highly accurate calculation and supports wider speed control ranges.

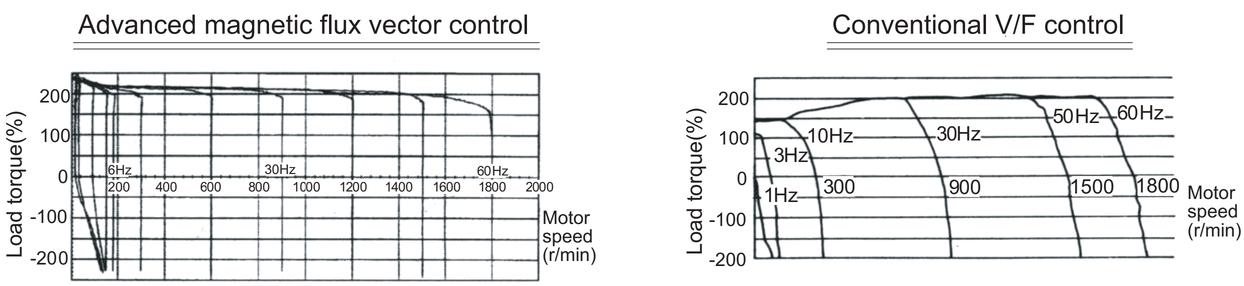


Fig.3.29 Example of speed-torque characteristics during Advanced magnetic flux vector control of the standard motor 3.7kW4P

Item		Advanced magnetic flux vector control	General-purpose magnetic flux vector control
The number of motors in combination use		1:1	1:1
Motor available for combination	Standard motor	Two-pole, four-pole, six-pole	Two-pole, four-pole, six-pole
	Constant torque motor	Four-pole	Four-pole
Encoder		Not required	Not required
Inverter capacity available for combination		Same as or one rank higher than the motor capacity	
Supported model		FR-A800, E700	FR-E700, D700, F700PJ
Speed control range (at driving)		1:120	1:15
Speed control		○	○
Torque control		×	×
Position control		×	×

○: Available ×: Not Available

3.4.4 Real sensorless vector control

A800

This control divides the inverter output current into an excitation current and a torque current by vector calculation and controls frequency and voltage at optimal levels so that a current corresponding with the load torque can flow. By this, the low-speed torque, speed control range and speed response can be improved, and a high torque of up to 200% (3.7kW or less) can be obtained at 0.3Hz.

- This control uses the estimated speed, which is calculated from the motor current and output voltage, as a speed feedback value. Also, this control has the current control loop as the vector control does, which separately allows the calculations for a necessary excitation current (a current necessary to generate a magnetic flux) and a torque current (a current proportional to the load torque).

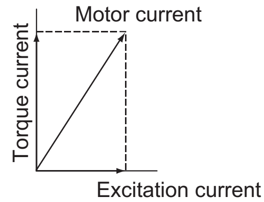


Fig.3.30 Real sensorless vector control

By controlling a torque current, responses to load changes become faster (fast response). Also, by issuing torque commands, the torque control is possible.

★ Using the Real sensorless vector control, high accuracy/fast response speed operation by the vector control can be performed with a standard motor without encoder.

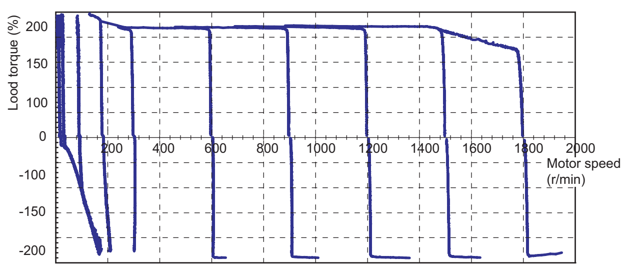


Fig.3.31 Example of speed-torque characteristics during Real sensorless vector control of the standard motor 3.7kW4P

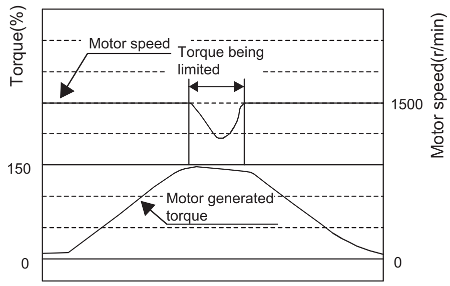


Fig.3.32 Example of torque limit characteristics of the standard motor SF-JR 3.7kW4P

Item		Real sensorless vector control	Advanced magnetic flux vector control
The number of motors in combination use		1:1	1:1
Motor available for combination	Standard motor	Two-pole, four-pole, six-pole	Two-pole, four-pole, six-pole
	Constant torque motor	Four-pole	Four-pole
Encoder		Not required	Not required
Inverter capacity available for combination		Same as or one rank higher than the motor capacity	
Supported model		FR-A800	FR-A800, E700
Speed control range (at driving)		1:200	1:120
Speed control		○ (zero speed)	○
Torque control		○	×
Position control		×	×

○: Available ×: Not Available

☒ Useful information

Real sensorless vector control

Vector control is a system that rotates and controls a dedicated squirrel-cage motor with an encoder or a standard squirrel-cage motor with an encoder in virtually the same manner for rotating and controlling a DC motor.
On the other hand, the Real sensorless vector control is a system developed to rotate a standard squirrel-cage motor in the condition similar to that for the vector control.

Features of the Real sensorless vector control system

(1) In vector control, the motor speed of the rotor is detected by the encoder installed at the shaft end and therefore the motor speed detection can be made accurately. On the other hand, in Real sensorless vector control, the motor speed of the rotor is estimated based on the motor voltage and current. This is why the detection is less accurate, but a standard motor can be used.

(2) Real sensorless vector control is useful "to minimize the speed fluctuation, to obtain low-speed torque, to prevent machine from breaking by excessive torque (torque limit), and to control torque, etc."
Note that with a severe load fluctuation, systems may become unstable for some equipment. In such cases, use the Advanced magnetic flux vector control. Also note that speed cannot be estimated if output frequency is close to 0Hz. To perform torque control in the low speed region or at a low speed with light load, perform the vector control using an encoder.

3.4.5 Vector control

V500 | A800+A8AP

This control detects the motor speed with an encoder and calculates a standard motor's slip to identify the load magnitude.

This control is a system which divides the inverter output current into an excitation current (a current necessary to generate a magnetic flux) and a torque current (a current proportional to the load torque) by vector calculation and controls frequency and voltage at optimal levels so that the necessary current can flow.

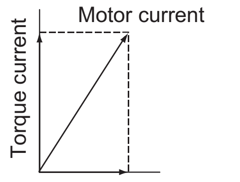


Fig.3.33 Vector control

The vector control has the current control loop, which separately allows the calculations for a necessary excitation current and a torque current.

By controlling a torque current, responses to load changes become faster (fast response). Also, by issuing torque commands, the torque control is possible.

To accurately calculate them, when using the vector control, use a dedicated motor featuring stable constants with an encoder featuring high accuracy.

For the vector control, a standard motor can also be used with an encoder installed on it. However, torque control is less accurate in such case.

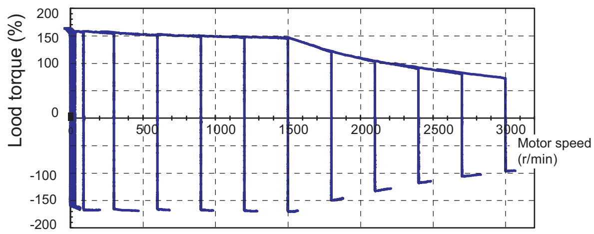


Fig.3.34 Example of speed-torque characteristics of the dedicated motor SF-V5RU H5K

Fig.3.35 Appearance of the vector control dedicated motor (SF-V5RU)

Item	Real sensorless vector control	Vector control
The number of motors in combination use	1:1	1:1
Motor	Standard motor	Dedicated motor, standard motor
Encoder	Not required	Encoder
Inverter capacity available for combination	Same as or one rank higher than the motor capacity (Compatible capacity of FR-A800+A8AP differs by the motor to be connected.)	
Supported model	FR-A800	FR-A800+A8AP, V500
Speed control range (at driving)	1:200	1:1500
Parameter setting	Simple	Not simple (detailed data required)
Response	Fast	Very fast
Speed control	○ (zero speed)	○ (zero speed, servo lock)
Torque control	○	○
Position control	×	○

○: Available ×: Not Available

3.4.6 PM sensorless vector control

A800

The speed and magnetic pole positions are detected and used for controlling the PM motor without a sensor (PLG). Because speed is detected in the inverter, a highly accurate control almost like an AC servo system can be achieved without a sensor (PLG). (Speed fluctuation ratio: ±0.05% (digital input))

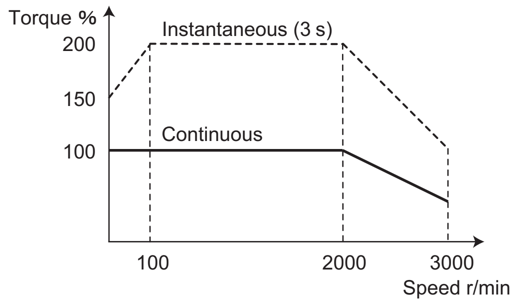
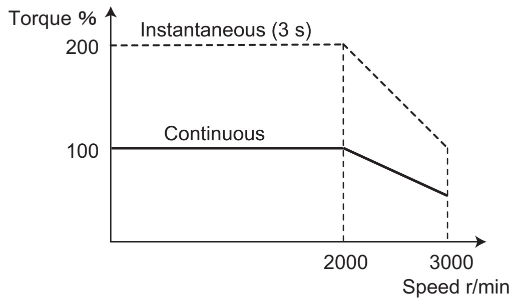
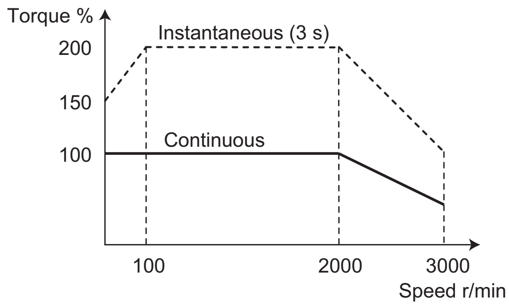
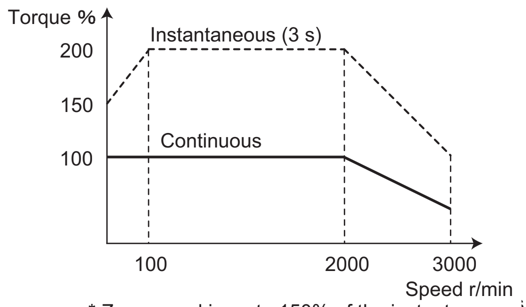
Combining with Mitsubishi Electric MM-CF series IPM motors facilitates aspects of high-level control such as "simple positioning control (200 pulse/rotation)" and "zero speed torque" without a PLG. Performing the IPM parameter initialization makes the IPM motor MM-CF ready for PM sensorless vector control. With A800, the PM motor auto tuning function enables operation of other manufacturers' permanent magnet (PM) motors.

Highly efficient motor control and highly accurate motor speed control can be performed by using the inverter with an IPM (internal permanent magnet) motor, which is more efficient than an induction motor.

Useful information

PM motor auto tuning function function
With FR-A800, the PM motor auto tuning function enables operation of other manufacturers' permanent magnet (PM) motors. In addition to operation of all Mitsubishi Electric induction motors and PM motors being available, the operation of induction motors and PM motors from other manufacturers is also available, meaning the cost of keeping stock for replacement motors can be reduced. (For induction motors and PM motors from other manufacturers, tuning may not be possible depending on its motor characteristics)

Under high frequency superposition control

Motor	Characteristics	For one rank higher capacity
MM-CF 1.5kW or lower		
MM-CF 2.0kW or higher		 * Zero speed is up to 150% of the instantaneous output torque.

Under current synchronization operation

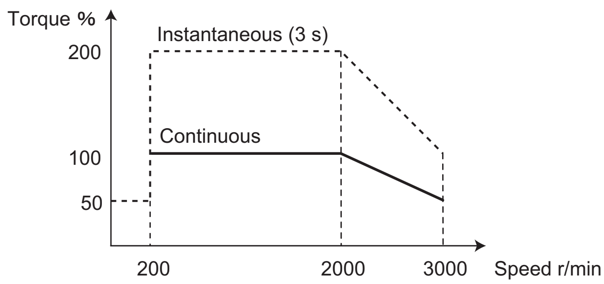
Motor	Characteristics
MM-CF All capacities	

Fig.3.36 Speed-torque characteristics of PM sensorless vector control for the PM motor MM-CF

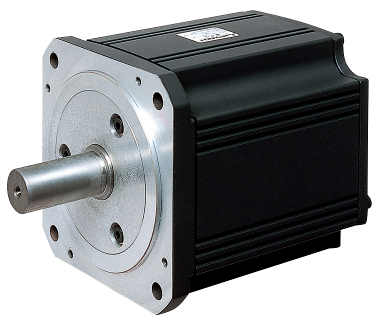
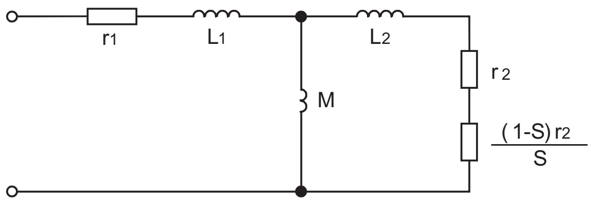


Fig.3.37 External view of PM motor (MM-CF)

Item	PM sensorless vector control	Vector control
The number of motors to be combined	1 : 1	1 : 1
Motor	PM motor	Dedicated motor, standard motor
Encoder	Not required	PLG
Inverter capacity available for combination	Equal to or one rank higher than the motor capacity	Equal to or one rank higher than the motor capacity (Compatible capacity of FR-A800+A8AP differs by the motor to be connected.)
Supported model	FR-A800	FR-A800+A8AP, V500
Speed control range (at driving)	1 : 1000	1 : 1500
Response	○	○
Speed control	○ (Zero speed, servo lock)	○ (Zero speed, servo lock)
Torque control	×	○
Position control	○ (with MM-CF)	○

3.4.7 Offline auto tuning function

With this function, an off-line inverter itself measures and stores motor circuit constants necessary for operating in the Advanced magnetic flux vector control, Real sensorless vector control and vector control.
More precisely, by turning the auto tuning command on, an inverter outputs the motor excitation signal with certain conditions. From values obtained at this time, such as a value of the current that flew, the inverter internally calculates the motor resistance values r_1/r_2, inductance values L_1/L_2/M, etc. and then saves them to the memory.



r_1 : Primary resistance
r_2 : Secondary resistance
L_1 : Primary inductance
L_2 : Secondary inductance
M : Excitation inductance
$\frac{(1-S)\,r_2}{S}$: Mechanical output equivalent resistance

Fig.3.38 Equivalent circuit of an induction motor

- An inverter itself measures the motor constants even with a special motor or other manufacturer's motor. This extends the application range and improves ease of use.
- The accurate measurement of the motor constants allows starting torque and low-speed torque to be improved.
- Wiring lengths of over 30m are supported by the Advanced magnetic flux vector control, Real sensorless vector control and vector control.
- Two types of the off-line auto tuning modes are available (FR-A800 series), and the tuning that matches your machinery can be performed.
  - Simpler and quicker constant measurement without motor rotation
  - More accurate constant measurement with motor rotation
- Online auto tuning (FR-A800 series)
  By quickly tuning the motor status at a start, high-accuracy operation is not affected by motor temperature, and a stable operation with high torque and ultra low speeds becomes possible.

3.4.8 Offline auto tuning function for PM motor

The motor constants necessary for the PM sensorless vector control are calculated automatically, and thus the motor is operated optimally even when motor constants vary or when the wiring distance is long. IPM and SPM motors other than IPM motor MM-CF can also be used.

- The inverter itself measures the motor constant even for the PM motors from other manufacturers, expanding the application range and making it easy to use.
- The PM sensorless vector control can be operated even if the cable length exceeds 30m (maximum 100m).
- The PM sensorless vector control enables easier and faster constant measurement (offline auto tuning) without rotating the motor.

Useful information

PM motor auto tuning function
With FR-A800, the PM motor auto tuning function enables operation of other manufacturers' permanent magnet (PM) motors. In addition to operation of all Mitsubishi Electric induction motors and PM motors being available, the operation of induction motors and PM motors from other manufacturers is also available, meaning the cost of keeping stock for replacement motors can be reduced. (For induction motors and PM motors from other manufacturers, tuning may not be possible depending on its motor characteristics)

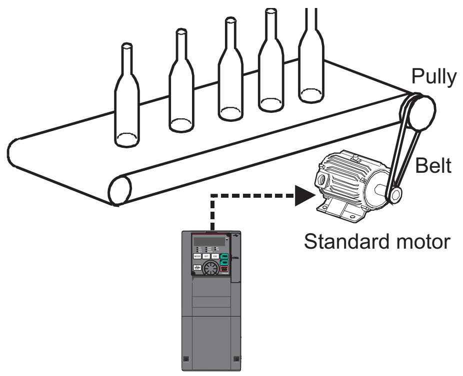
3.5 Control methods

Control methods can be categorized into three types: speed control, position control, and torque control. In speed control, analog voltage is typically used to control rotation speed. In position control, limit switches and high-accuracy encoders are typically used to control rotation amount of a standard motor. In torque control, the current flowing through a standard motor is controlled to output constant torque.
These control methods are further explained in the following section.

3.5.1 Speed control

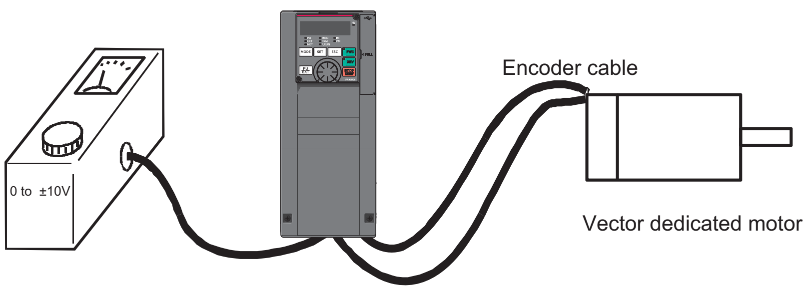
(1) Open loop control

Like general-purpose inverters, this control method does not use speed feedback.
The command system uses an analog voltage command, which is used for many applications such as the conveyor speed control, fan wind amount control, pump flow amount control, etc.
The slip at the rated torque depends on the characteristics of a motor. Approximately 3 to 5% speed fluctuation occurs.
Late model inverters are less affected by temperature drifts due to digital controlling such as speed data being set internally, and setting digital commands (pulse train, parallel data and communication). Advanced magnetic flux vector control, Real sensorless vector control and PM sensorless control can be also used to suppress the speed fluctuation ratio to 1% or less.
This speed control method is used for almost all general-purpose inverters.



(2) Semi-closed loop control

In semi-closed loop control, a detector installed to the motor detects the actual speed and feeds it back to the control circuit. With this, fluctuation of the motor speed is compensated.
Main types of detectors are tacho-generator and encoder. Recently, encoders are used in the majority of cases. For the semi-closed loop control too, the analog voltage or current is used for the speed command. However, inputting pulse trains or using the digital input allows a high accuracy speed control for the draw operation or continuous speed control operation.

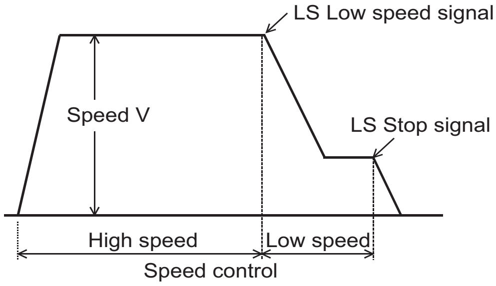


3.5.2 Position control

The position control allows not only the control of the motor speed but also the control to stop at the target stop position. There are many control methods such as the simple method to stop at the target position by taking the external sensor signals into the stop signal, the method to perform a high accuracy positioning with an encoder installed to the motor, and to the advanced method to perform a positioning to continuously-changing target stop positions by tracking or synchronization.

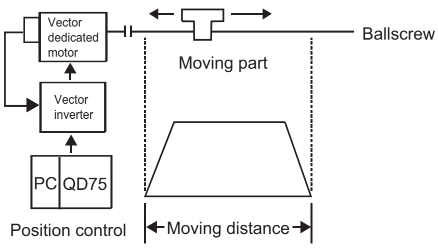
(1) Open loop control

This control is used for the applications that do not need high accuracy for stopping.
The motor decelerates to a stop when it receives the signal from a limit switch set just before the target position.
Fluctuation of inverter's deceleration start points degrades the stop position accuracy. However, being inexpensive, this control method is used for applications that do not require high accuracy.



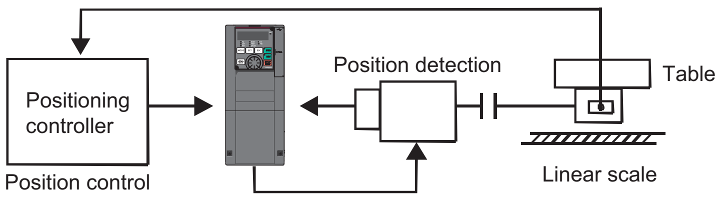
(2) Semi-closed loop control

An encoder installed to a motor performs feedback (Estimated value under PM sensorless vector control). For example, a vector dedicated motor operates for the command input to a vector inverter and the feedback is looped back. At this moment, a command is calculated to zero the difference between the input command amount and the feedback amount for rotating the motor.



(3) Full-closed loop control

This control is performed by the feedback from a linear scale or encoder installed to the machine side.
With an encoder installed to the operating part at the end of the machine, positioning can be performed with high accuracy without being affected by backlashes and machine deviations.
Note that machine structures must be rigid. This control method is used for machine tools, etc, which require highly accurate control.

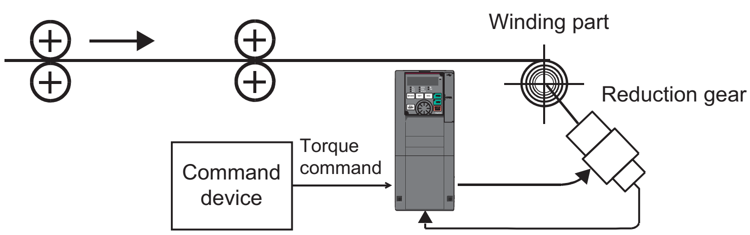


3.5.3 Torque control

In torque control, motor generated torque (current) is controlled. Torque control is different from torque limit. In torque control, torque (current) against a torque command is controlled. When the load torque is small, the speed automatically increases, and when it is large, the speed decreases. When the torque equals the torque command, the speed is maintained. This control method is typically used for winding/unwinding.
Torque limit sets a limit in torque amount. It is used when excessive torque may damage the machine or when brake is applied to a machine directly engaged with a motor (mecha-lock).
For the torque control, the current flowing in the motor must be detected and controlled. Therefore, the torque control is supported by the vector inverter, or the inverter of Real sensorless vector control or Vector control, which perform current detection.

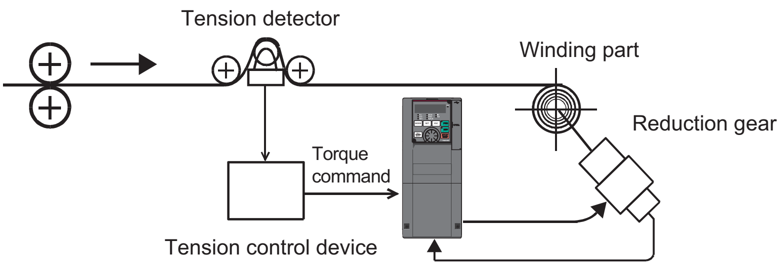
(1) Open loop control

This control is used for the applications that do not require high torque accuracy such as an unwinding or winding axis. The analog command is generally used for the torque command. For this control, it must be taken into account that the torque accuracy varies depending on the temperature (temperature drift) and machine loss.



(2) Closed loop control

This control is used for the applications that require high tension accuracy such as an unwinding or winding axis (for paper, film, etc.).
This control feeds back the tension applied to the actual products to a tension control device.



3.6 Protective Function

3.6.1 Purposes and types of protective functions

An inverter provides various protective functions whose purposes are largely classified into those to "protect the inverter" and those to "protect a motor from overheat". In addition to the protective functions, an inverter is equipped with alarm functions to inform that the operation status is abnormal. The following explanations are made based on the FR-A800 series inverter.

- Protection
  - Inverter protection
    - Overcurrent shut-off
      - During acceleration [E.OC1]
      - At constant speed [E.OC2]
      - During deceleration [E.OC3]
    - Regenerative overvoltage shut-off [E.OV1] [E.OV2] [E.OV3]
    - Output side short (short between cables) [E.OC1] [E.OC2] [E.OC3]
    - Output side earth (ground) fault overcurrent [E.GF]
    - Instantaneous power failure [E.IPF]
    - Undervoltage [E.UVT]
    - Inrush current control circuit fault [E.IOH]
    - Brake transistor alarm detection [E.BE]
    - Overload [E.THT]
    - Heatsink overheat [E.FIN]
  - Motor overheat protection
    - Overload [E.THM] [E.OLT]
    - PTC thermistor operation [E.PTC]
    - External thermal relay operation [E.OHT]
  - Others
    - Plug-in option connection fault [E.OPT] [E.OP1] [E.1 to 3]
    - Storage device fault [E.PE] [E.PE2]
    - Parameter unit disconnection [E.PUE]
    - Retry count excess [E.RET]
    - Output phase loss [E.LF]
    - Input phase loss [E.ILF]
    - CPU fault [E.CPU] [E.5 to 7]
    - 24VDC power output short circuit [E.P24]
    - Operation panel power supply short circuit [E.CTE]
    - Brake sequence fault [E.MB1 to 7]
    - Output current detection value excess [E.CDO]
    - Communication fault [E.SER] [E.USB]
    - Analog input fault [E.AIE]
    - Opposite rotation deceleration fault [E.11]
    - Internal circuit fault [E.13] [E.PBT]
    - Loss of synchronism detection [E.SOT]
    - Safety circuit fault [E.SAF]
    - Overspeed occurrence [E.OS]
    - Speed deviation excess detection [E.OSD]
    - Signal loss detection [E.ECT]
    - Excessive position fault [E.OD]
    - Encoder phase fault [E.EP]
    - 4 mA input fault [E.LCI]
    - Pre-charge fault [E.PCH]
    - PID signal fault [E.PID]
    - User definition error by the PLC function [E.16 to 20]

- Alarms
  - The cooling fan is faulty.
    - Fan fault [FN]
  - The operation status is abnormal.
    - Overcurrent stall prevention (during acceleration, at constant speed, during deceleration) [OL]
    - Overvoltage stall prevention (during deceleration) [oL]
  - Operation stop notification
    - PU stop [PS]
    - Electronic thermal relay pre-alarm [TH]
    - Regenerative brake duty pre-alarm [RB]
    - Safety Stop [SA]
  - Others
    - Error [Err.] [HOLD] [LOCD] [Er1 to 4, 8] [rE1 to 4, rE6 to 8]
    - Maintenance signal output [MT1 to 3]
    - Parameter copy [CP]
    - Speed limit display [SL]
    - USB host error [UF]
    - Home position return error [HP1 to 3]
    - 24 V external power supply operation [EV]

3.6.2 Mechanism of protective functions

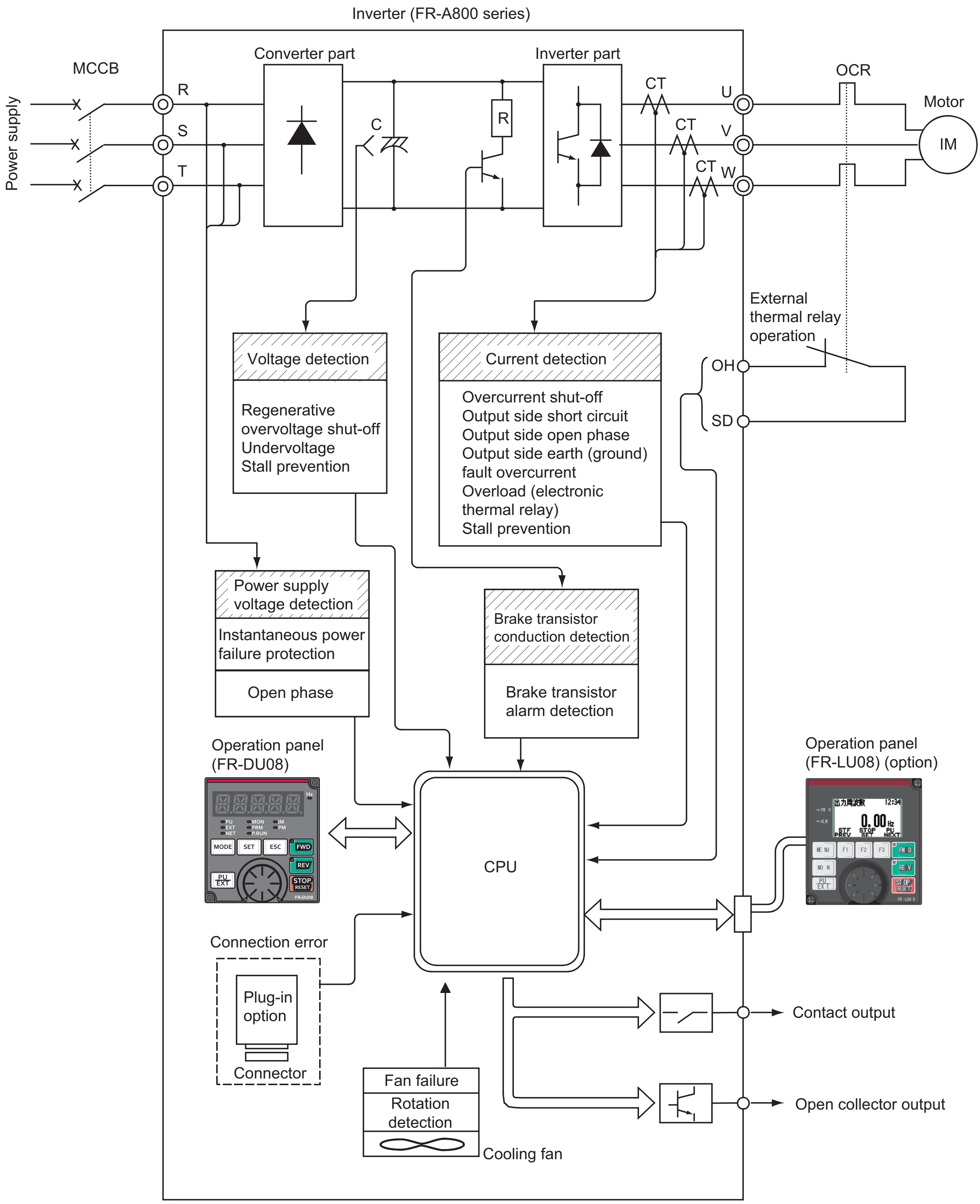
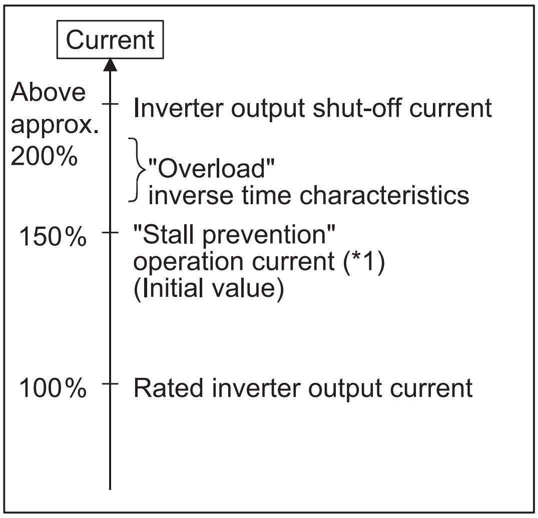
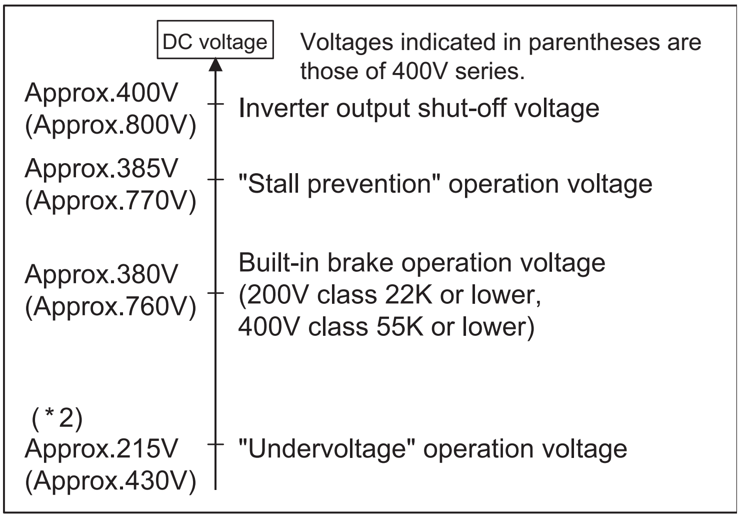


Fig.3.39 Protective functions related circuit

3.6.3 Current/voltage level at which protective functions operate

The protective functions operate when the detected current or voltage is at the level shown below. (For the FR-A800 series)





(*1) During ND rating, replaced by changed operation current (%) if the operation current level is changed.

(*2) Approx. 150VAC (Approx. 300VAC) when converted to AC input voltage

Useful information

A regenerative overvoltage shut-off (E.OV1 to E.OV3) is a phenomenon that occurs only when a regenerative power from a motor is large. Note, however, that an inverter occasionally trips while a motor is at stop due to overvoltage. This phenomenon occurs in the following process: surge voltage is applied from the power supply side, the smoothing capacitor is charged, and the voltage level reaches the output shut-off voltage level. The most possible source of this phenomenon is the switching operation of the power factor adjustment capacitor in the power supply system (high or low pressure).
To avoid this phenomenon, install an AC reactor (or power factor improving reactor).

3.6.4 Display and output signals when protective functions operate

Protective function operates

- Display
  - The alarm definitions are displayed on the parameter unit display.
- Output signals
  - The alarm output (contact signal) is turned on.
  - The open collector output (E.IPF) is turned on at an instantaneous power failure.

Alarm function operates

- Display
  - Displayed at the right end of the parameter unit display (OL).
- Output signals
  - The error output (contact signal) is not turned on.
  - The open collector output (OL) is turned on when the stall prevention is operated.
  - If the parameter is preset, the open collector output is turned on when pre-alarm is operated.

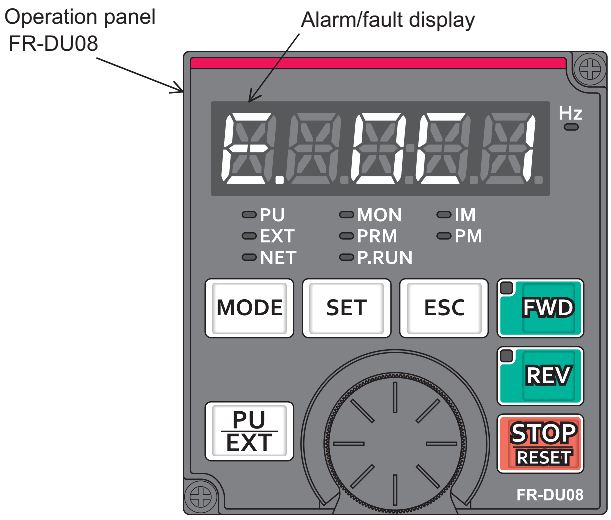


Fig.3.40 Display example at fault occurrence

3.6.5 Reset method

(1) When a protective function operates, the parameter unit indicates an error on its display and the inverter outputs a fault signal to disable its outputs.

(2) Reset the inverter to restart it. The inverter holds the abnormal status until reset.
Follow the procedure below to reset the inverter.
1) Short the reset terminals provided on the inverter between RES and SD, for 0.1s or longer, and then open the terminals. (The inverter cannot be restarted with the terminals shorted.)
2) Open the power supply terminals (R, S, T) once, wait 0.1s or longer, and then close them.
3) Use the inverter reset function provided in the help functions of the parameter unit.
4) Press STOP RESET on the operation panel (parameter unit).

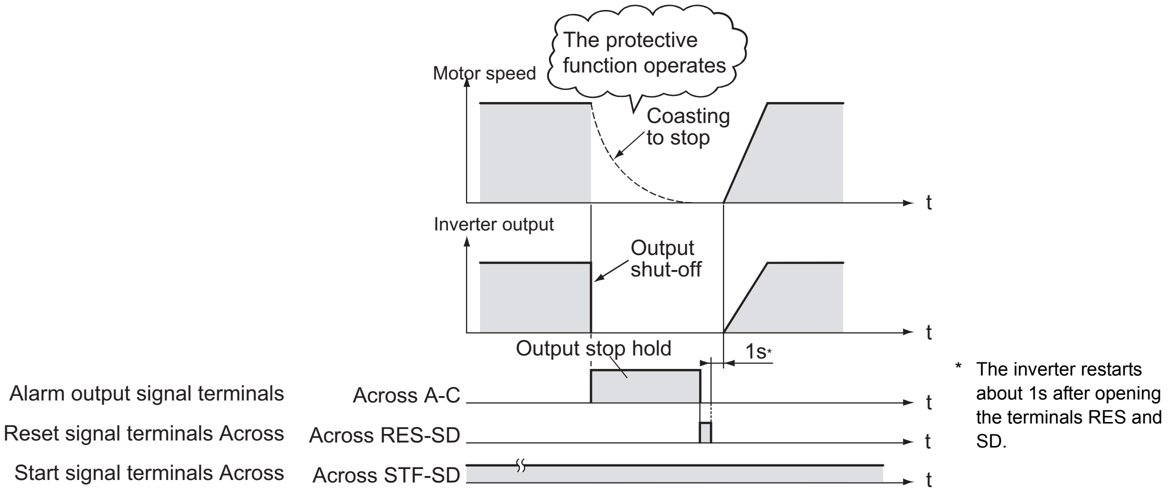


Fig.3.41 Timing chart of the reset operation

(3) In the initial setting of the inverter, reset is always enabled (even during operation).
The reset can be also set to be enabled only while a protective function is activated (E100(Pr.75)=1,3,15,17,101,103,115,117). This is useful when you want to avoid mis-input of reset signals in normal operation.
However, when E100(Pr.75)= any of "100 to 103 and 114 to 117", if the inverter is restarted within three minutes after activation of the electronic thermal O/L relay or the overcurrent protective function (E.THM, E.THT, E.OC[]), the inverter will not accept any reset command (RES signal, etc.) for about three minutes. (The reset limit function is available with the FR-A820-75K or higher and FR-A840-75K or higher.)

Useful information

If the reset is performed with the inverter while the motor is rotating, the transistor base shut-off is performed, and then the motor starts coasting. If the reset signal is turned off, the motor, which is currently coasting, restarts rotating (the inverter restarts from the starting frequency). This may cause an overcurrent trip. For this reason, do not reset the inverter while the motor is rotating.

3.6.6 Retry function

When an alarm occurs in an inverter while the retry function is enabled, the inverter automatically resets the alarm, restarts and continues the operation. When this function is selected, stay away from the inverter as it will restart suddenly after a fault stop.

3.7 Acceleration/Operating Characteristics of Inverter

3.7.1 Start

Input the inverter start signal (turn on the terminals across STF and SD or across STR and SD) and the frequency command signal to the inverter. Then the inverter outputs the starting frequency, and the motor generates torque.
If the motor start torque in the starting frequency is larger than the load start torque, the motor starts rotating. If the load torque is larger than the motor start torque, the motor stays locked. In such a case, increase the output frequency gradually. The motor starts rotating when the motor start torque exceeds the load torque T_L as shown in Fig.3.42.
Note that setting the start frequency too high may cause excessive locking current at the motor and bring overcurrent (E.OC1) or overload (E.THT) trip.

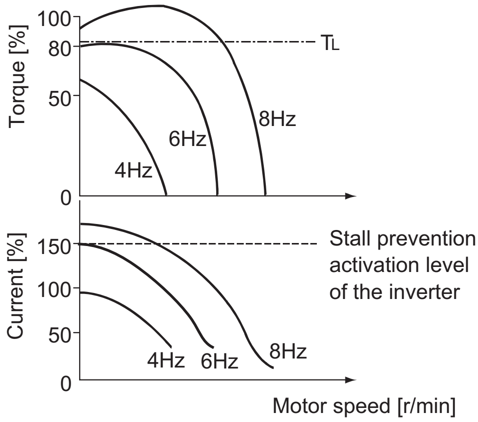


Fig.3.42 Start torque (standard boost)

When a standard motor is rotated by an inverter (V/F control), the definition of motor start torque differs from that of when rotated by a commercial power supply and is as follows.
In the low-frequency range, the start torque refers to the maximum torque that can be generated with up to 150% larger capacity than the inverter overcurrent capacity. The term start torque in this context differs in definition from start torque used in commercial power supply related context. Accordingly, start torque with the definition introduced in this section is referred to as "maximum start torque".
Let's find out the maximum start torque of Fig.3.42. The maximum output frequency is 6Hz in the inverter's stall prevention operation level (150%). From this, the maximum torque at 6Hz is the maximum starting torque.
In frequencies lower than 6Hz, locking the motor shaft does not cause an overcurrent trip on the inverter. Note, however, that locking for a long time may cause an overload shut-off (E.THM).

☒ Useful information

An inverter is provided with a function that sets the starting frequency (0 to 60Hz).
The higher the starting frequency is, the larger the motor start torque and starting current are. Do not change the default start frequency unless there is a load such as a vertical lift load whose load torque is larger than the motor torque at start, causing the motor to rotate in the reverse direction.
To increase the start torque, adjust the manual torque boost.

3.7.2 Acceleration

After start up, an inverter gradually increases the output frequency to the frequency command value in accordance with the acceleration time setting value.
As described in Section 2.4.3 Slip, the motor accelerates with a delay of the slip compared to the synchronous speed, which is proportional to the motor output frequency f.
A value of this slip depends on values of the load inertia moment, load torque and motor generated torque. If the acceleration time is set sufficiently long, the output frequency f and motor speed N increase in proportion to each other. (Refer to Fig.3.43.)
Note that too short acceleration time causes a large gap between f and N, by which f and N increase with a large slip value (refer to Fig.3.44.). This makes a motor current larger and may generate overcurrent, resulting in protective functions, such as the stall prevention function or the overcurrent shut-off function, to operate. (If an inverter capacity is increased whereas a motor capacity is not increased, the overcurrent resistance becomes relatively higher. Accordingly, the protective functions are not easily activated.)
For a general-purpose inverter, the acceleration time must be set in accordance with the load as described above to minimize the start current.

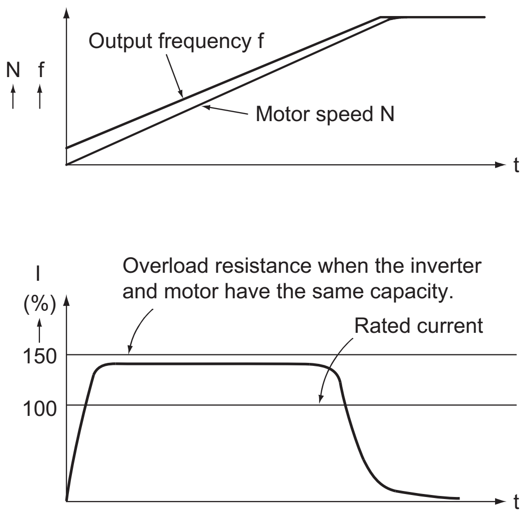


Fig.3.43 Acceleration characteristics (with sufficient acceleration time)

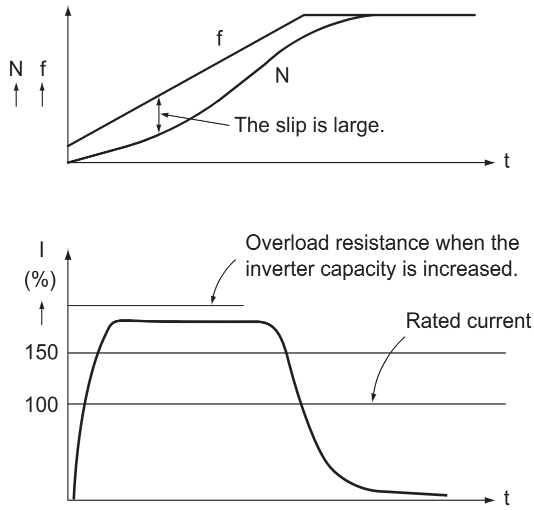


Fig.3.44 Acceleration characteristics (with insufficient acceleration time)

Useful information

Generally, if a motor is powered directly from a commercial power supply, a current that is 6 to 7 times larger than the rated current flows in the motor (refer to Section 2.5). The motor starts in the acceleration time that is defined by the load characteristics (refer to Section 2.10.1).
If an inverter with the same capacity as the motor capacity is used to directly start the motor (e.g. On the inverter output side, turn MC on.) in the same manner, a trip occurs with the start current. Therefore, an inverter must start with a low frequency to start a motor. (At approximately 3 to 6Hz, the start current does not exceed 150% of the rated current.)
The reason that nothing must be turned on or off on the inverter output side is that the start current is directly input and flows as described above.

3.7.3 Overcurrent stall prevention

When the motor current exceeds 150% (of the inverter's permissible load amount), the output frequency is reduced to prevent an overcurrent trip from occurring.

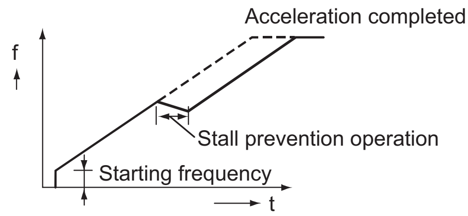


Fig.3.45 Stall prevention operation during acceleration

Useful information

Measures for when the overcurrent shut-off $\boxed{\text{E.OC1}}$ operated during acceleration

(a) When a trip occurs right after the start signal is turned on
- •Decrease the torque boost.
- •Increase the torque boost. Or, increase the starting frequency.
  This measure is applied to when the motor is rotating in the reverse direction (such as when a vertical lift load is used).

(b) When the motor trips and does not accelerate after its rotation is started
- •Set a longer value to the acceleration time.
- •Increase the torque boost.
- •Modify mechanical looseness.
  This measure is applied to when the machine does not start even though the motor rotates.

(c) When a trip occurs at 10-odd Hz or higher
- •Set a longer value to the acceleration time.

* The FR-A800 series inverters have the monitoring function, which displays the inverter's output frequency at fault occurrence on the operation panel.
A fault display appears when the inverter trips. After that, the frequency, output current, and output voltage at fault occurrence can also be displayed.

3.7.4 Constant-speed operation

When the output frequency matches the frequency command value, the acceleration ends and the motor continues to rotate at a constant speed.

Overcurrent stall prevention

During the constant-speed operation, if a motor current exceeds 150% (Stall prevention activation level), the inverter decreases the output frequency once to prevent an overcurrent-caused trip from occurring.
The inverter returns the output frequency to the original value when a motor current becomes smaller than 150%.

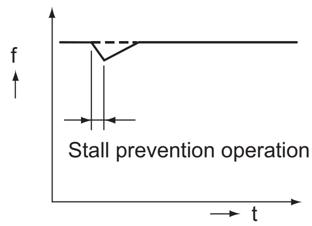


Fig.3.46 Stall prevention operation at a constant speed

Useful information

Measures for when the overcurrent shut-off $\boxed{\text{E.OC2}}$ operated during the constant-speed operation

(a) When the operation is performed at the base frequency or lower
- •Increase the torque boost

(b) When the operation is performed at 10Hz or lower
- •Decrease the torque boost.

(c) Increase the inverter capacity if the load torque is temporarily larger than 150% of the rated motor torque.

3.8 Deceleration/Stop Characteristics of Inverter

3.8.1 Deceleration

When the inverter start signals (STF and STR) are turned off or when the frequency command signal is set to a value below the output frequency, an inverter decreases the output frequency in accordance with the deceleration time setting value.

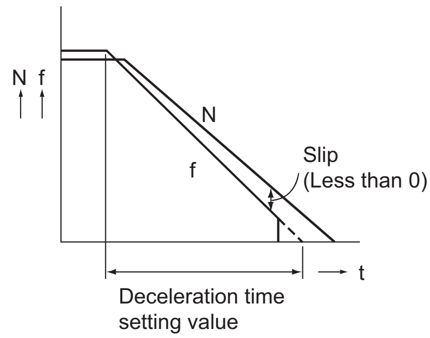


Fig.3.47 Deceleration characteristics

During deceleration, the motor speed is faster than the synchronous speed, which is equivalent to the inverter output frequency. In this condition, the motor functions as a generator and returns the energy to the inverter. This is why DC voltage (voltage of the smoothing capacitor) increases.
→ This operation is called regeneration.
To stop a motor rotating with a commercial power supply, turn off the magnetic contactor used for stopping a motor. The motor coasts to stop using the load torque as a braking force. (Refer to Section 2.10.1 for stop time.)
With an inverter, the motor does not coast to stop by turning the start signal off but decelerates to stop in accordance with the deceleration time setting value.
Depending on the deceleration time setting value, the motor goes into the following status.

Table 3.3 Relationship between deceleration time and regeneration

Deceleration time condition	Motor status	Motor slip
Deceleration time setting value > Coasting stop time	Driving (motor)	3 to 5% or less
Deceleration time setting value < Coasting stop time	Regeneration (generator)	Less than 0

During regeneration, a motor functions as a generator, charging the smoothing capacitor on the converter part. Therefore DC voltages of this smoothing capacitor increase at both ends (voltage between the terminals P-N).
Setting the deceleration time too short may activate the regenerative overvoltage prevention function or the overcurrent (regenerative current) prevention function. Set a relatively long deceleration time. Installation of an optional FR-BU2 brake unit or FR-CV power regeneration common converter can reduce the chance of the regenerative overvoltage protection activation.

Overvoltage stall prevention
If the DC voltage becomes even higher, the inverter stops decreasing the output frequency. This is to avoid the regenerative overvoltage shut-off protective function being operated.

Overcurrent stall prevention
If the motor current exceeds the specified value during deceleration, the output frequency is increased to prevent overcurrent protection from occurring.

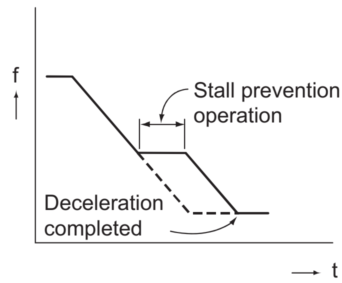


Fig.3.48 Stall prevention operation during deceleration

Useful information

Regenerative avoidance function, which adjusts the frequency in rising bus voltage, is useful to avoid regenerative overvoltage from occurring when the frequency and deceleration time are variable.

3.8.2 Stop

(1) When the inverter start signal (STF/STR) is turned off, the motor decelerates as shown in Fig.3.49. When the output frequency goes down to the DC injection brake operation frequency or lower, the DC voltage is applied to the motor, and then the motor stops. This is called DC injection brake. After the DC injection brake is performed for a certain time, the base signal of a transistor is turned off, by which the output is shut off.
Zero speed control is also available under Real sensorless vector control. Zero speed control and servo lock are available under vector control or PM sensorless vector control.

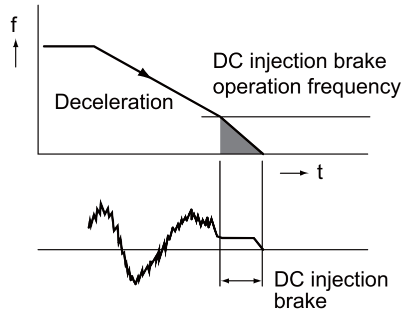


Fig.3.49 DC injection operation

DC injection brake

When the DC voltage is applied to a motor which is rotating, a brake torque is generated. This brake torque becomes zero when the motor stops.
Activating the DC injection brake for a long time may cause overheating of the motor. Take caution on this point.
(The operation frequency, operation time and operation voltage can be changed.)

Zero speed control

A brake is applied to keep 0r/min. Unlike servo lock, the motor shaft does not go back to its original position when it is rotated by an external force.

Servo lock

Motor shaft position is maintained. Even if it is rotated by an external force, it goes back to the original position.

(2) If the magnetic contactor (MC) on the inverter input side is turned off, a power failure is detected and the base circuit of the transistors is shut off. As a result, the motor coasts to stop. Therefore, when using an inverter to make the motor stop through deceleration, do not turn off the input power supply of the inverter.

Useful information

Measures for when the overcurrent shut-off E.OC3 operated during deceleration

(a) When a motor with a brake is used and trips right after deceleration starts
Refer to Section 5.6.7.

(b) When a trip occurs right before (while the DC injection brake is in operation) the motor stops
•Decrease the DC injection brake voltage.

(c) Set a longer value to the deceleration time.

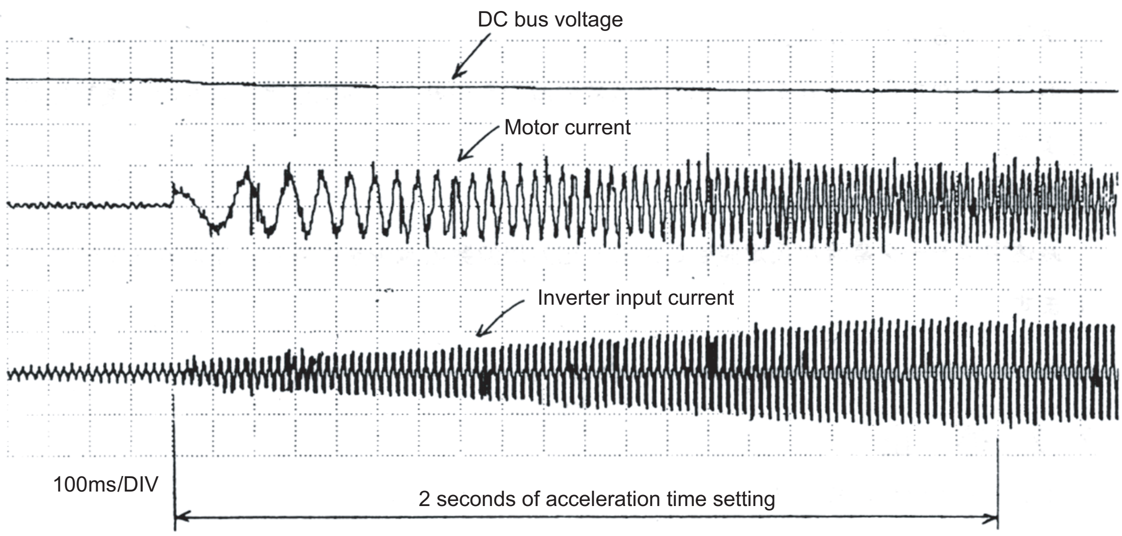


Fig.3.50 Measurement example of acceleration characteristics

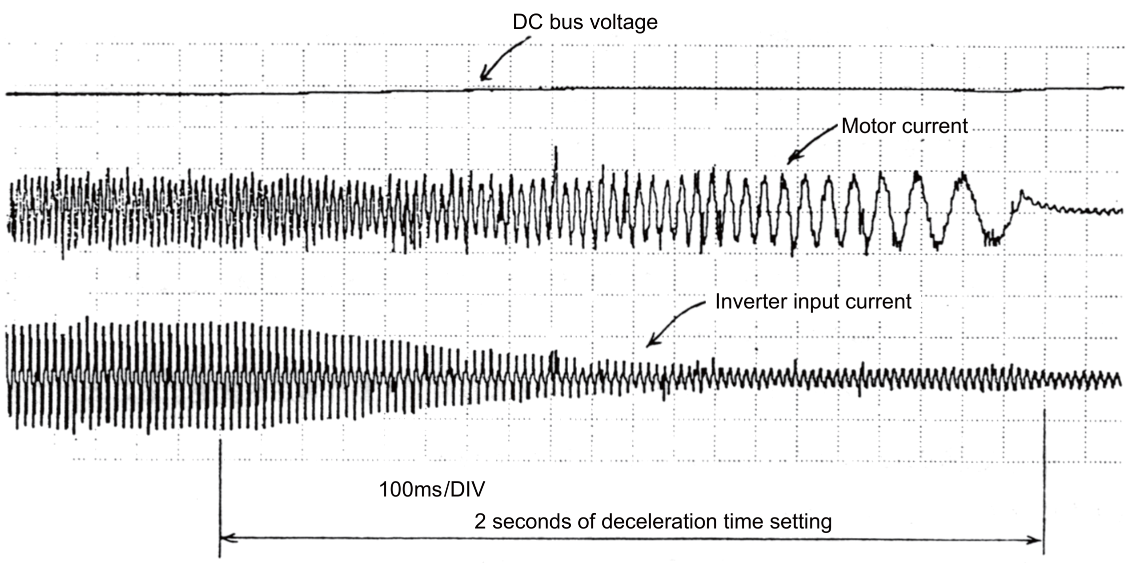


Fig.3.51 Measurement example of deceleration characteristics

3.9 Efficiency and Power Factor of Inverter

3.9.1 Efficiency

As described in Section 3.1, an inverter is a power supply conversion unit consisting of a section that performs forward conversion (the converter part) and the other section that performs reverse conversion (the inverter part), and therefore losses are unavoidable for such conversion sections. In spite of these losses, generally, inverters are said to improve power savings. The following describes the reason for this, using the formula of an inverter input current and efficiency.

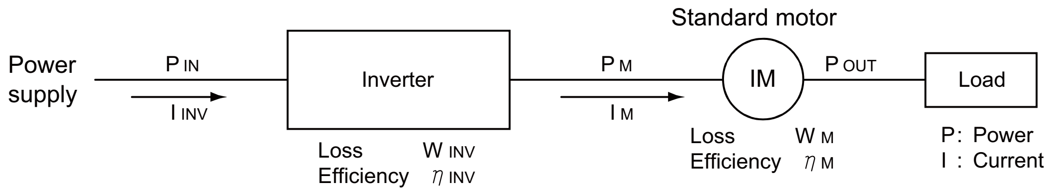


Fig.3.52 I/O power relation chart

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}} = \frac{\text{Output}}{\text{Output} + \text{Loss}} \quad \cdots\cdots \quad (3.1)$$

$$\text{Inverter input power } P_{IN} = \begin{matrix}\text{Inverter output power}\\ \text{(Motor input power)}\end{matrix}\ P_M + \text{Inverter loss } W_{INV} = \frac{\text{Inverter output power } P_M}{\text{Inverter efficiency } \eta_{INV}} \quad \cdots \quad (3.2)$$

$$\text{Motor input power } P_M = \text{Motor output } P_{OUT} + \text{Motor loss } W_M = \frac{\text{Motor output } P_{OUT}}{\text{Motor efficiency } \eta_M} \quad \cdots\cdots \quad (3.3)$$

$$\text{Motor output } P_{OUT} = \text{Motor output torque} \times \text{Motor speed} = \frac{\text{Machine force}}{\text{Machine efficiency}} \quad \cdots\cdots \quad (3.4)$$

From the above, the inverter input current can be calculated as follows:

$$\text{Inverter input power} = \text{Motor output} + \text{Motor loss} + \text{Inverter loss} = \frac{\text{Motor output}}{\text{Total efficiency}} \quad \cdots\cdots \quad (3.5)$$

$$\text{Total efficiency} = \text{Inverter efficiency } \eta_{INV} \times \text{Motor efficiency at inverter drive } \eta_M \quad \cdots\cdots \quad (3.6)$$

As shown in Formula (3.5), the motor loss increases due to harmonics etc. when an inverter is used. In addition to this, there is also an inverter loss meaning an inverter needs larger input power than a commercial power supply does to realize the same motor speed. However, if the motor speed is decreased by an inverter, the motor output decreases in the same manner. Accordingly, the lower the speed becomes, the less input power is needed even if the load torque is constant. (For reduced-torque loads such as fans and pumps, input power used decreases significantly, leading to energy savings.)

3.9.2 Power factor

Normally, as shown in Fig.3.53, a power factor can be calculated from a phase angle ϕ between voltage and current. For an inverter, however, a power factor cannot be defined as $\cos\phi$ since the input current of an inverter is in a distorted waveform including harmonic as described in Section 3.2. (A power-factor meter indicates approximately 1 if used.) On the other hand, a power factor is equivalent to a ratio of the effective power to the apparent power. Therefore the power factor for an inverter can be calculated in Formula (3.7).

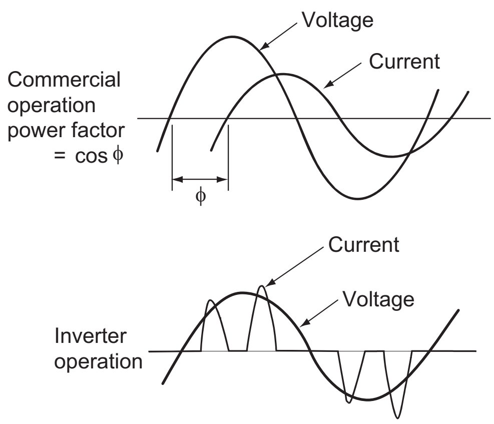


Fig.3.53 Input voltage/current waveform (3-phase)

$$\text{Power factor} = \frac{\text{Effective power}}{\text{Apparent power}} = \frac{\text{Effective power } P_{IN}}{\text{Effective power} + \text{Ineffective power}}$$
$$= \frac{\text{Inverter input power } P_{IN}}{\sqrt{3} \times \text{Power supply voltage} \times \text{Inverter input current } I_{INV}} \cdots\cdots (3.7)$$

3.9.3 Inverter input current and power factor improvement

In the waveform of inverter input current, a distortion ratio changes in accordance with the impedance (reactance of transformers or cables) on the power supply side, resulting in the change of input current (effective) value. However, as described in Section 3.9.1, the power supply voltage and inverter input power do not change as long as the motor output does not change. Therefore, Formula (3.7) is used to calculate a power factor. The larger the reactance on the power supply side is, the smaller the current is (i.e. the better the power factor is). On the other hand, when an inverter is directly installed next to a high-capacity power transformer, etc., the reactance is small, and the current is large, thus the power factor is low.

In order to improve the power factor, power supply side reactance must be larger. To raise the power supply side reactance, install a DC reactor (improves to about 93%) at the inverter's DC circuit, or an AC reactor (improves to about 88%) or a high power factor converter (improves to about 99%) at the AC input side. (For the details of FR-HAL and FR-HEL, refer to page 72.)

1 BASICS OF INVERTERS
2 MOTOR CHARACTERISTICS AT INVERTER DRIVE
3 INVERTER PRINCIPLES AND ACCELERATION/DECELERATION CHARACTERISTICS
4 ENERGY SAVING WITH INVERTERS
5 CAPACITY SELECTION AND OPERATION METHOD FOR MOTOR AND INVERTER
6 PRECAUTIONS WHEN USING INVERTERS
7 PERIPHERAL DEVICES AND OPTIONS
APP APPENDICES

(1) AC reactor FR-HAL(H)

AC reactor improves the waveform factor of the inverter input current and the power factor, reducing the power supply capacity. Also, it is effective in reducing the input side harmonic current.

Improvement effect		Power supply power factor 88% (92.3% when calculated with 1 power factor for fundamental wave according to the Architectural Standard Specifications (Electrical Installation) supervised by the Ministry of Land, Infrastructure, Transport and Tourism of Japan) (when load is 100%)
Operating environment	Surrounding air temperature	-10 to +50°C
	Ambient humidity	90%RH or less
	Vibration	5.9m/s^2 or less
	Ambiance	No dust and dirt, corrosive gas, flammable gas
Voltage		3-phase 200 to 240VAC 50/60Hz (380 to 480V 50/60Hz)
Connecting method		Connect to the inverter input side.

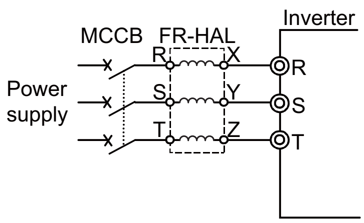
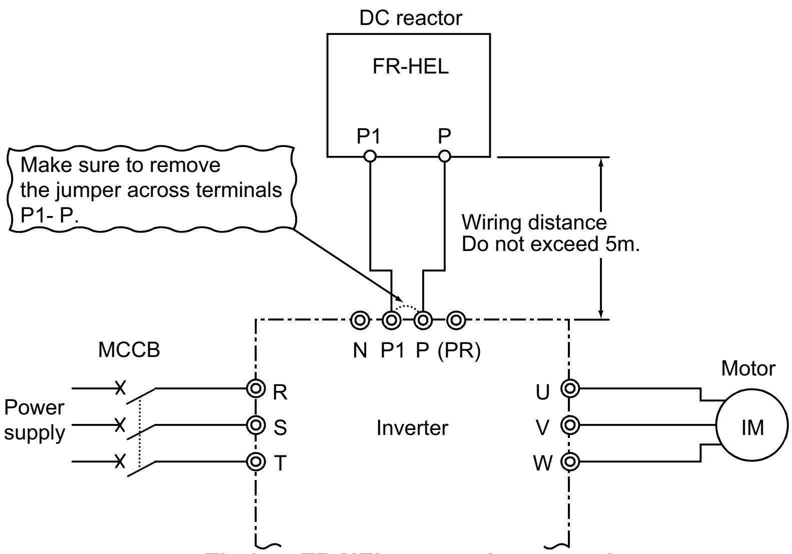


Fig.3.54 FR-HAL connection example

(2) DC reactor FR-HEL(H)

The DC reactor is smaller and lighter than the AC reactor and allows for less losses with the same effect.

Improvement effect		Power supply power factor 93% (94.4% when calculated with 1 power factor for fundamental wave according to the Architectural Standard Specifications (Electrical Installation) supervised by the Ministry of Land, Infrastructure, Transport and Tourism of Japan) (when load is 100%)
Operating environment	Surrounding air temperature	-10 to +50°C
	Ambient humidity	90%RH or less
	Vibration	5.9m/s² or less
	Ambiance	No dust and dirt, corrosive gas, flammable gas



*The cable between the reactor and the inverter should be 5m or less and as short as possible. The size of the cable should be the same as or larger than that of the power supply cable.

Fig.3.55 FR-HEL connection example

☒ Useful information

By making the input current smaller with a power factor improving reactor, the following advantages are obtained.

- A power factor improving reactor can downsize the peripherals (MCCB, MC) at the inverter's input side.
- Harmonic current can be smaller.
- An inverter can be protected from the surge voltage of the power supply side
- It can also control the converter module's peak current at power-ON. The power factor improving ratio with an AC reactor (FR-HAL) is only up to about 88%, but with a DC reactor (FR-HEL), it is up to about 93%.

An input power, motor current and inverter input current respectively for each of the following conditions: a conveyor (7.5kW load output at rated torque) is operated at 30m/min with a commercial power supply, a conveyor is operated at 30m/min and 15m/min with an inverter is shown below.
Given values are: the power supply is 200V60Hz, the motor efficiency η_M = 0.9, the motor power factor cosφ = 0.88

Operation status	Motor Input current	Inverter input current	Motor current	Inverter input current
Commercial power supply operation (30m/min)	8.33kW	-	27.3A	-
Inverter operation (30m/min)	8.82kW	9.29kW	28.9A	28.8 (Inverter power factor 0.93)
				38.3 (Inverter power factor 0.7)
Inverter operation (15m/min)	4.69kW	5.21kW	31.8A	21.5

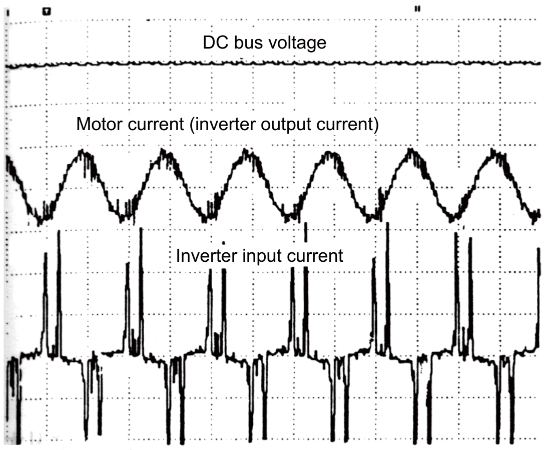


Fig.3.56 Measurement example of I/O current waveform (50Hz)

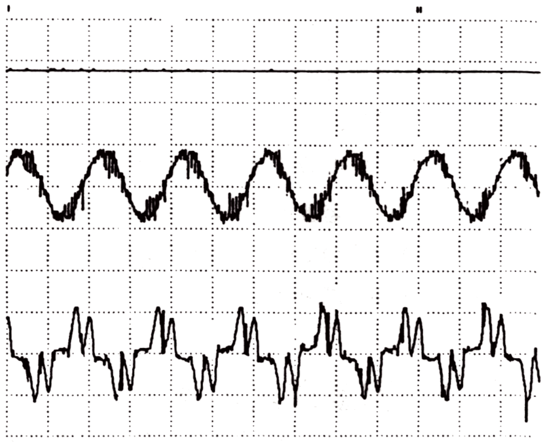


Fig.3.57 Measurement example of I/O current waveform (50Hz with a power factor improving reactor)

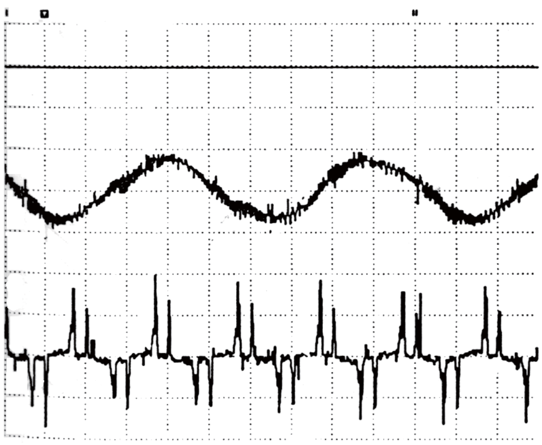


Fig.3.58 Measurement example of I/O current waveform (20Hz)

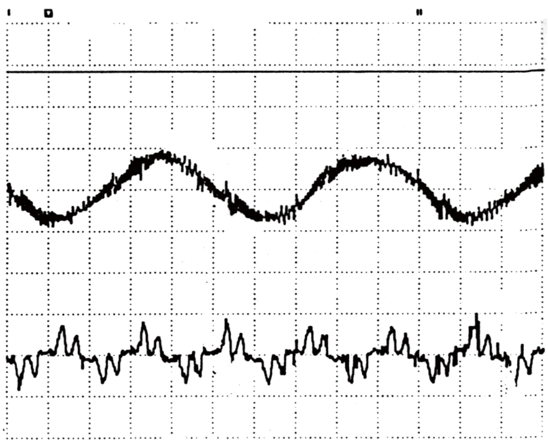


Fig.3.59 Measurement example of I/O current waveform (20Hz with a power factor improving reactor)

Chapter 4 ENERGY SAVING WITH INVERTERS

4.1 Energy Saving with Speed Control

(1) Energy saving for variable-torque load

To drive a load, such as fans and pumps, which requires torque in proportion to the square of the speed (variable-torque load application), use G003(Pr. 14) Load pattern selection. Setting G003(Pr. 14) Load pattern selection = "1" makes the output voltage vary in a square curve with the output frequency in the area lower than the base frequency.

Fig.4.1 shows the relation between air volume and the input (power) to the motor under damper control and inverter control.
Even if air volume goes down under damper control, the input to the motor stays roughly the same.
On the other hand, given the same conditions, the input to the motor drastically reduces under inverter control.
The amount indicated with the arrow is the energy saved by using inverter control instead of damper control.

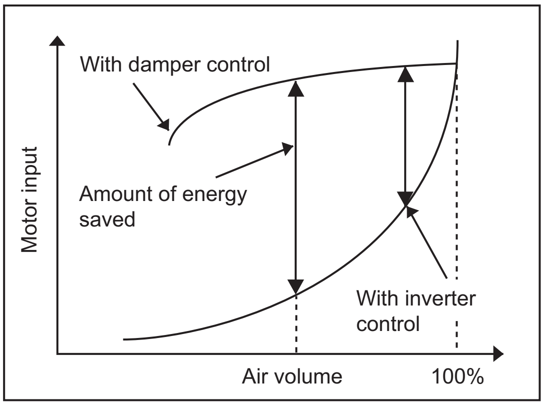


Fig.4.1 Energy saving characteristics

(2) Energy saving for constant-torque load

Energy saving for constant-torque load, such as conveyors, can be also expected by lowering the speed.
Based on the relation between the speed and load torque indicated in Fig.4.2, the required power is estimated.
The required power is calculated as "speed × load torque", and is the shaded area in the Fig.4.2.

The required power at 50% air volume (flow rate) and at 50% moving speed for fans/pumps and conveyors are compared as below.

- **Fans and pumps**
  The required power amount is indicated as , and is one-eighth the amount under 100% air volume (flow rate).
- **Conveyors**
  The required power amount is indicated as , and is half the amount under 100% speed.
  Greater energy saving effect is expected for fans and pumps, which require smaller power than conveyors do.

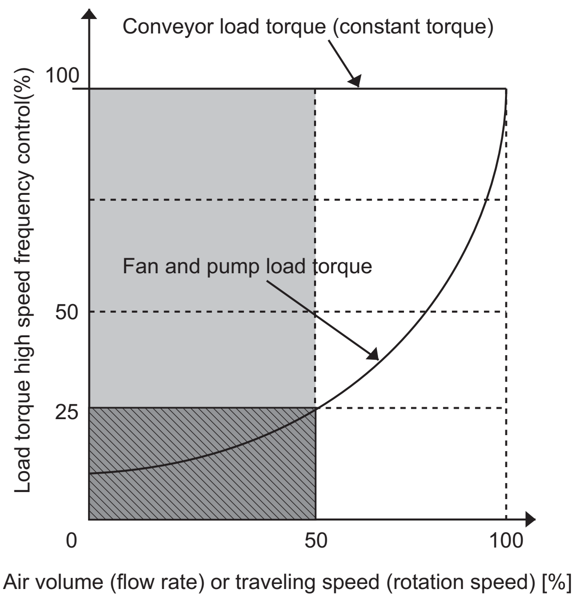


Fig.4.2 Comparison of required power

4.2 Energy Saving with Optimum Excitation Control

Under Optimum excitation control, motors are controlled to exhibit the maximum efficiency. For applications such as fans and pumps, motor efficiency rather than torque generation is important. Thus, the inverter's output current is divided into excitation current and torque current based on the calculation under vector control, and these current values are used to generate the least motor losses.
An inverter controls a motor so that the ratio between the excitation current Id and the torque current Iq brings the maximum efficiency. With this method, energy saving effects can be expected during constant-speed operation as well as during acceleration.
Setting G030(Pr. 60) Optimum excitation control = "9" will select Optimum excitation control for FR-A800, F700P, F700PJ, E700, D700 series inverters.

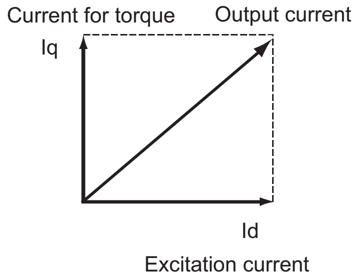


Fig.4.3 Current vector

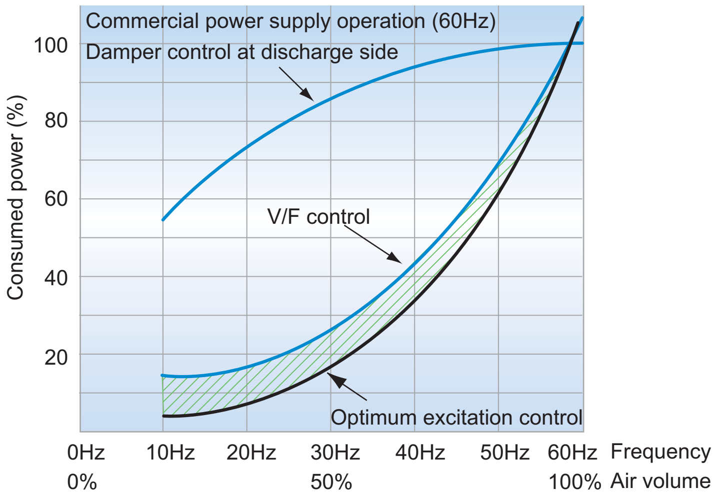


Fig.4.4 Blower operation characteristics

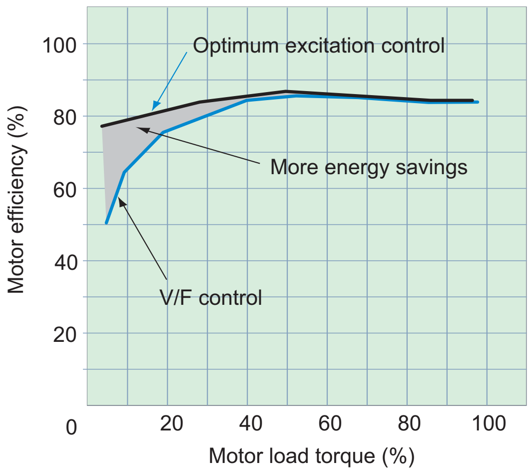
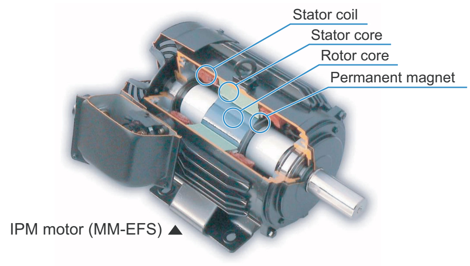


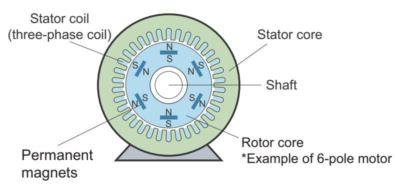
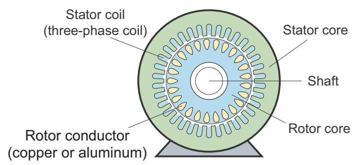
Fig.4.5 Motor efficiency with FR-A800 Optimum excitation control

4.3 Energy Saving with IPM Motor

IPM motors (MM-EF, MM-EFS) are synchronous motors that have strong permanent magnets embedded in their rotors.



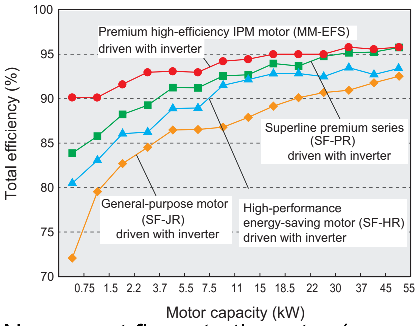
"Motor structure (section view)"

IPM motor (synchronous motor)	General-purpose motor (induction motor)
	

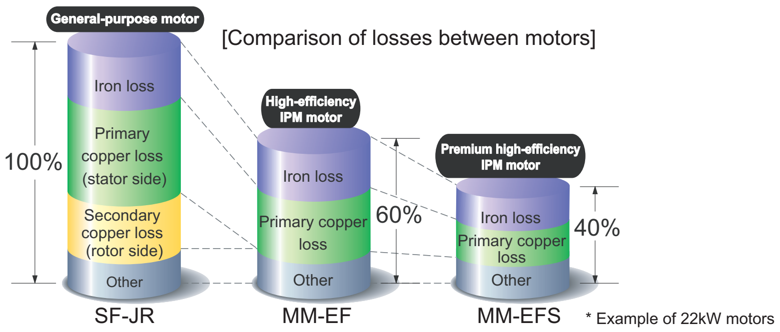
4.3.1 Characteristic of IPM motors

- The IPM motors that have permanent magnets embedded in their rotors are even more efficient than the high-performance energy-saving motors.

[Comparison of efficiency]



- No current flows to the rotor (secondary side), and no secondary copper loss is generated.
- Magnetic flux is generated with permanent magnets, and less motor current is required.
- Embedded magnets provide reluctance torque (reluctance torque occurs due to magnetic imbalance on the rotor), and the reluctance torque can be used.



4.3.2 Efficiency levels of IPM motors

High-efficiency IPM motor "MM-EF series" is equivalent to IE3 (premium efficiency).
Premium high-efficiency IPM motor "MM-EFS series" provides even better efficiency that is equivalent to IE4 (super premium efficiency), the highest efficiency class.

* As of October 2010

High-performance energy-saving motor superline premium series (SF-PR)

Efficiency	IEC 60034-30 Efficiency class *2	Efficiency of Mitsubishi Electric motors	
		General-purpose motor	IPM motor
High	IE4 (super premium efficiency) *1	——	Premium high-efficiency IPM(MM-EFS/MM-THE4)
	IE3 (premium efficiency)	High-performance energy saving motor superline premium series (SF-PR)	High-efficiency IPM (MM-EF/SF-THE3)
	IE2 (high efficiency)	High-performance energy saving motor (SF-HR/SF-THE)	——
	IE1 (standard efficiency)	Standard three-phase motor (SF-JR/SF-TH)	——
Low	Below the class		

*1: IE4 is specified in IEC 60034-31 (guidelines for selecting high power efficiency motors and their variable speed controllers).
*2: IE1, IE2, IE3 are specified in IEC 60034-30 (efficiency classes for single speed, three-phase squirrel-cage motors (IE codes)).

Chapter 5 CAPACITY SELECTION AND OPERATION METHOD FOR MOTOR AND INVERTER

This chapter describes points and measures when an inverter is selected according to the capacity, number and operation status of a motor to be driven.
Since the detailed explanation on the actual capacity selection is given in technical notes, this chapter focuses on what to consider for capacity selection.

☒ POINTS for understanding !

1.Most suitable combination of motor and inverter capacities
2.Capacity selection for driving multiple motors
3.Difference between acceleration and deceleration

5.1 Capacity Selection

5.1.1 Before selecting a capacity

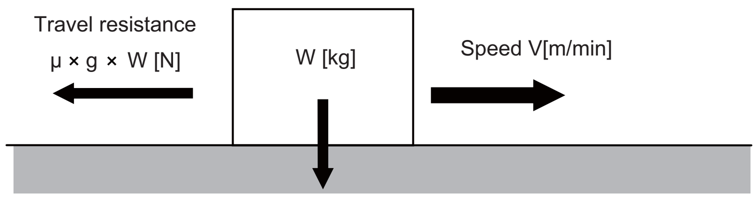
Before selecting a capacity, it is necessary to know the operating environment, the work to be performed, and whether the functions and performance of an inverter meet the requirements. Based on this information, select a motor, and an inverter or a vector inverter to control the motor. In terms of the hardware basics, the same concept can be applied to both inverters and vector inverters.

5.1.2 Selecting a motor according to driving force

The formula to obtain the driving force differs depending on horizontal or vertical (up-down) movement.

(1) Horizontal movement

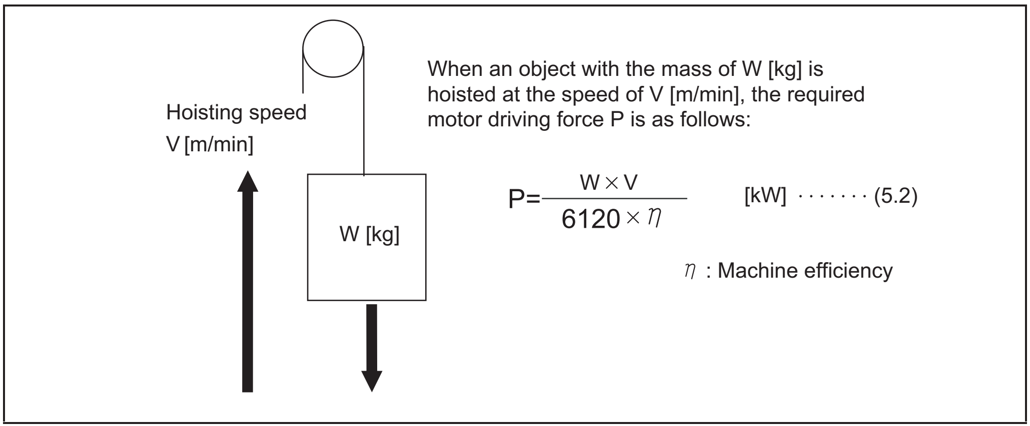
The motor power P is calculated based on total weight W [kg], travel speed V [m/min], friction coefficient μ, and machine efficiency η of a moving object. g = 9.8m/s^2



$$P=\frac{\mu \times W \times V}{6120 \times \eta} \text{ [kW]} \quad \cdots\cdots (5.1)$$

[Example 1]
Under the condition that the mass is 80kg, the object speed is 80m/min, the friction resistance is 0.2 and the machine efficiency is 0.8, the driving force required for the motor is:
P = 0.2 × 80 × 80/(6120 × 0.8)
= 0.26kW

(2) Vertical movement



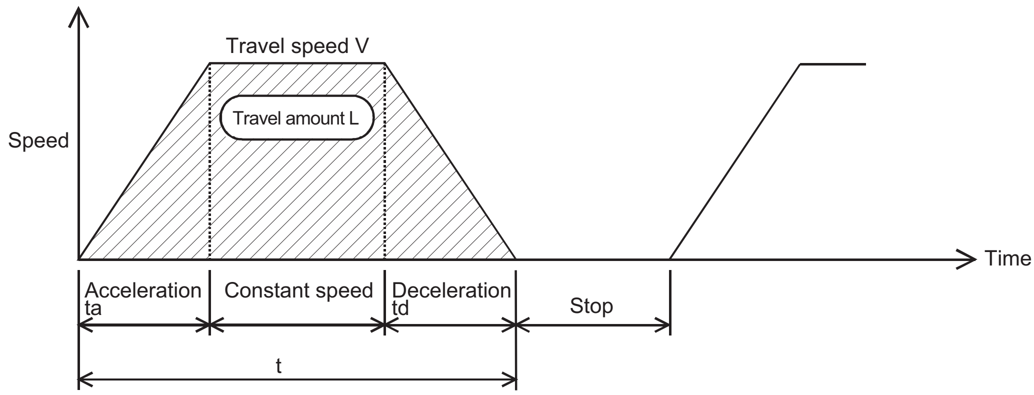
[Example 2]

Under the condition that the mass is 50kg, the object speed is 60m/min and the machine efficiency is 0.8, the driving force required for hoisting is:

P = 50 × 60/(6120 × 0.8)
= 0.61kW

5.1.3 Operation pattern

The operation pattern is a sequence of operating statuses throughout a cycle and includes traveling time and stopping time. The gray area below indicates the travel distance.



When the travel speed is V [mm/s], travel time is t [s], acceleration and deceleration times are respectively ta [s] and td [s], travel distance is L [m], their relation is as shown in the following formula.

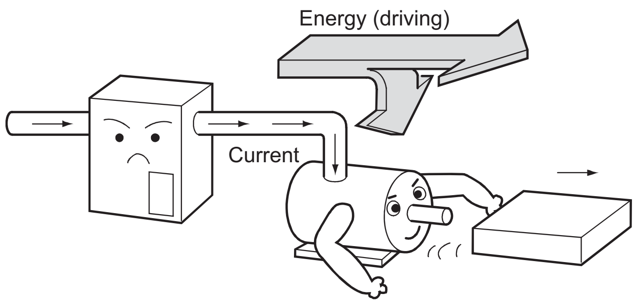
$$L = V \times \frac{ta}{60} \times \frac{1}{2} + V \times \frac{(t\text{-}ta\text{-}td)}{60} + V \times \frac{td}{60} \times \frac{1}{2}\ [m] \cdots\cdots (5.3)$$

5.1.4 Capability of inverter

The capability (not function) to drive a motor can be understood from the energy flow, which changes according to the operation status.

(1) During acceleration or constant-speed operations

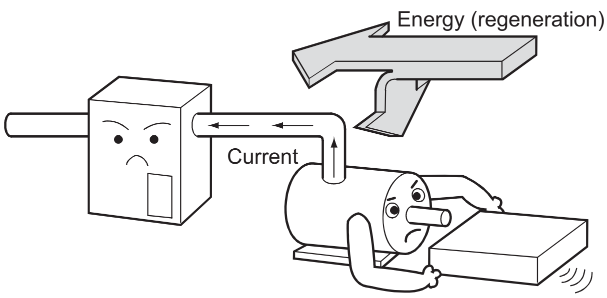
The capability is a peak current which indicates the largest current an inverter can offer when a motor requests. This amount is expressed as a rated output current or an overload current rating.



(2) During deceleration

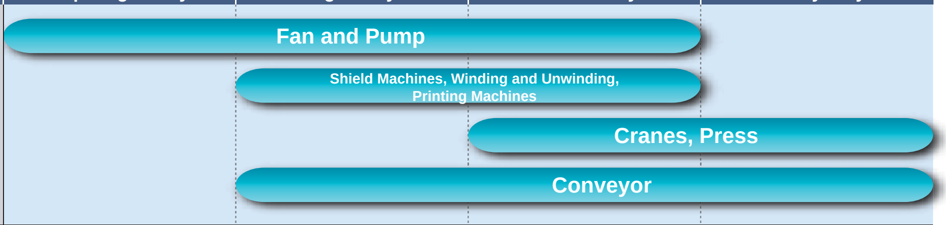
During deceleration, a motor acts as a generator and the energy flows back into the inverter side contrary to acceleration and constant-speed operations. The capability for disposing of (consuming) this energy is the inverter's capability during deceleration.

The motor consumes part of energy regenerated by load, the remaining energy is disposed by inverter.
To be specific, the smoothing capacitor terminal voltage is increased by regenerative energy, the inverter suppresses this increased voltage under the specified value, by consuming the energy or returning it to the power supply side.



5.1.5 Multiple rating

Rated current and four different overload capacity ratings (SLD rating (super light duty), LD rating (light duty), ND rating (normal duty), HD rating (heavy duty)) can be selected with E301 (Pr.570) multiple rating setting.
The optimum inverter can be selected to suit the application, and equipment size can be reduced with an inverter of SLD or LD rating. The HD rating is best suited for applications requiring low speed and high torque.
In FR-A800 series, if inverter or motor with capacity of 75kW or more use, make sure DC reactor is installed according to motor capacity.

Rating	SLD Super light duty	LD Light duty	ND Normal duty	HD Heavy duty
Application				
Pr.570 (E301) setting	0	1	2 (Initial value)	3
Overload current rating (inverse-time characteristics)	110% 60 s, 120% 3 s	120% 60 s, 150% 3 s	150% 60 s, 200% 3 s	200% 60 s, 250% 3 s
Surrounding air temperature	40°C	50°C	50°C	50°C

●Inverter by rating
200V class

Inverter model FR-A820-□	SLD (Super light duty)		LD (Light duty)		ND (Normal duty initial value)		HD (Heavy duty)	
	Motor capacity (kW)*1	Rated current (A)	Motor capacity (kW)*1	Rated current (A)	Motor capacity (kW)*1	Rated current (A)	Motor capacity (kW)*1	Rated current (A)
0.4K	0.75	4.6	0.75	4.2	0.4	3	0.2	1.5
0.75K	1.5	7.7	1.5	7	0.75	5	0.4	3
1.5K	2.2	10.5	2.2	9.6	1.5	8	0.75	5
2.2K	3.7	16.7	3.7	15.2	2.2	11	1.5	8
3.7K	5.5	25	5.5	23	3.7	17.5	2.2	11
5.5K	7.5	34	7.5	31	5.5	24	3.7	17.5
7.5K	11	49	11	45	7.5	33	5.5	24
11K	15	63	15	58	11	46	7.5	33
15K	18.5	77	18.5	70.5	15	61	11	46
18.5K	22	93	22	85	18.5	76	15	61
22K	30	125	30	114	22	90	18.5	76
30K	37	154	37	140	30	115	22	90
37K	45	187	45	170	37	145	30	115
45K	55	233	55	212	45	175	37	145
55K	75	316	75	288	55	215	45	175
75K	90/110	380	90	346	75	288	55	215
90K	132	475	110	432	90	346	75	288

400V class

Inverter model FR-A840-□	SLD (Super light duty) Motor capacity (kW)*1	SLD Rated current (A)	LD (Light duty) Motor capacity (kW)*1	LD Rated current (A)	ND (Normal duty initial value) Motor capacity (kW)*1	ND Rated current (A)	HD (Heavy duty) Motor capacity (kW)*1	HD Rated current (A)
0.4K	0.75	2.3	0.75	2.1	0.4	1.5	0.2	0.8
0.75K	1.5	3.8	1.5	3.5	0.75	2.5	0.4	1.5
1.5K	2.2	5.2	2.2	4.8	1.5	4	0.75	2.5
2.2K	3.7	8.3	3.7	7.6	2.2	6	1.5	4
3.7K	5.5	12.6	5.5	11.5	3.7	9	2.2	6
5.5K	7.5	17	7.5	16	5.5	12	3.7	9
7.5K	11	25	11	23	7.5	17	5.5	12
11K	15	31	15	29	11	23	7.5	17
15K	18.5	38	18.5	35	15	31	11	23
18.5K	22	47	22	43	18.5	38	15	31
22K	30	62	30	57	22	44	18.5	38
30K	37	77	37	70	30	57	22	44
37K	45	93	45	85	37	71	30	57
45K	55	116	55	106	45	86	37	71
55K	75/90	180	75	144	55	110	45	86
75K	110	216	90	180	75	144	55	110
90K	132	260	110	216	90	180	75	144
110K	160	325	132	260	110	216	90	180
132K	185	361	160	325	132	260	110	216
160K	220	432	185	361	160	325	132	260
185K	250	481	220	432	185	361	160	325
220K	280	547	250	481	220	432	185	361
250K	315	610	280	547	250	481	220	432
280K	355	683	315	610	280	547	250	481
Inverter model FR-A842-□	**SLD (Super light duty) Motor capacity (kW)*1**	**SLD Rated current (A)**	**LD (Light duty) Motor capacity (kW)*1**	**LD Rated current (A)**	**ND (Normal duty initial value) Motor capacity (kW)*1**	**ND Rated current (A)**	**HD (Heavy duty) Motor capacity (kW)*1**	**HD Rated current (A)**
315K	400	770	355	683	315	610	280	547
355K	450	866	400	770	355	683	315	610
400K	500	962	450	866	400	770	355	683
450K	560	1094	500	962	450	866	400	770
500K	630	1212	560	1094	500	962	450	866

Remark

The inverter module and the converter module are physically separated for FR-A842-315K to 500K. Combine the inverter module and converter module for use.

Overload current rating

SLD	110% 60 s, 120% 3 s (inverse-time characteristics) at surrounding air temperature 40°C
LD	120% 60 s, 150% 3 s (inverse-time characteristics) at surrounding air temperature 50°C
ND	150% 60 s, 200% 3 s (inverse-time characteristics) at surrounding air temperature 50°C
HD	200% 60 s, 250% 3 s (inverse-time characteristics) at surrounding air temperature 50°C

* 1: The applicable motor capacity is the maximum applicable capacity of a Mitsubishi Electric 4-pole standard motor.

5.1.6 Points for capacity selection

In addition to compatibility with a driven motor, load characteristics and operation methods/statuses must be considered when selecting inverter capacity.

(1) Motor capacity

Note that when V/F control is used with an inverter drive, the motor output torque in the low-frequency range is smaller than that when V/F control is used with the commercial power supply. Otherwise, unexpected troubles occur such as disability of the inverter start-up. The same can be said for motor temperature rise. (Refer to Section 2.4 and Section 2.5)

(2) Operation method

When selecting the inverter capacity by the capacity or number of driven motors, first select the inverter with a rated inverter current greater than the total of all motor currents.
Driving multiple motors with one inverter is a feature of the inverter drive. However, the inverter capacity may become extremely large depending on the operation method, which is not economically efficient. In addition, this kind of drive easily causes capacity selection errors. V/F control must be selected to drive multiple motors with one inverter since driving multiple motors is not available with Advanced magnetic flux vector control, etc.
The following lists the general operation methods:
- One motor is driven with one inverter.
- Multiple motors are driven with one inverter.
- Several motors are sequentially started with one inverter.
- Motor output shaft is turned on/off with a clutch.

1) When one motor is driven

Rated output current of inverter $\geq$ rated current of motor $\times$ 1.05 ················(5.3)

- Rated output current of inverter: Indicated in the specifications column of a catalog.
- Rated current of motor: Value of motor rating plate
- 1.05: Increases by distorted waveform

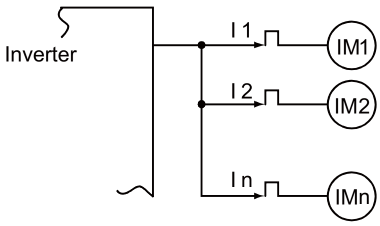
NOTE

(a) Selecting an inverter corresponding to a motor using the motor capacity "kW" is not a proper method. Select an inverter so that the condition of formula (5.3) can be satisfied in reference to the rated motor current. The reason is, when a number of pole increases with same motor capacity (kW), the rated current becomes large & motor's efficiency and power factor get reduced.
For the standard motors (2, 4, 6P), selecting an inverter according to "kW" does not cause a specific problem.

(b) The motor with a capacity larger than the inverter capacity cannot be used except for LD or SLD ratings.

2) When operating multiple motors in parallel with one inverter

Rated output current of inverter ≥ total of rated motor current × 1.05 . . . . (5.4)



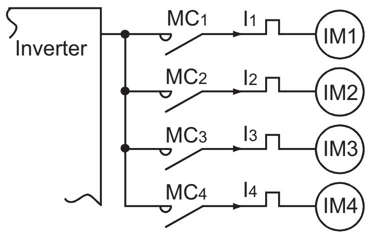
NOTE

When multiple motors are operated in parallel, the motors cannot be protected by the built-in electronic thermal relay function. Provide a thermal relay for each motor on the inverter output side.
For a continuous drive at low-speed, however, install a temperature detection device on the motors since the motors cannot be protected by the thermal relay function.

3) When several motors are sequentially started with inverter

Rated output current of the inverter ≥ Total rated current of the started motors × 1.05
+ Starting current for the largest-capacity motor . . . . (5.5)

[Example] When sequentially starting four motors as below, the current reaches the maximum when starting (turning ON the MC_4 of) the last motor (IM_4) while the three other motors are already running.
The amount of the motor current I_4 becomes six to eight times the rated current.



NOTE

(a) To select a capacity of an inverter, which uses a clutch to turn ON/OFF the output motor shaft, follow the sequential starting procedure described above. In the formula (5.5), substitute "0" for the rated current of started motors, and use only the starting current for the motor, which is to be turned ON/OFF.
(b) The built-in electronic thermal O/L relay function cannot provide thermal protection to the several motors driven in parallel. When driving several motors in parallel, provide thermal relays to each motor. Those thermal relays, however, do not provide thermal protection in continuous low-speed operation. Provide additional thermometers for the motors.
(c) Activation of the stall prevention function suddenly changes the frequency. When starting motors sequentially, this activation also suddenly changes the speeds of already started motors.

(3) Operation pattern

When the acceleration or deceleration time is restricted, the selection of inverter capacity cannot be fully made only by matching the inverter capacity with the motor capacity (selecting with a current).

The capacity must be selected so that the predetermined acceleration/deceleration time can be satisfied. The inverter capacity may increase for the operation which repeats acceleration/deceleration in a short time or for the vertical lift operation. Make sure to fully consider the inverter capacity in advance.

[Example] 1) When rapid acceleration/deceleration or cycle operation is performed. (machine tool, cart, etc.)

2) When the vertical lift operation is performed.

MEMO

Can the inverter with one rank higher capacity be used?

■ When the inverter capacity is increased, the motor torque (force) becomes larger.

The motor generated torque when an inverter is used is less than that when the commercial power supply is used. Depending on the size of the load, the current increases for insufficient torque (force), and the protection function may be activated.

To solve insufficient torque, one of two methods can generally be taken: increasing the motor capacity (the inverter capacity must also be increased) or increasing only the inverter capacity with the motor capacity left unchanged. Since the former method costs more and makes motor dimensions larger than the latter, the latter is frequently taken.

The increased inverter capacity allows for a larger inverter output current, which increases the motor generated torque.

■ Increasing the inverter capacity does not contribute in suppressing motor temperature rise.

When the rise of the motor temperature occurs during a continuous operation at low-speed, it cannot be improved even if the inverter capacity is increased.

Since a motor is cooled off with its own cooling fan, the cooling capability cannot be improved by increasing the inverter capacity.

When the inverter's capacity is increased, a measure against the motor overheat must be considered since the motor is forced to operate. In this case, it is important to properly set the inverter's electronic thermal relay function according to the motor capacity.

5.2 Selection with Operation Pattern

The basic operation pattern of a motor is start → acceleration → constant speed → deceleration → stop.
Each process has points for selection which are described below.

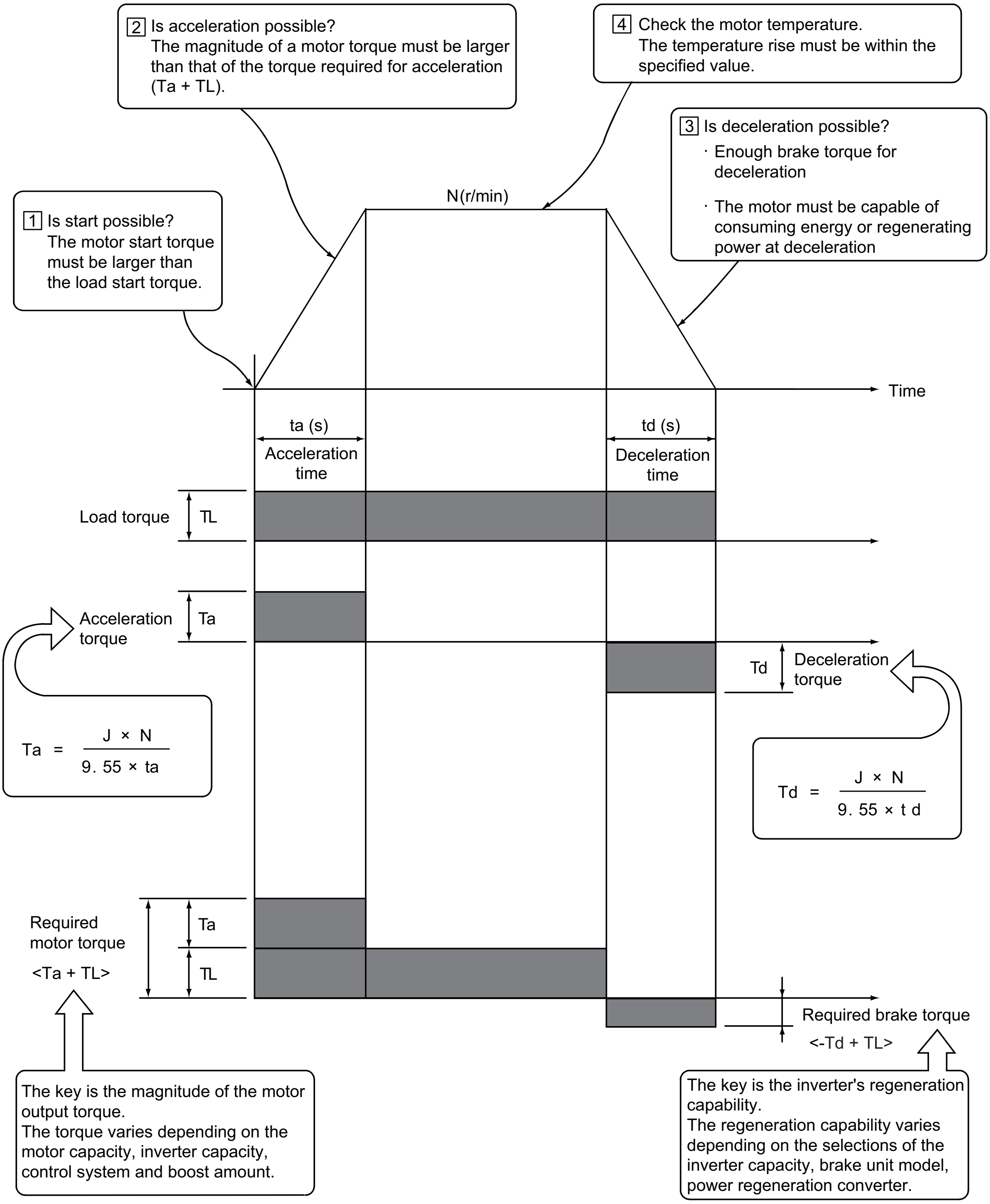


Fig.5.1 Operation pattern and torque

5.2.1 Start

The motor starts at the intersection of the motor generated torque with the load torque (point A in Fig.5.2). Since the motor is locked while the inverter output frequency is between 0 and point A, the intersection point must be at the maximum start frequency or below to prevent the inverter from tripping due to the locked rotor current. (Refer to Section 3.7.1)

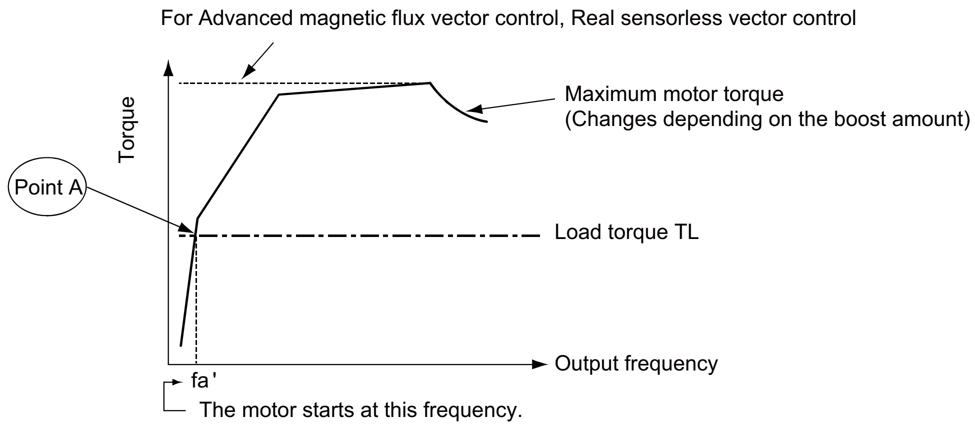
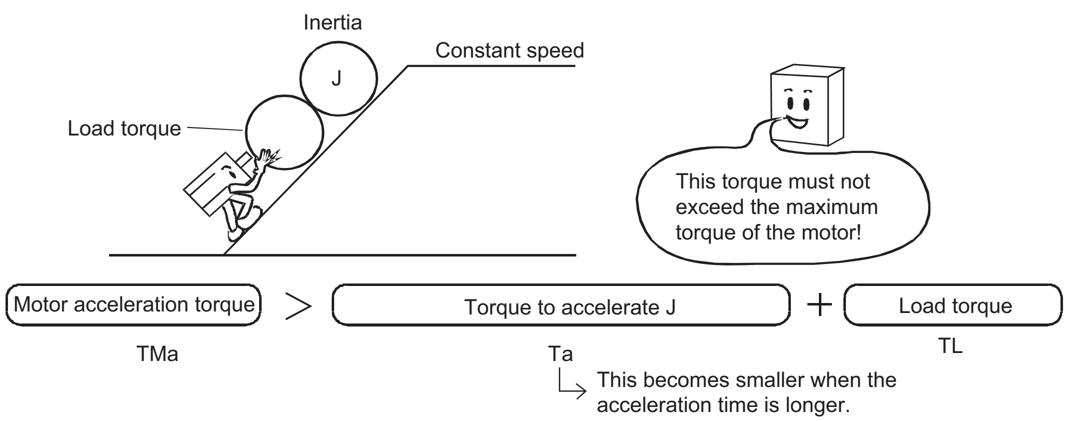


Fig.5.2 Start of motor

5.2.2 Acceleration

The magnitude of motor output torque must be more than that required for the acceleration (Ta + TL).



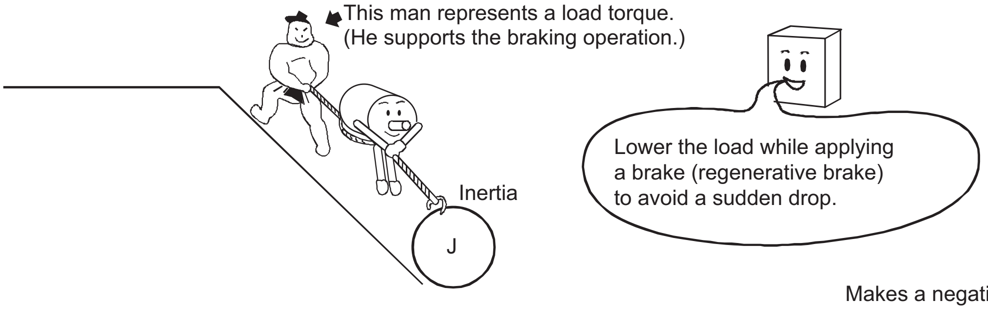
Useful information

To increase the acceleration capability and the start torque

- Select the Advanced magnetic flux vector control (FR-A800, E700 series), the Real sensorless vector control (FR-A800 series) or the General-purpose magnetic flux vector control (FR-E700, F700PJ, D700 series).
- Increase the torque boost adjustment amount.
- Increase the inverter capacity.
- Increase the motor and inverter capacities.

5.2.3 Deceleration

The magnitude of the regenerative brake torque is determined according to the motor and inverter loss. That is to say, the deceleration capability is determined by the inverter loss for an inverter with a built-in brake and by the motor loss for an inverter without a built-in brake. Using a higher-capacity inverter with built-in brake can increase the regenerative braking torque, but using a higher-capacity inverter without built-in brake does not increase the regenerative braking torque. For this reason, FR-BU2 type brake unit is used.



Makes a negative value smaller.

Reduction torque of the motor > | Torque to decelerate J + Load torque |

TMd   -Td   TL

→ This becomes smaller when the deceleration time is longer.

While the magnitude of the brake torque has been satisfied, it is necessary to consider the brake resistor's capacity not to overheat during deceleration. The energy regenerated to the inverter at deceleration (W_{INV}) must be fully consumed within the capability of the brake resistor.
When a larger brake capability is required, use a power regeneration common converter (FR-CV) which generates the braking power by returning the regenerative energy (W_{RC}) to the power supply.

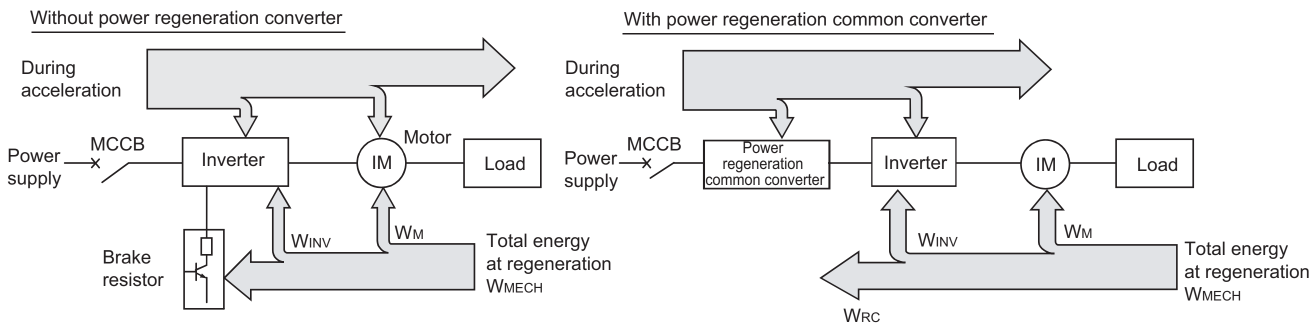


Fig.5.3 Flow of energy at deceleration

☒ Useful information

To increase the regenerative brake torque

- Increase the inverter capacity.
  This method is effective when the regenerative brake circuit is built in an inverter; however, not effective when it is not.
- Use the power regeneration common converter (option).
- Use the brake unit (option).
- When the a brake unit is already being used, use one with a larger capacity or the power regeneration common converter. However, when the capacity of the brake unit is larger than the capacity of the inverter it is being used with, the inverter capacity must be increased.

5.2.4 Regenerative brake function

(1) Regenerative brake circuit operation

The inverter applies brakes to the motor speed by consuming the regenerated energy. This consuming circuit is a regenerative brake circuit.
The operation is explained taking a built-in type regenerative brake circuit in Fig.5.4 as an example.
The voltage E of the smoothing capacitor C increases with the regenerative energy.
When the voltage exceeds the specified value, the transistor on the regenerative brake circuit TRd conducts, and the current Id flows to the regenerative brake resistor R.
The regenerative brake resistor generates heat with this current, and the regenerative energy is consumed. The energy charged in the capacitor decreases with this operation, and the voltage E drops. When the voltage E drops below the specified value, the transistor on the regenerative brake circuit TRd stops conducting, and the current of the regenerative circuit is shut off.

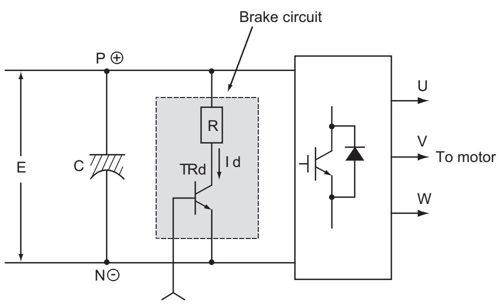


Fig.5.4 Brake circuit

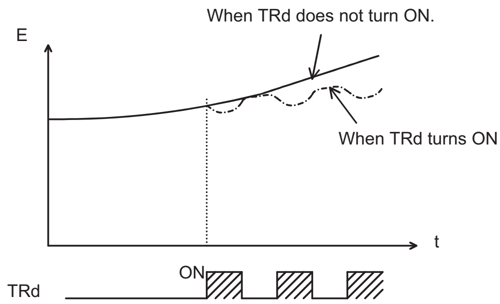


Fig.5.5 DC voltage (across P and N)

These operations are repeated during deceleration. However, the duty of the regenerative brake circuit decreases or the circuit may not operate when the regenerative energy is small (the torque required for deceleration is small).
The duty of the built-in regenerative brake circuit must be adjusted according to the regenerative option to be used. Refer to the instruction manual and catalog of the inverter for the built-in regenerative brake circuit duty. Unnecessary changes of the brake duty may trigger overheating of the regenerative brake resistor and transistor failures.
An optional brake unit is the equivalent of a built-in brake circuit installed outside.

Useful information

The necessity of a brake unit is defined as follows.
A brake unit is required when the voltage immediately after deceleration start goes up close to the stall prevention activation voltage indicated in Section 3.6.3. To check the DC voltage, measure the DC voltage across terminals P and N using a tester or use the monitor.
Furthermore, when the voltage is maintained above the brake operation voltage, even if the brake unit is built in to the inverter, increase the brake unit capacity in case of insufficient brake capability.

(2) Heat capacity of the regenerative brake (temperature rise)

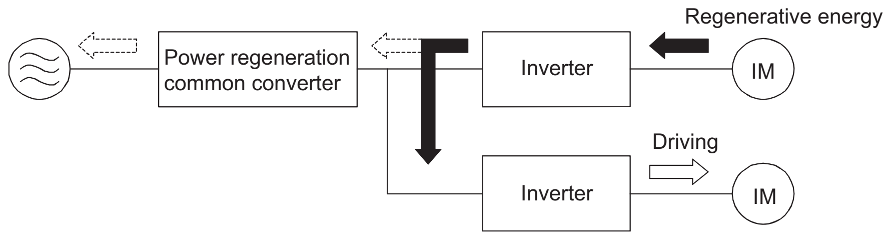
Capacity of the regenerative brake unit is determined by the regenerative brake torque, which is explained in the previous section, and the consumed power. The regenerative brake torque is subject to the regenerative current value flowing in the brake resistor, which is determined by a resistance value (Ω) of the resistor. When the regenerative current flows for a long time, the heat generation exceeds the permissible value of the resistor.

This permissible value is the rated power of the resistor (W). For the high-frequency operation pattern or the continuous regeneration load (a lift, etc.), consideration of the heat capacity for the regenerative brake is required.

Power regeneration common converters (FR-CV), which are often used for lift operation, require large torque and consumption energy but provide the following benefits.

1) It enhances the brake capacity (regenerative torque).
Capable of 100% torque continuous regeneration and maximum 150% torque and 60 second regeneration.

2)Logical common converter system
Using the regenerative energy for other inverters and returning the remaining energy to the power supply lead to the energy savings.



The remains of the regenerative energy return to the power supply side as shown in dotted lines.

3) Easy enclosure design
Adopting a compact body allows an easy in-enclosure design. Installing a heatsink outside the enclosure suppresses the rise of in-enclosure temperature and downsizes the enclosure.

Useful information

A lift generally spends longer time for the regenerative operation. Therefore, the time for one cycle and the load torque at the negative torque for the lifting height (m) (especially machine efficiency) are important factors for capacity selection.

5.2.5 Rise of motor temperature

The motor temperature rise for the continuous operation is different from that for the cycle time operation. This fact requires the consideration of motor heat according to operation methods.

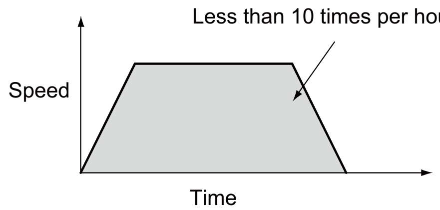
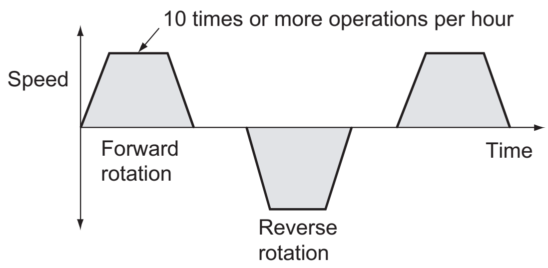
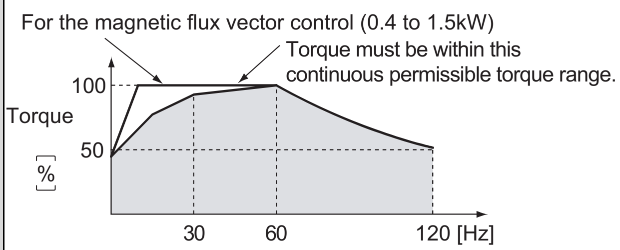
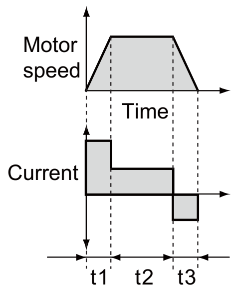
	Continuous operation	Cycle time operation
Operation frequency		
Consideration of motor heat	 •Consider the torque value of the output characteristics for the running speed.	 Obtain the motor equivalent current value from the current for each running interval and the cooling coefficient. The result must be below the rated motor current. The temperature rise of the inverter operation is generally smaller than that of the commercial power supply operation due to the restrictions of the inverter overload current rating.

Fig.5.6 Operation pattern and motor temperature rise

5.3 Effect of Machine Reduction Ratio

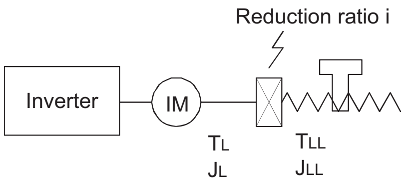
For small capacity standard motors (7.5kW 4P or less), up to 120Hz are available. Previously, the machine-side reduction speed ratio was limited by the maximum machine speed at 50Hz or 60Hz. By increasing the output frequency (60Hz to 120Hz maximum), the reduction speed ratio is increased, the load torque at the motor shaft and inertia moment of the load are reduced, and also the following benefits are provided.

1) Startups become easier as the reduction ratio increases.
2) Continuous use is enabled at low-speed. (The standard motor will do on the occasion when the inverter-dedicated constant-torque motor should be selected.)
3) A motor can be used in the wide speed deviation range.
4) Motor speed increases.

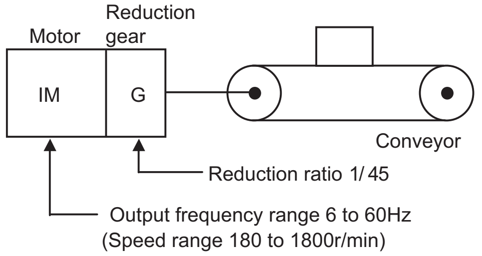
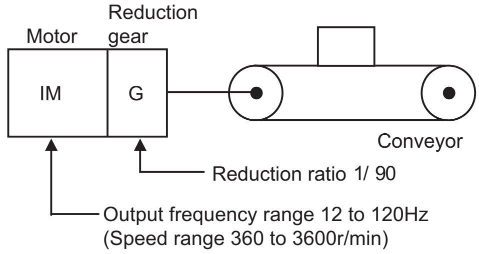
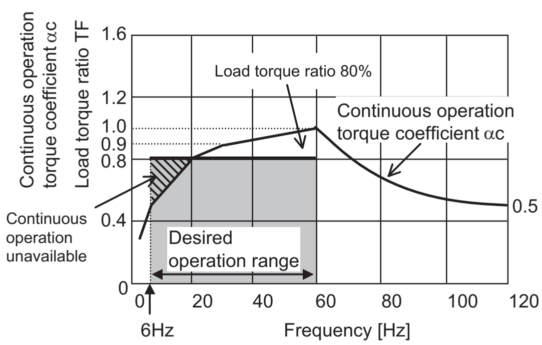
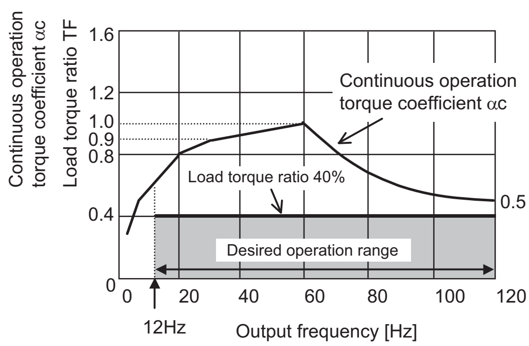
Relationship between the reduction ratio i and the motor shaft-equivalent load torque T_L and load inertia moment

$T_L = T_{LL} \times i$ — T_{LL}: Load torque for load shaft

$J_L = J_{LL} \times i^2$ — J_{LL}: Load inertia moment for load shaft



Load/operation specification	● Machine name conveyor ● Conveyor speed 30 [m/min]	● Transmission ratio 1 : 10 ● Power supply 220V 60Hz

Design A	Design B
	
● Load torque T_{LR} (at motor shaft) 80% of the rated motor torque ● Maximum speed 1800 [r/min]	● Load torque T_{LR} (at motor shaft) Because the reduction ratio of Design A is doubled : Load torque = 80% ÷ 2 = 40% ● Maximum speed 3600 [r/min]
	

By doubling the reduction ratio of Design A, the load torque at motor shaft becomes half in Design B. The non-operative range (6 to 20Hz) of Design A can be operated in Design B.

Remarks ● Operation at 120Hz may not be available depending on the motor capacity, the number of motor poles and the decelerator type. Check at which frequency the motor can operate in advance.

5.4 Capacity Selection Procedure

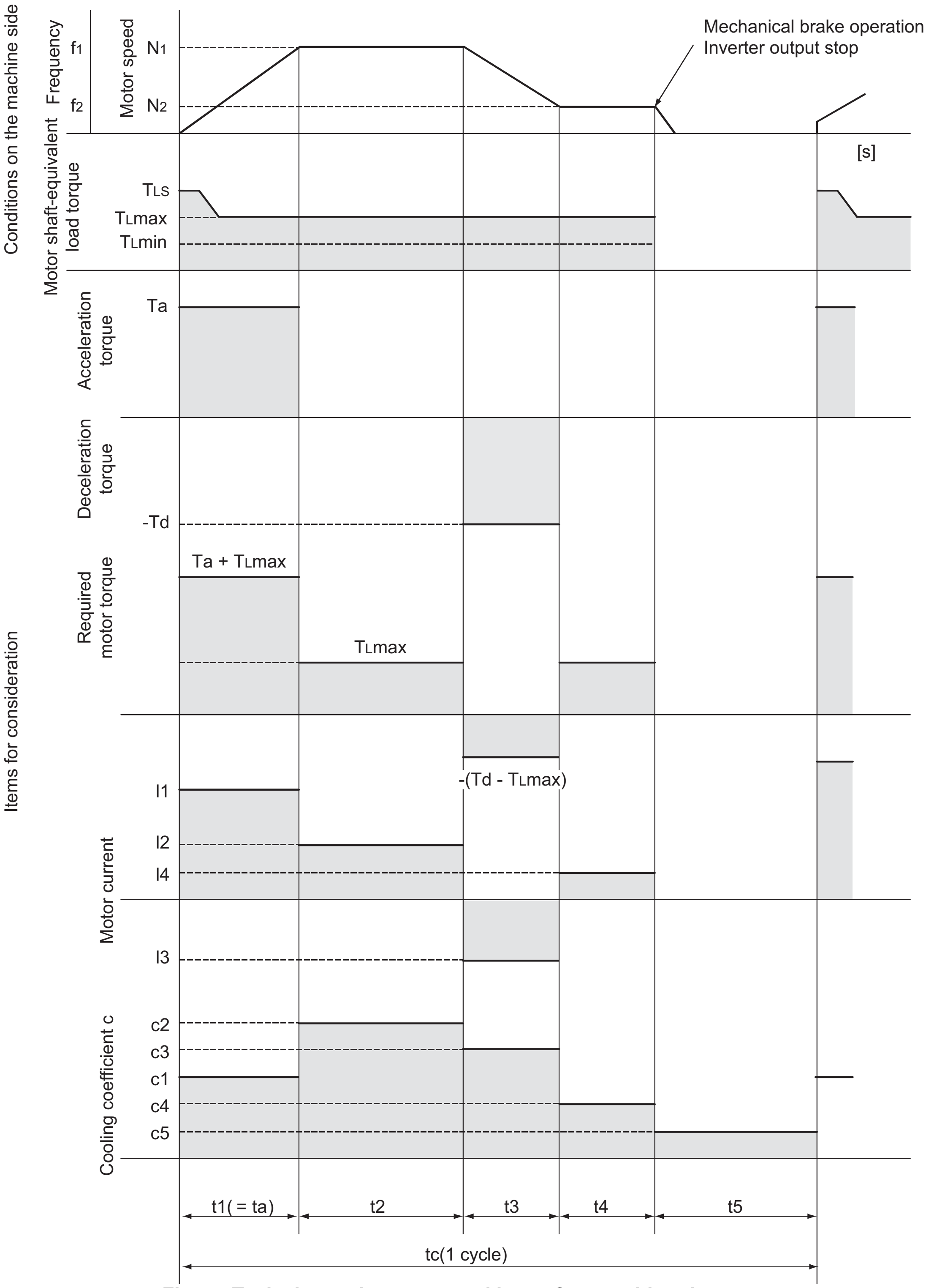


Fig.5.7 Typical speed patterns and items for consideration

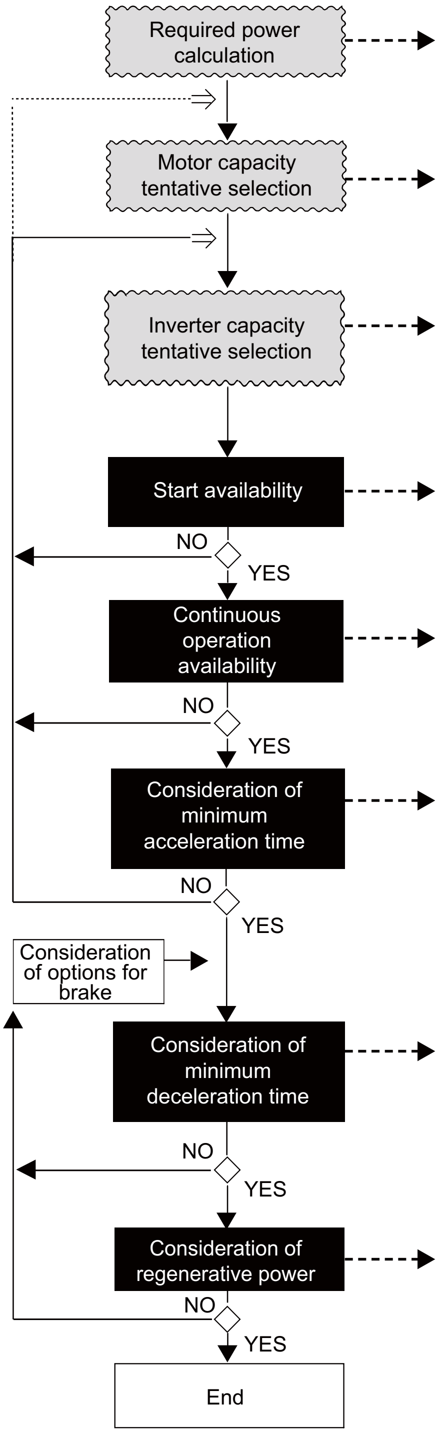
Table5.1 List of data symbol and unit

	Data	Symbol	Unit
Machine side data	Required power	P_L	kW
	Motor capacity	P_M	kW
	Number of motor poles	P	—
	Motor speed	N	r/min
	Frequency	f	Hz
	Travel speed	V	m/min
	Load mass	W	kg
	Machine efficiency	η	—
	Friction coefficient	μ	—
	Motor shaft-equivalent load torque	T_L	N·m
	Motor shaft-equivalent start load torque	T_{LS}	N·m
	Motor shaft-equivalent load inertia moment	J_L	kg·m^2
	Inertia moment of motor shaft-equivalent mechanical brake	J_B	kg·m^2
	Cycle time (1 cycle)	tc	s
	Time for each running interval	tn	s
	Acceleration time	ta	s
	Deceleration time	td	s
	Minimum acceleration time	tas	s
	Minimum deceleration time	tds	s
	Acceleration	Acc	m/s^2
Data used for consideration	Rated motor speed	N_M	r/min
	Rated motor torque	T_M	N·m
	Maximum motor start torque	T_{MS}	N·m
	Acceleration torque	Ta	N·m
	Deceleration torque	Td	N·m
	Load torque ratio	TF	%
	Motor inertia moment	J_M	kg·m^2
	Maximum torque coefficient for short time *	αm	—
	Continuous operation torque coefficient *	αc	—
	Maximum start torque coefficient *	αs	—
	Acceleration torque coefficient *	αa	—
	Brake torque coefficient (Generic name) *	β	—
	Hot coefficient *	δ	—
	Cooling coefficient *	C	—
	Motor current	I	%
	Motor equivalent current value	I_{MC}	%
Regenerative power	Regenerative power absorbed by a motor	W_M	W
	Average power regenerated to the inverter	W_{INV}	W
	Average power regenerated from a machine	W_{MECH}	W
	Continuous permissible power of braking unit	W_{RC}	W
	Permissible power for short time per running of the braking unit	W_{RS}	W
Stop accuracy	Stop time	tb	s
	Coasting distance	S	mm
	Stop accuracy	$\Delta\varepsilon$	mm

* For the coefficient for each data, refer to the Technical Note No.30 (Capacity Selection II [Data]) and the Technical Note No.31 (Capacity Selection II [Selection]) by Mitsubishi Electric.

5.4.1 Consideration procedure for vertical lift operation

Selection flowchart

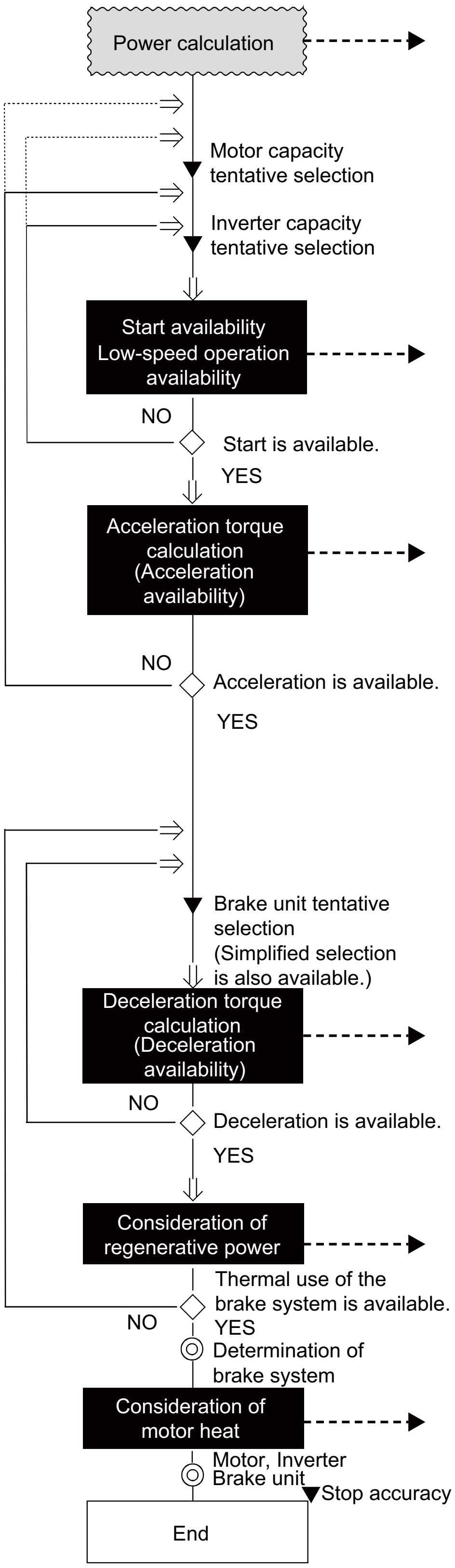


Selection outline	Judgment
●Calculate the required power for consideration.	(Required power P_L) (Load torque T_L)
●Tentatively select the motor capacity to be used according to the size of the required power.	Motor capacity P_M ≥ Required power P_L Rated motor torque T_M ≥ Load torque T_L
●Tentatively select the inverter capacity compatible with the tentatively selected motor capacity.	Inverter capacity P_{INV} ≥ Motor capacity P_M (Rated inverter output current > Rated motor current)
●Consider the start availability since the motor must start rotation from stop for the operation.	Motor start torque T_{MS} > Load torque at start T_{LS}
●Consider whether the magnitude of load is within the permissible temperature of the motor.	Motor continuous operation torque T_{MC} > Load torque T_L
●Calculate the minimum value of the acceleration time. ●Consider whether the planned acceleration time is satisfied.	Minimum acceleration time tas < Planned acceleration time ta Minimum acceleration time tas ≤ 45 seconds
●Calculate the minimum value of the deceleration time. ●Consider whether the planned deceleration time is satisfied. ●Calculate the torque required for deceleration from the deceleration time during operation.	Minimum deceleration time tds < Planned deceleration time td Deceleration torque Td
●Consider the processing capacity of the regenerative power during deceleration.	Permissible power for short time W_{RS} > Regenerative power during deceleration W_{INV}
●Consider the processing capacity of the regenerative power during the continuous regenerative operation.	Continuous permissible power W_{RC} > Regenerative power during the continuous operation W_{INV}

Calculation formula, etc.	Reference material/item	Remarks (precautions, etc.)
● Load torque T_L $T_L = 9550 \times P_L/N$ [N・m]	● Technical Note No.30 [required power calculation] (Refer to the appendix)	● Note the reduction of motor output torque for operation at 60Hz or more. Avoid torque insufficiency.
● Rated motor torque T_M $T_M = 9550 \times P_M/N_M$ [N・m]	● Motor catalog/Instruction manual ● Technical Note No.30 Refer to [Table of characteristics] in Chapter 4 Motor/Brake Characteristics.	● The permissible motor speed (operating frequency range) differs according to the motor capacity, pole numbers and model.
—————————	●Inverter catalog (Standard specifications)	● The motor generated torque differs according to the inverter type or the control. (Magnetic flux vector control < V/F control) ● A built-in brake circuit may or may not exist depending on the inverter type.
● Motor start torque = Maximum start torque Maximum start torque $T_{MS} = T_M \times \alpha s \times \delta > T_{LS}$	●Technical Note No.30 Refer to [Data for each torque type] in Chapter 2 Driving Capability Data. αs: Maximum start torque coefficient δ: Hot coefficient	● The start torque of the magnetic flux vector control is larger than that of the V/F control. ● The start torque can be improved just by increasing the inverter capacity.
Continuous operation torque coefficient αc > Load torque ratio $TF = T_L/T_M$ or Continuous operation torque $T_M \times \alpha c > $ Load torque T_L	●Technical Note No.30 Refer to [Continuous torque] in Chapter 2 Driving Capability Data. αc: Continuous operation torque coefficient	● For the magnetic flux vector control, the continuous operation torque range becomes larger with the motor capacity.
● Minimum acceleration time tas $tas = \dfrac{(J_L + J_M) \times N}{9.55 \times (T_M \times \alpha_a - T_{Lmax})}$ [N・m]	● Technical Note No.30 Refer to [Torque type] in Chapter 2 Driving Capability Data. αa: Acceleration torque coefficient	● The acceleration torque of the magnetic flux vector control is larger than that of the V/F control. ● Recalculate with the linear acceleration torque coefficient when the minimum acceleration time exceeds 45 seconds.
●Minimum deceleration time tds $tas = \dfrac{(J_L + J_M) \times N}{9.55 \times (T_M \times \beta + T_{Lmin})}$ [N・m] ●Deceleration torque Td	● Technical Note No.30 Refer to [Braking capability torque types] in Chapter 3 Driving Capability Data. β: Deceleration torque coefficient	● The value of the minimum deceleration time differs according to the presence/absence of a built-in brake resistor. ● Consider using options for the brake when the minimum deceleration time is larger than that planned.
●Regenerative power from a load W_{MECH} ●Power absorbed by the motor W_M ●Regenerative power to the inverter $W_{INV} = W_{MECH} - W_M$ [W]	● Technical Note No.30 Refer to [Braking capability torque types] in Chapter 3 Driving Capability Data. W_{RS}: Permissible power for short time W_{RC}: Continuous permissible power	●The capacity of regenerative power (permissible power) differs according to the inverter type and capacity. ●The power regeneration converter may be required for continuous regeneration.

5.4.2 Consideration procedure for cycle operation

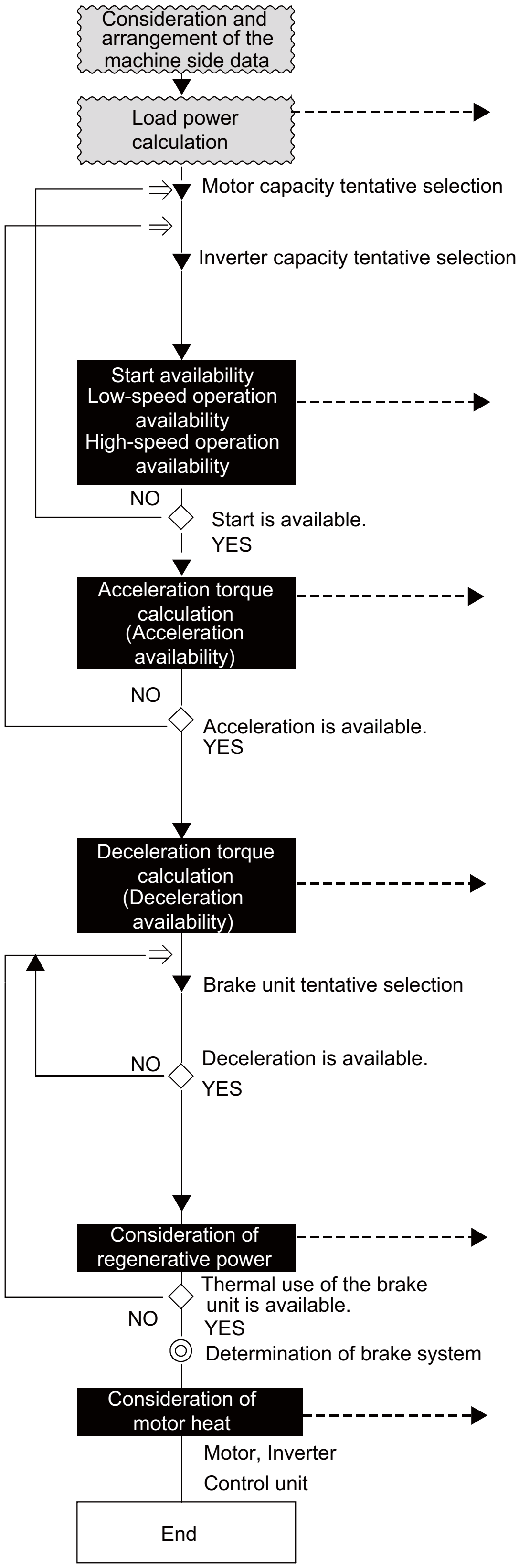
Selection flowchart



Selection outline	Judgment
$P_L = \dfrac{\mu W \times V}{6120 \times \eta}$ [kW] Also calculate the load torque and inertia moment.	Tentatively selected motor capacity $P_M > P_L$
(1) Select the motor capacity larger than the required power.	
(1) Select the inverter equivalent to the motor capacity. (2) Increase the inverter capacity for the acceleration torque increase as necessary.	Tentatively selected inverter capacity ≥ P_M
• Check that the motor start torque and the torque at low speed are larger than the load torque. δ: Motor hot coefficient	$T_{MS} > T_{LS}$ $T_M \times \alpha_m \times \delta > T_{LS}$
• Calculate the relationship between the acceleration speed and the acceleration time • Acceleration torque $Ta = \dfrac{\Sigma J \times Nmax}{9.55 \times ta}$ [N · m] • Calculate the torque required for acceleration αa: Linear acceleration torque coefficient	$\alpha a > \dfrac{Ta + T_{Lmax}}{T_M}$
• Deceleration torque $Td = \dfrac{\Sigma J \times Nmax}{9.55 \times td}$ [N · m] • Calculate the torque required for deceleration. βmin: Brake torque coefficient	$\beta min > \dfrac{Td - T_{Lmin}}{T_M}$
(1) Check the permissible power for short time. (2) Check the average regenerative power. W_{INV}: Power regenerated to the inverter td: Deceleration time during 1 cycle tc: Entire time of 1 cycle	$W_{INV} < W_{RS}$ $W_{INV} \times td/tc < W_{RC}$
Check that the equivalent current value does not exceed 100%. $I_{MC} = \sqrt{\dfrac{\Sigma(In^2 \times tn)}{\Sigma(Cn \times tn)}} < 100$ [%]	
• Calculate the stop accuracy of the mechanical brake.	

5.4.3 Consideration procedure for vertical lift operation

Selection flowchart



Selection outline

Required power $P_L = \dfrac{W \times V}{6120 \times \eta}$ [kW]

(1) Select the motor capacity larger than the required power.
(2) Increase the motor capacity for the start torque increase.

(1) Select the inverter equivalent to the motor capacity.
(2) Increase the inverter capacity for the acceleration torque increase.

(1) Motor start torque T_{MS} > Load torque at start T_{LS}
(2) Motor torque at low speed
$T_M \times \alpha m \times \delta$ > Load torque T_L
(3) Motor torque at high speed
$T_M \times \alpha m$ > Load torque T_L

Acceleration torque

$$Ta = \frac{\Sigma J \times N}{9.55 \times ta} \quad [\mathrm{N \cdot m}]$$

Ta: Acceleration torque
ta: Acceleration time [s]

Consider the availability of acceleration.
$Tamax < \alpha a \times T_M$ αa: Acceleration torque coefficient

Deceleration torque

$$Td = \frac{\Sigma J \times N}{9.55 \times td} \quad [\mathrm{N \cdot m}]$$

Td: Deceleration torque
td: Deceleration time [s]

$Tdmax < \beta min \times T_M$
β min: Brake torque coefficient
(Tentatively select the brake unit according to Data volume of the technical note.)

(1) Check the permissible power for short time.
$W_{INV} < W_{RS}$
(2) Check the continuous permissible power.
$W_{INV} \times t/tc < W_{RC}$
W_{INV}: Power regenerated to the inverter
t: Time taken for the minus load torque [s]
tc: Entire time of 1 cycle [s]

Motor equivalent current value

$$I_{MC} = \sqrt{\frac{\Sigma(In^2 \times tn)}{\Sigma(Cn \times tn)}} < 100 \quad [\%]$$

[Notes]

The difference between elevator applications from other applications is that the elevator application has a positive torque load mode (usually rising) and negative torque load mode (usually lowering), and cycle time operation with specified position stop is always performed. The following section explains the precautions for using a general-purpose inverter for such applications.

(1) Vertical lift operation

- Control method

  For the following reasons, it is preferable to select Advanced magnetic flux vector control, Real sensorless vector control or vector control.
- An elevator is always accompanied by the overload operation. Therefore, the start torque of 150% or more is required.
- For an elevator with counterweight, the negative load may be generated even at rise according to the load magnitude. The output voltage must be optimally controlled to avoid the overcurrent.

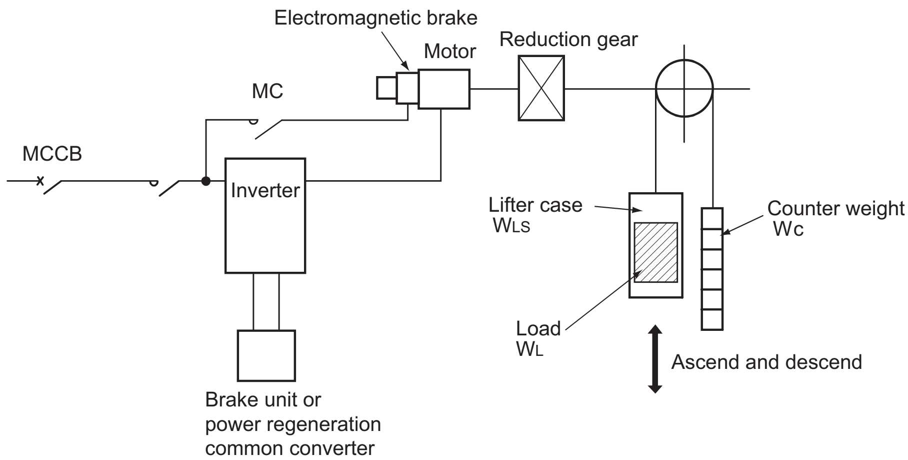


Fig.5.8 Configuration example of lift with counterweight

- Mechanical brake opening timing

  Open : For avoiding a drop of the load, open the mechanical brake after the RUN (running) signal of the inverter is turned on with the start signal.

  Close: For avoiding abrasion of the brake lining and overcurrent, fully decelerate, close the mechanical brake and turn on the inverter MRS (output stop) signal.
- Descending operation

  Rotation by a load causes the regenerative operation in many cases.

  Since the inverter cannot independently absorb the regenerative energy, a braking option (power regeneration converter, brake unit, etc.) is required.
- Motor selection

  If the continuous operation is not performed at low speed, the constant torque motor is not required.

Remark

In FR-A800 series, the brake sequence function A100 (Pr. 278) to A106 (Pr. 285), A110 (Pr. 292), A108 (Pr.639) to A126 (Pr.648), A128 (Pr.650), A129 (Pr.651)) prevents load slippage at start due to poor brake timing and overcurrent alarm in stop status. (Refer to FR-A800 Instruction Manual (Detailed))

(2) Regenerative operation

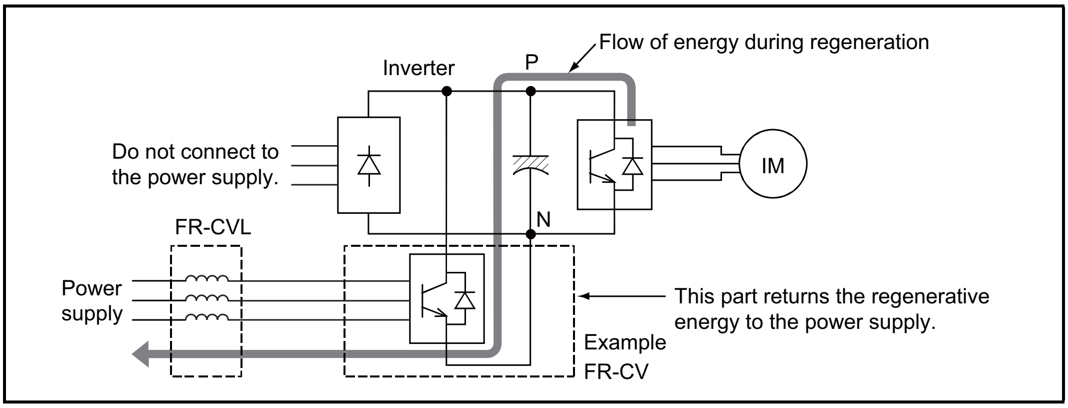


Fig.5.9 Regenerative operation

When the motor is rotated by an external force (e.g. gravity) such as the descending operation of a lift, the energy generated by the motor as a generator is stored in the smoothing capacitor, and the voltage between the both capacitor ends (between terminals P and N) increases.
This status is called a regenerative operation.
When this regenerative energy is absorbed by the following systems, the braking power is generated in the motor.

Resistance consumption system	: This system consumes the regenerative energy with heat. Since the initial cost is low, it is suitable for a small capacity inverter.
Power regeneration system	: This system returns the regenerative energy to the power supply. Since large braking power can be expected with an energy saving effect, it is suitable for a large capacity inverter.

★It should be fully noted that when the braking unit capacity is insufficient, the voltage between both capacitor ends (between terminals P and N) increases and the inverter falls into OVT (regenerative overvoltage) trip.
Setting G002(Pr.19) (Base frequency voltage) in the inverter according to the power supply voltage prevents the frequent occurrence of the OCT (overcurrent) alarm during regeneration.

(3) Low-speed operation

●Low-speed torque

Torque shortage is likely to occur during low-speed operation by inverter. Use a control method (Advanced magnetic flux vector control, Real sensorless vector control, etc.) that can generate high torque, or make an appropriate torque boost setting to meet the machine application.

●Motor temperature rise

When the continuous operation is performed at low speed, the motor temperature rise becomes large.
Fully consider using a constant torque motor or reviewing the operation pattern.
The appropriate boost setting is also effective to suppress the temperature rise during low-speed operation.

- Stable operation
  High torque at start or at low speed does not exactly mean that smooth operations can be performed at low speed.
  To know how slowly smooth operations can be performed, the speed control range is used.
  For applications to be operated smoothly at ultra low speed, the vector control (speed control range 1:1500) or PM sensorless vector control (speed control range 1:1000) are the most suitable.
  <<Example>>
  The speed control range 1:200 (Real sensorless vector control) means that if the maximum speed is performed at 60Hz, 1/200 of the frequency, i.e. up to 0.3Hz, is the applicable range for a smooth operation.

Useful information

★ The encoder speed feedback operation of FR-A800 series, etc. is highly effective for moderate load fluctuation. However, it should be noted that the operation may be unstable sometimes due to the control response delay against the uneven rotation by torque ripples at low speed and therefore does not completely solve the issue.

(4) Inverter and mechanical safety brake

A lift must be equipped with a mechanical safety brake for holding products for ascending and descending.
This safety brake is also used for the positioning stop of vertical lifting. An interlock circuit must be installed to prevent the conflict with the deceleration torque from the inverter regenerative brake.

(5) Selecting a fast response inverter

A fast response speed such as one to two seconds to reach high speed is required for lift acceleration/deceleration time.

(6) Configurating a fail-safe system for safety

The lift may naturally drop when the motor torque is lost due to inverter protective circuit activation, power failure, power-off or motor stop. Configure a fail-safe sequence ladder in consideration of this risk.
It is also recommended to install the overspeed relay on the machine side in case a motor should stall.

(7) Measures against vibration/impact and cable disconnection

When an inverter is installed into a moving machine such as a crane, measures must be fully taken against vibration, impact and the overrun by power cable disconnection.

5.5 Capacity selection software

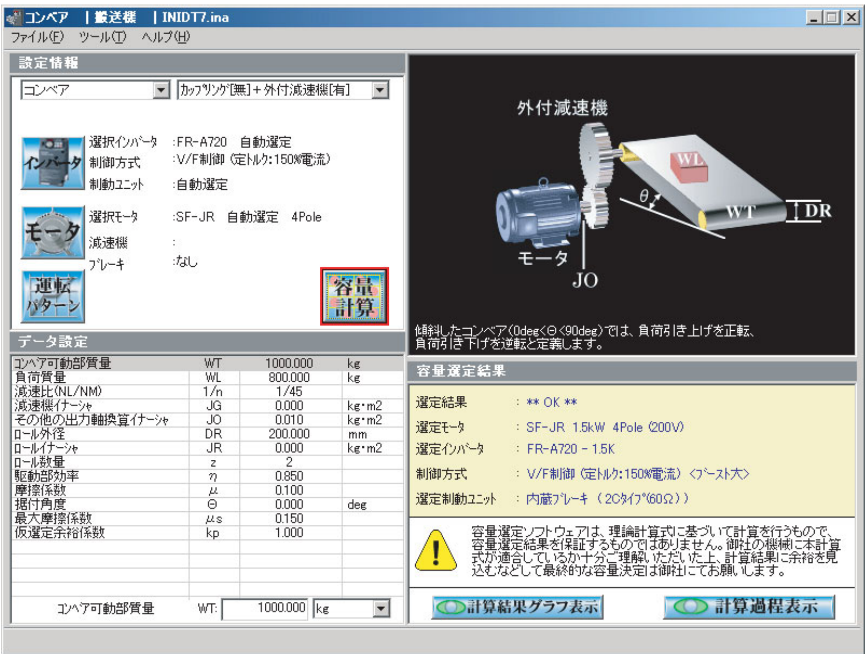
Just select a machine structure and enter the data. This software calculates capacities automatically. Useful tool functions such as inertia calculation and unit conversion are also available with the software.
The software is available for downloading from the following website.
Mitsubishi Electric FA Website http://www.MitsubishiElectric.co.jp/fa/

(1) For inverter (FR-SW2-SEL-WJ)

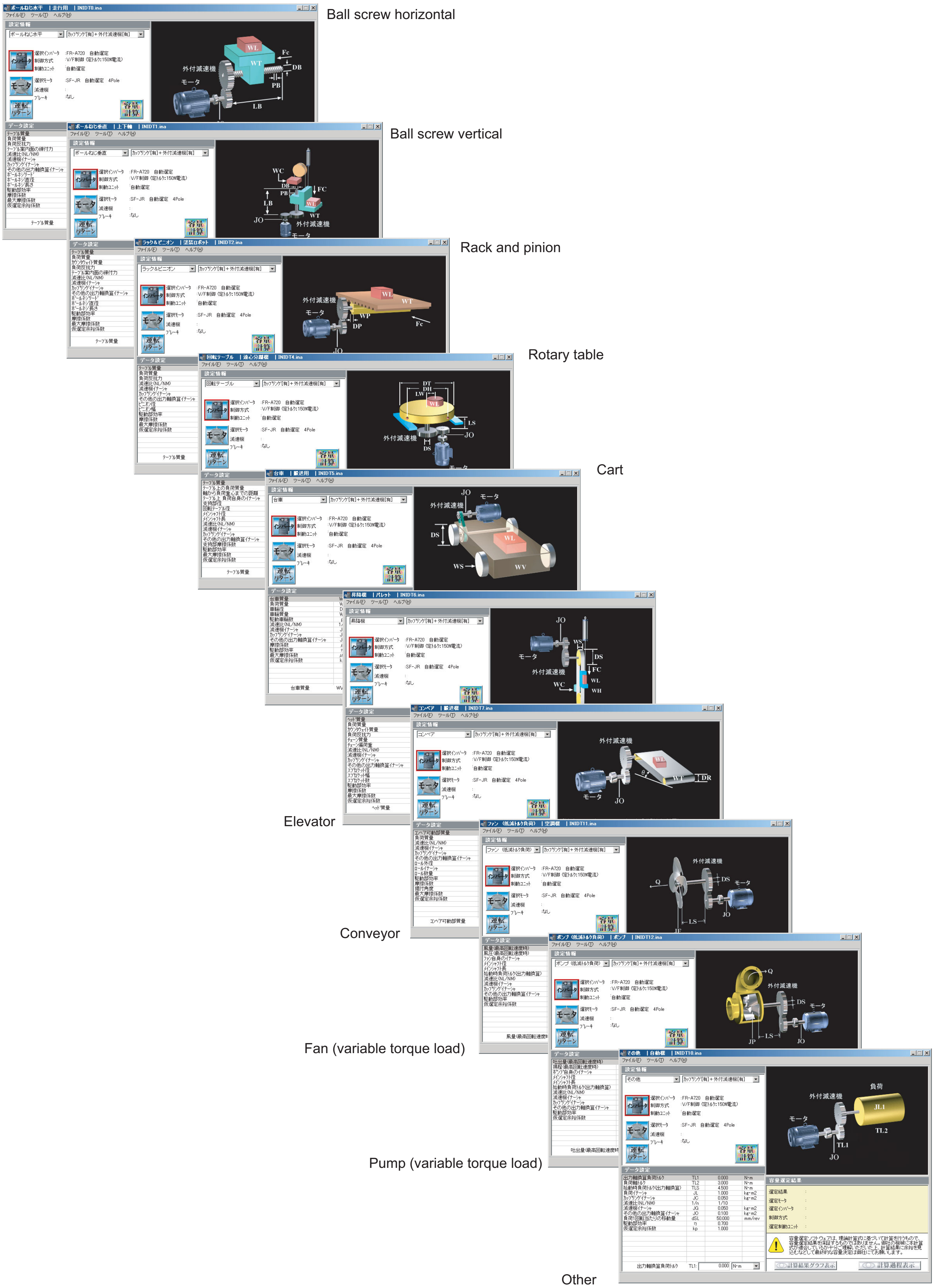
(1) Specification

Item		Specification
Type of machine structure component		Ball screw horizontal, ball screw vertical, rack and pinion, rotary table, cart, elevator, conveyor, fan (variable torque load), pump (variable torque load), other (inertia direct input)
Result output	Item	Selection of inverter model, motor model, brake unit, and control method
	Printing	Prints entered specifications, operation pattern, calculation process, motor speed (feed rate), torque graph, and sizing results.
	Data saving	Entered specifications, operating patterns, sizing results, and fax forms are saved with a file name.
Moment of inertia calculation function		Cylinder, misalignment prism, speed, linear motion, suspension, cone, truncated cone

(2) Input screen (Example of conveyor)



(3) Input screen examples other than for conveyor



(4) Example of calculation

The details of calculation can be checked and also printed out.

```
****************************************************************************************************
  サイクル運転 計算過程      [ コンベア   |   搬送機   | INIDT7.ina ]
****************************************************************************************************

<< 負荷・運転仕様 >>
1.ﾓｰﾀ1回転当たりの移動量
      dS = π x DR x 1/n x 1/nm
         = 3.14159 x 200.000 x 1/45 x 1.000
         = 13.962634  [mm/rev]

2.移動速度・ﾓｰﾀ回転速度・運転周波数
    Vn = Nn x dS / 1000   [m/min]    (移動速度)
    Nn = Vn / dS x 1000   [r/min]    (回転速度)
    fn = Nn x Pole / 120  [Hz]       (運転周波数)
```

運転ﾊﾟﾀｰﾝ	回転速度 [r/min]	移動速度 [m/min]	運転周波数 [Hz]	max	min
1	V1 = 0 ～ 8.378	N1 = 0 ～ 600.000	f1 = 0 ～ 20.000		*
2	V2 = 8.378 ～ 8.378	N2 = 600.000 ～ 600.000	f2 = 20.000 ～ 20.000		*
3	V3 = 8.378 ～ 0	N3 = 600.000 ～ 0	f3 = 20.000 ～ 0		
4	V4 = 0 ～ 25.133	N4 = 0 ～ 1800.000	f4 = 0 ～ 60.000	*	
5	V5 = 25.133 ～ 25.133	N5 = 1800.000 ～ 1800.000	f5 = 60.000 ～ 60.000	*	
6	V6 = 25.133 ～ 0	N6 = 1800.000 ～ 0	f6 = 60.000 ～ 0		

max：最大運転周波数　　min：最小運転周波数

3.負荷所要動力・負荷ﾄﾙｸ・ｲﾅｰｼｬと負荷質量の関係

負荷質量 WL	負荷 所要動力	ﾓｰﾀ軸換算 負荷ﾄﾙｸ	始動時の 負荷ﾄﾙｸ	直線運動の 物体ｲﾅｰｼｬ	ﾓｰﾀ軸換算 負荷ｲﾅｰｼｬ
無	PLR1	TLR1	TLS1	JF1	JL1
有	PLR2	TLR2	TLS2	JF2	JL2

```
4.負荷所要動力
    PLR1 = (μ x WT x Vmax) / (6120 x η)          (WL無)
         = (0.1 x 1000.000 x 25.133) / (6120 x 0.85)
         = 0.483136   [kW]

    PLR2 = (μ x (WT + WL) x Vmax) / (6120 x η)    (WL有)
         = (0.1 x (1000.000 + 800.000) x 25.133) / (6120 x 0.85)
         = 0.869645   [kW]

5.ﾓｰﾀ換算負荷ﾄﾙｸ
    TLR1 = (μ x WT x g x Vmax) / (2 x π x Nmax x η)             (WL無)
         = (0.1 x 1000.000 x 9.80665 x 25.133) / (2 x 3.14159 x 1800.000 x 0.85)
         = 2.56383    [N·m]

    TLR2 = (μ x (WT + WL) x g x Vmax) / (2 x π x Nmax x η)      (WL有)
         = (0.1 x (1000.000 + 800.000) x 9.80665 x 25.133) / (2 x 3.14159 x 1800.000 x 0.85)
         = 4.614894   [N·m]

6.始動時負荷ﾄﾙｸ
    TLS1 = (μs x WT x g x Vmax) / (2 x π x Nmax x η)            (WL無)
         = (0.15 x 1000.000 x 9.80665 x 25.133) / (2 x 3.14159x 1800.000 x 0.85)
         = 3.845745   [N·m]

    TLS2 = (μs x (WT + WL) x g x Vmax) / (2 x π x Nmax x η)     (WL有)
         = (0.15 x (1000.000 + 800.000) x 9.80665 x 25.133) / (2 x 3.14159 x 1800.000 x 0.85)
         = 6.922341   [N·m]

7.直線運動する物体のｲﾅｰｼｬ
     JF1 = WT x (dS / 20π)^2 x 10^-4           (WL無)
         = 1000.000 x (13.962634 / (20 x 3.14159))^2 x 10^-4
         = 0.004938   [kg·m2]

     JF2 = (WT + WL) x (dS / 20π)^2 x 10^-4    (WL有)
         = (1000.000 + 800.000) x (13.962634 / (20 x 3.14159))^2 x 10^-4
         = 0.008889   [kg·m2]
```

(5) Sizing example

● Carrier machine (Conveyor)

Machine structure component	Conveyor
Coupling/external reduction gear	Coupling (without) + external reduction gear (with)
Selection of inverter	FR-A800 (automatic selection)
Control method	V/F control (constant-torque: 150% current)
Brake unit	Automatic selection
Selection of motor	SF-JR 4P (Automatic selection)
Reduction gear	-
Brake	Without

● Specifications

Mass of conveyor moving part	WT	1000.000	kg
Load mass	WL	800.000	kg
Reduction ratio (NL/NM)	1/n	1/45	
Reduction gear inertia	JG	0.000	kg・m^2
Converted inertia value for other output axis	JO	0.010	kg・m^2
Roll outer diameter	DR	200.000	mm
Roll inertia	JR	0.000	kg・m^2
Roll quantity	Z	2	
Efficiency of driving parts	ε	0.850	
Friction coefficient	η	0.100	
Installation angle	θ	0.000	
Maximum friction coefficient	μs	0.150	
Temporary selection margin coefficient	κp	1.000	

● Operation pattern

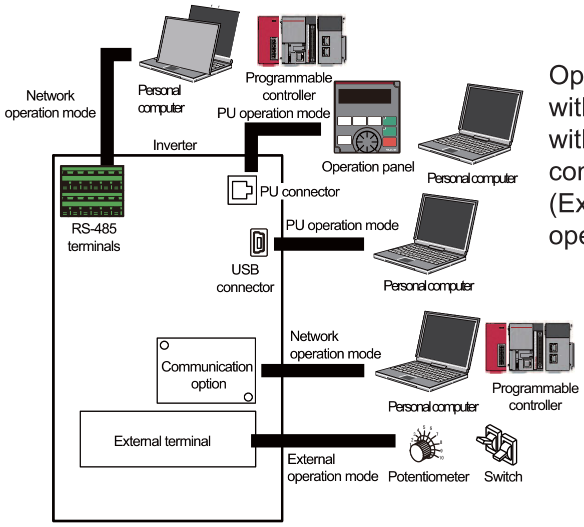
	Travel speed [m/min]	Operation frequency [Hz]	Time [second]
1)	v1 = 0 to 8.378	f1 = 0 to 20	2
2)	v2 = 8.378 to 8.378	f2 = 20 to 20	7
3)	v3 = 8.378 to 0	f3 = 20 to 0	2
4)	v4 = 0 to 25.133	f4 = 0 to 60	6
5)	v5 = 25.133 to 25.133	f5 = 60 to 60	9
6)	v6 = 25.133 to 0	f6 = 60 to 0	6

5.6 Operation Method

5.6.1 Types of operation methods

A major characteristic of the inverter is the operation with various signals. Operation methods of an inverter (start, stop and variable speed) are roughly classified as follows.
The explanation is given using the inverter FR-A800 series as an example.

Basic configuration

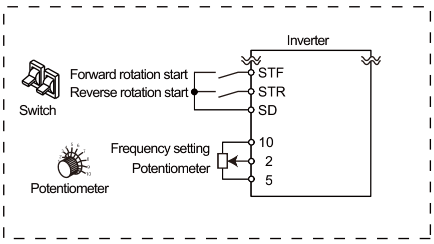


Operation mode can be selected from: the operation with external signals (External operation), operation with PU (FR-DU08/FR-LU08) (PU operation), combined operation with PU and External operation (External/PU combined operation), and the Network operation.

1) Operation with external signals — D000 (Pr.79)=0,2 — External start and stop signals (STF, STR) + External frequency setting signals

- Frequency setting potentiometer (volume)
- External signals 0 to 5, 0 to 10VDC
- Analog signals 4 to 20mADC
- Digital signals (BCD, binary)
- Contact signals (Multi-speed setting)
- Pulse train

When an external frequency setter or start switch, etc. is connected to a control circuit terminal of the inverter.

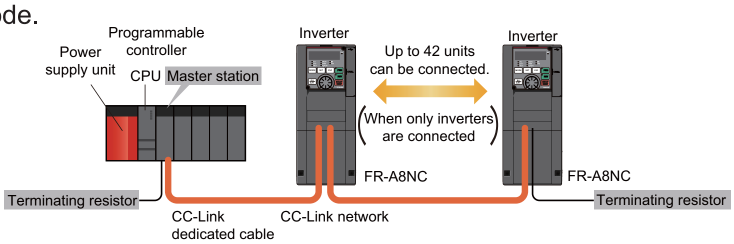


When power is switched ON or when power comes back ON after an instantaneous power failure, the inverter can be started up in the Network operation mode.

D001 (Pr.340) =1,2,10,12

- Computer link · · · Operated in combination with a computer
- CC-Link · · · Operated in combination with a PLC

etc.



2) PU operation with operation panel or parameter unit (option)

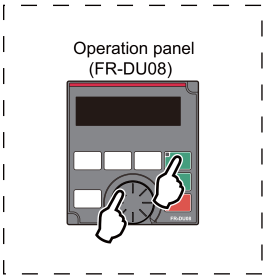
D000 (Pr.79)=0,1

Only the keys of the operation panel or parameter unit are used.

PU start signal (FWD) (REV) + PU frequency setting signal

Operation setting of the PU keys.

Only the keys of the operation panel or parameter unit are used.



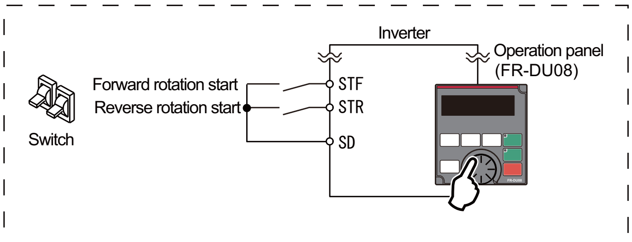
3) PU/External combined operation

When a frequency is set with operation panel or parameter unit, and a start command is given by an external start switch.

D000 (Pr.79)=3

External start and stop signals (STF, STR) + Frequency setting by PU

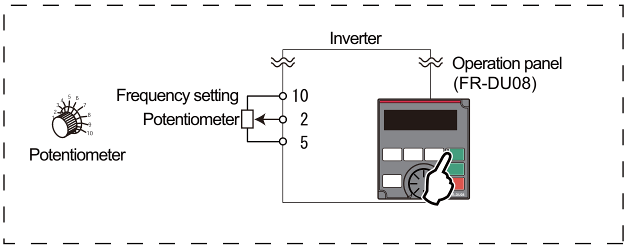
Operation setting by the PU keys.



PU start, Stop signal (FWD) (REV) + External frequency setting signals

When a frequency is set with external potentiometer, multi-speed signal, or JOG signal, and a start command is given by keys of the operation panel or parameter unit.

D000 (Pr.79)=4



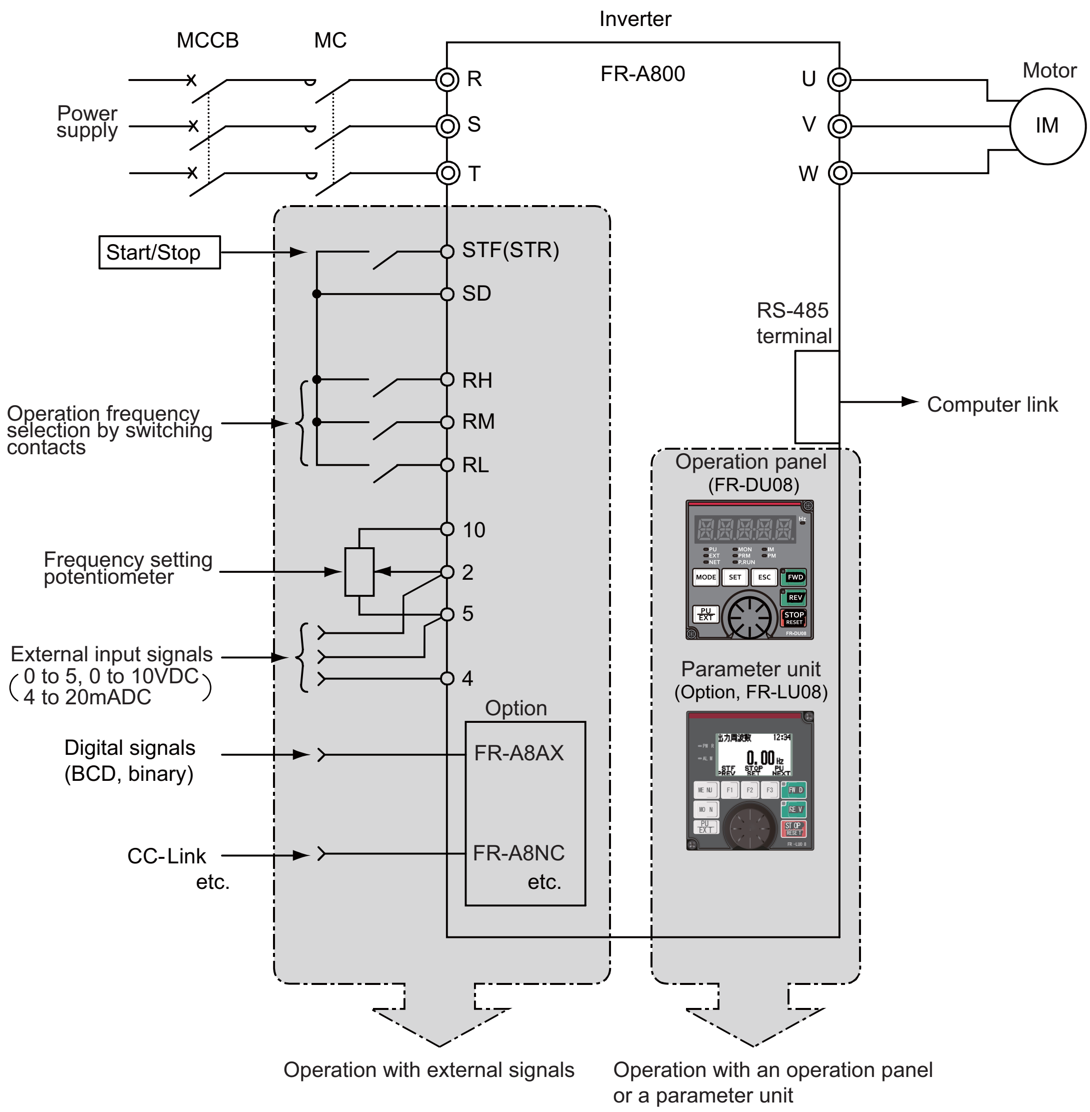


Fig.5.10 Operation method of inverter

5.6.2 Operation procedure outline

The general procedure for "Operation with external signals" is as follows.

Power-on	Function setting	Start	Operation	Stop	Power-off
The input side magnetic contactor MC is turned on.	Set values of the functions required for the parameter unit. (For first-time operation)	When the start signal is turned on, the inverter starts and accelerates the motor. Terminals STF-SD on (shorted)	Variable-speed operation is performed with the frequency setting signals.	When the start signal is turned off, the inverter decelerates and stops the motor. Terminals STF-SD off (open)	The input side magnetic contactor MC is turned off.

5.6.3 Overview of the function setting (parameter setting)

Multiple functions are provided with FR-A800 series, and initial values are set for those functions. Therefore, operations can be performed without setting functions. Set only the necessary functions according to the operation specifications.

(1) When initial values are usable

Function setting is not required.

(2) Functions commonly set

Functions to be used differ according to the operation specifications. The following functions are "the major functions commonly set".

- Acceleration [Function number 7]
- Deceleration [Function number 8]
- Electronic thermal O/L relay [Function number 9]

Function	Pr.	Pr. group	Name	Screen display	Setting range	Minimum setting increment	Initial value FM	Initial value CA
Basic function	0	G000	Torque boost (handle)	Trq.Bst1	0 to 30%	0.1%	6% (Note 1) 4% (Note 1) 3% (Note 1) 2% (Note 1) 1% (Note 1)	
	1	H400	Maximum frequency	Max. F1	0 to 120Hz	0.01Hz	120Hz (Note 2) 60Hz (Note 3)	
	2	H401	Minimum frequency	Min. F1	0 to 120Hz	〃	0Hz	
	3	G001	Base frequency	VFbase F1	0 to 590Hz	〃	60Hz	50Hz
	4	D301	Multi-speed setting (high speed)	PresetF1	0 to 590Hz	〃	60Hz	50Hz
	5	D302	Multi-speed setting (middle speed)	PresetF2	0 to 590Hz	〃	30Hz	
	6	D303	Multi-speed setting (low speed)	PresetF3	0 to 590Hz	〃	10Hz	
	7	F010	Acceleration time	Acc.T1	0 to 3600s	0.1s	5s (Note 4) 15s (Note 5)	
	8	F011	Deceleration time	Dec.T1	0 to 3600s	0.1s	5s (Note 4) 15s (Note 5)	
	9	H000 C103	Electronic thermal Motor rated current	Set THM	0 to 500A (Note 2) 0 to 3600A (Note 3)	0.01A (Note 2) 0.1A (Note 3)	Inverter rated current	
	10	G100	DC injection brake operation frequency	DC Br.F	0 to 120Hz, 9999	0.01Hz	3Hz	
	11	G101	DC injection brake operation time	DC Br.T	0 to 10s, 8888	0.1s	0.5s	
	12	G110	DC injection brake operation voltage	DC Br.V	0 to 30%	0.1%	4% (Note 6) 2% (Note 6) 1% (Note 6)	
	13	F102	Starting frequency	Start F	0 to 60Hz	0.01Hz	0.5Hz	
	14	G003	Applied load selection	Load VF	0 to 5	1	0	

(Note 1) Varies according to capacity.
6%: FR-A820-0.75K or lower, FR-A840-0.75K or lower
4%: FR-A820-1.5K to FR-A820-3.7K, FR-A840-1.5K to FR-A840-3.7K
3%: FR-A820-5.5K, FR-A820-7.5K, FR-A840-5.5K, FR-A840-7.5K
2%: FR-A820-11K to FR-A820-55K, FR-A840-11K to FR-A840-55K
1%: FR-A820-75K or higher, FR-A840-75K or higher
(Note 2) The setting range or initial value for the FR-A820-55K or lower and FR-A840-55K or lower.
(Note 3) The setting range or initial value for the FR-A820-75K or higher and FR-A840-75K or higher.
(Note 4) The setting range or initial value for the FR-A820-7.5K or lower and FR-A840-7.5K or lower.
(Note 5) The setting range or initial value for the FR-A820-11K or higher and FR-A840-11K or higher.
(Note 6) Varies according to capacity.
4%: FR-A820-7.5K or lower, FR-A840-7.5K or lower
2%: FR-A820-11K to FR-A820-55K, FR-A840-11K to FR-A840-55K
1%: FR-A820-75K or higher, FR-A840-75K or higher

Remark

In FR-A800 series, the specification varies by type as shown in the table below.

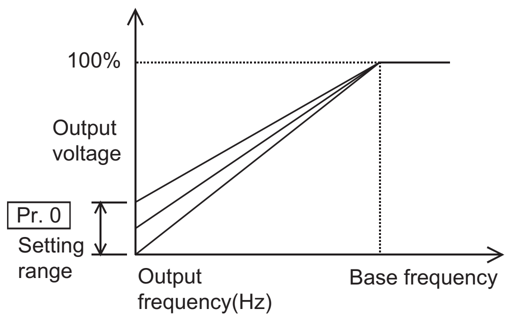
Type	Monitor output	Initial setting			
		Control logic	Rated frequency	Pr.19 Base frequency voltage	Built-in EMC filter
FM (terminal FM equipped model)	Terminal FM (pulse train output) Terminal AM (analog voltage output (0 to ±10 VDC))	Sink logic	60Hz	9999 (same as the power supply voltage)	OFF
CA (terminal CA equipped model)	Terminal CA (analog current output (0 to 20 mADC)) Terminal AM (analog voltage output (0 to ±10 VDC))	Source logic	50Hz	8888 (95% of the power supply voltage)	ON

(3) Parameter number and definition

(Note) Pr. is an abbreviation of Parameter.

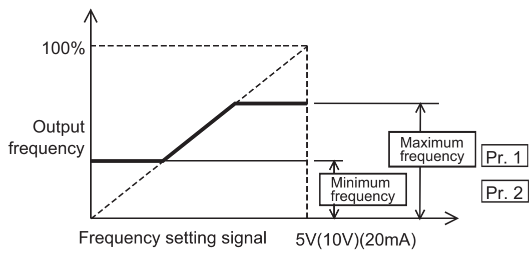
1) G000(Pr.0) Torque boost

This parameter compensates the output voltage for the low speed area under V/F control and increases motor torque at low speeds.
Increase the setting value when the distance to the motor is long or the motor torque in the low speed area is insufficient.
However, if the setting value is increased too much, an overcurrent trip occurs.
The initial values differ depending on the inverter capacity.

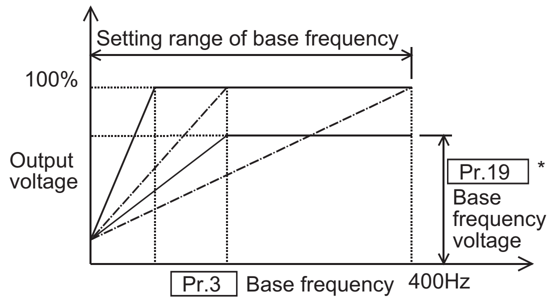


2) H400(Pr.1) Maximum frequency, H401(Pr.2) Minimum frequency

These parameters determine the upper and lower limits of the inverter output frequency.
The inverter clamps the frequency to prevent the frequency from exceeding the upper limit and dropping below the lower limit.
·Initial value H400(Pr.1): 120Hz
H401(Pr.2): 0Hz
For safety measures, set the machine's maximum operation frequency as the maximum frequency.

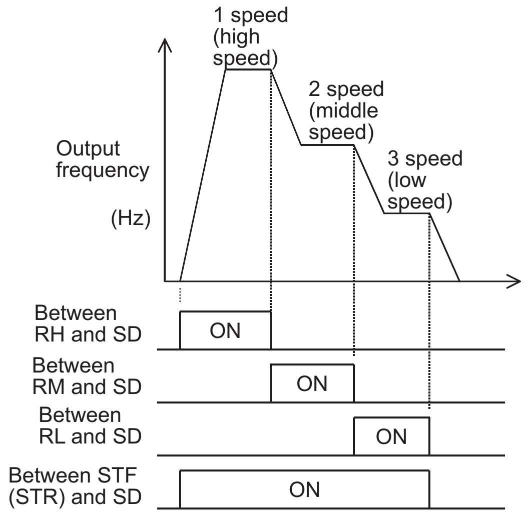


3) G001(Pr.3) Base frequency
This parameter is used to adjust the reference frequency of the inverter to the rating of the motor during V/F control.
·Initial value G001(Pr.3): 60Hz
When operating a standard motor, normally set this parameter to 60Hz.

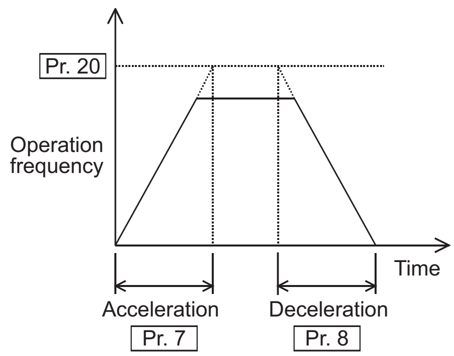


* If Pr.19 is set to 9999 (initial value), the maximum output voltage will be the same as the power supply voltage.

4) D301(Pr.4), D302(Pr.5), D303(Pr.6) Multi-speed settings
These parameters determine the frequency at each operation speed when the operation with external signals switches between three speed levels of high, middle and low. Multi-speed settings have priority over the speed command by analog input signals (0 to 5V, 0 to 10V, 4 to 20mA)
·Initial values
D301(Pr.4): 60Hz (High speed)
D302(Pr.5): 30Hz (Middle speed)
D303(Pr.6): 10Hz (Low speed)
Set these parameters according to the specification of the machine operation.



5) F010(Pr.7) Acceleration time, F011(Pr.8) Deceleration time
These parameters determine the acceleration time and deceleration time when the motor is started and stopped.
Set the acceleration and deceleration times between 0Hz and the F000(Pr.20) setting.
·Initial value F010(Pr.7): 5s
F011(Pr.8): 5s
Set these parameters according to the specification of the machine operation.



6) H000(Pr.9) Electronic thermal relay
This parameter sets the electronic thermal relay function for the motor protection.
Set the current value to protect the motor.
Set the rated current (A) of the motor in H000(Pr.9) Electronic thermal (If the motor has both 50 Hz and 60 Hz ratings and the G001(Pr.3) Base frequency is set to 60 Hz, set to 1.1 times the 60 Hz rated motor current.)
For dedicated motors, set the values on the rating plates.
Such settings will provide the protective characteristic considering the low cooling capability of the motor at low-speed operation.

5.6.4 Starting/Stopping methods

Follow the method described in Fig. 5.11 (1) to start/stop a motor in typical operations. Note the remarks when following the method (2) or (3). Failure to follow the instructed methods may interfere with proper operation or damage the inverter.

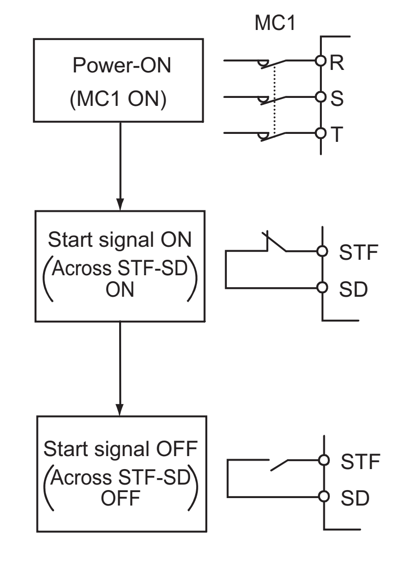
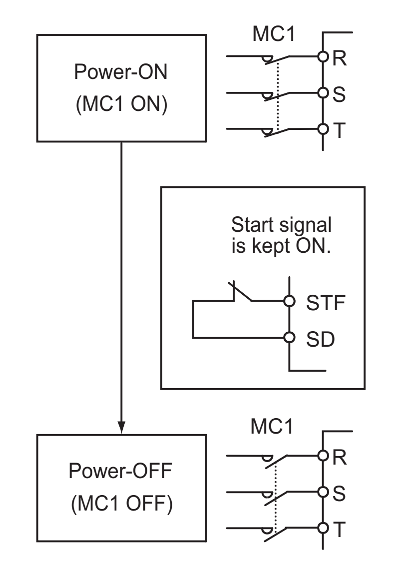
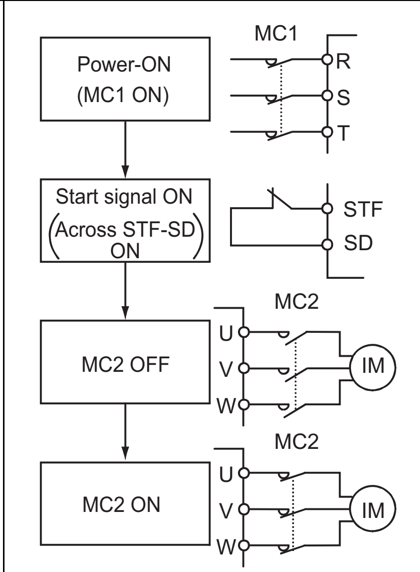
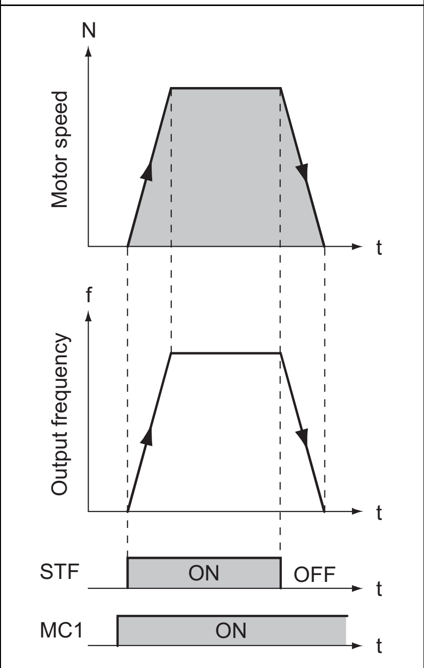
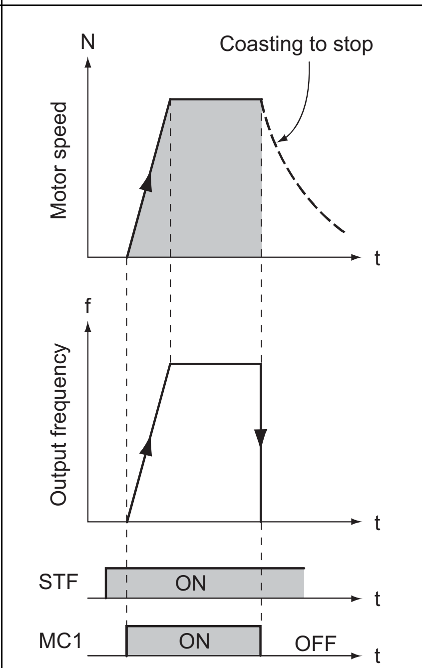
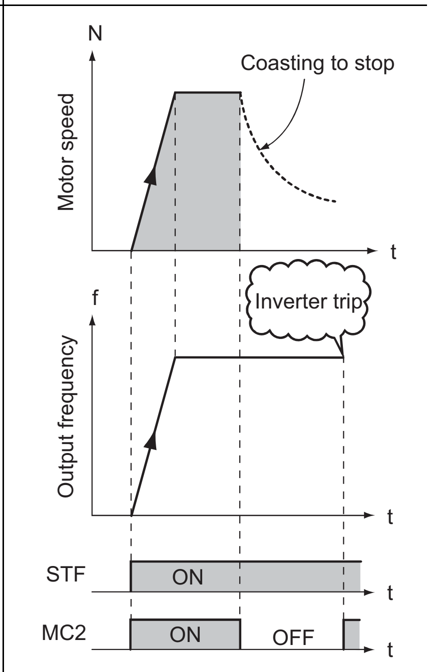
	(1)	(2)	(3)
Method	The motor is started and stopped with the terminals (STF, STR).	The motor is started and stopped with the input side magnetic contactor (MC1) of the inverter.	The motor is started and stopped with the output side magnetic contactor (MC2) of the inverter.
Operation procedure			
Motor speed/inverter output			
Remarks	The motor starts when the terminals STF-SD are turned on and decelerates to stop when they are turned off.	Frequently turning on and off the MC1 may damage the inverter.	When the MC2 is turned on, the overcurrent protection is activated and the inverter trips. Switch OFF and ON while the inverter and motor are both stopped, or use a higher-capacity inverter.

Fig.5.11 Starting/Stopping methods

5.6.5 Start/stop with the input side magnetic contactor MC

(1) An inverter is not designed on the assumption that it is started/stopped with the input side magnetic contactor (MC1).

(2) When the AC power supply is turned on by the input side magnetic contactor (MC1), a large inrush current flows to the large-capacity smoothing capacitor in the inverter. To suppress this current, a short-time rating control resistor is installed at the place shown in Fig.5.12. In addition, a relay or magnetic contactor (MC3) is installed to short both ends of the resistor when charging the capacitor is completed.

(3) When an inverter is frequently turned on/off using the input side MC, the repeated inrush current causes overheat of the control resistor and eventually breakage. If the relay or input side magnetic contactor (MC1) shorting the resistor is turned on in this state, a large inrush current flows into the smoothing capacitor through the converter elements (diodes) for charging. This uncontrolled inrush current damages the converter elements.

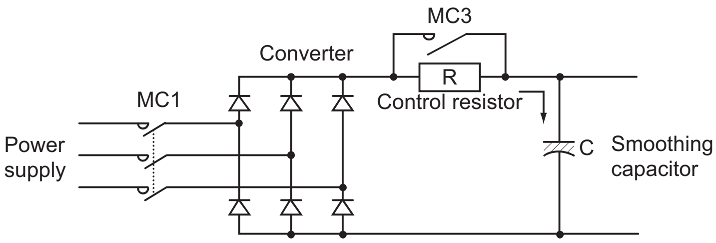


Fig.5.12 Converter circuit

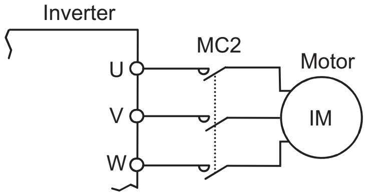
(4) Using MC1 for start/stop operation will damage the converter elements and also shorten the service life of smoothing capacitor shortening relays and a magnetic contactor (MC3). Avoid such usage.

(5) When a motor is stopped by turning off the input side magnetic contactor (MC1), the regenerative brake unique inverter control is not operated. The motor coasts to stop. When an instantaneous power failure or a power failure occurs, the motor also coasts to stop.

☒ Useful information

For a machine which requires the motor (including the inverter) to be shut off from the power supply at the end of every operation to prevent hazardous conditions, it is recommended to use the output side magnetic contactor (MC2) installed between the inverter and the motor for shutting off the motor from the power supply.

(Note)Turn on the output side magnetic contactor (MC2) when the inverter is stopped (output stop). (Turn off the MC2 after turning on the terminals MRS-SD.)



5.6.6 Inverter start during motor coasting

The inverter cannot be started during motor coasting. (Except when the automatic restart after instantaneous power failure function, which performs frequency search at every start, is enabled.) The following explains the reasons and precautions.

(1) A residual voltage is generated in the motor when it coasts to stop. If the voltage is applied to the motor from the inverter in that status, the phases of the motor residual voltage (sine wave) and inverter output voltage (PWM) do not match and the overcurrent occurs. (Reference: The overcurrent is also generated when switching from ⅄ to Δ is performed in the ⅄-Δ starting system on the commercial-power supply operation.)

(2) The inverter always outputs the starting frequency (variable according to 0.5Hz parameter) at start. If the motor is coasting at this time, the regenerative overcurrent occurs due to the rapid braking operation to decelerate the motor to the synchronous speed of the starting frequency. A regenerative overvoltage trip may also occur.

(3) Generally, a coasting interlock timer on the sequence provides an interlock to prevent the inverter from being started during motor coasting.

(4) To continue an operation without stopping the motor in the case of an instantaneous power failure, etc., the automatic restart after instantaneous power failure function is effective.

(5) Activating the automatic restart after instantaneous power failure function, which performs frequency search at every start, enables the inverter to detect the coasting frequency at start and to accelerate the motor in synchronization with the detected frequency.

5.6.7 Using a motor with electromagnetic brake

The following shows the precautions and circuit example when a motor with brake is operated with an inverter.

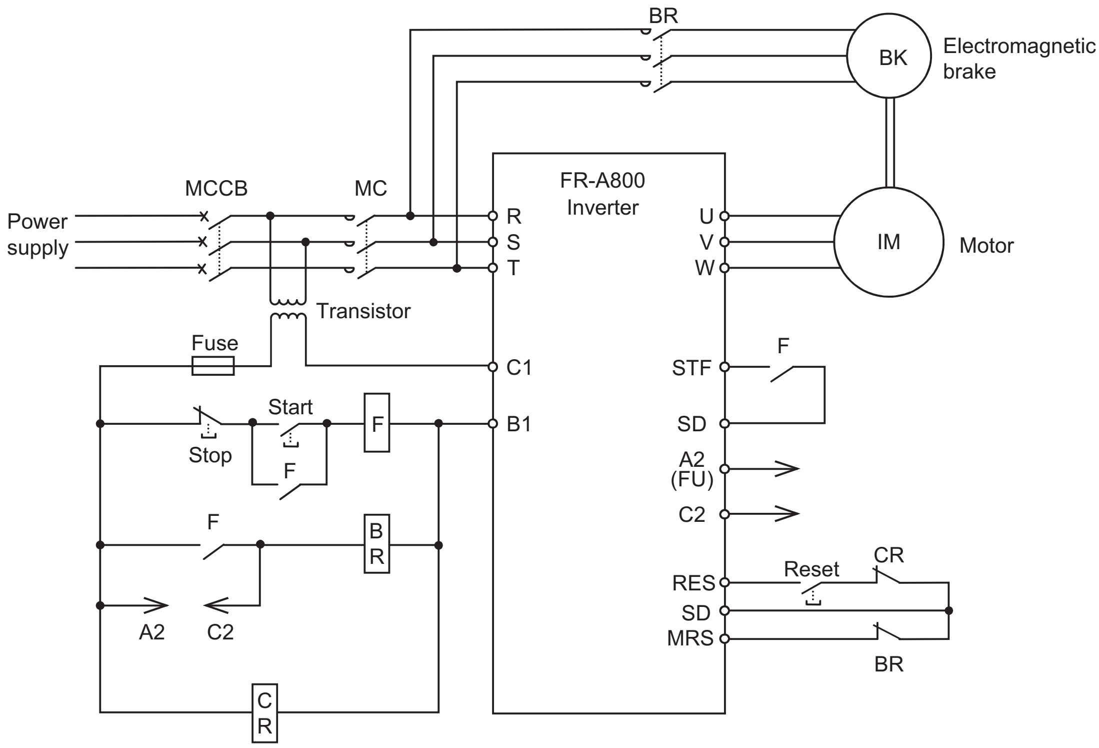


Fig.5.13 Circuit example of motor with brake

(1) Always provide the power supply for brake from the input side of the inverter.

(2) To stop a motor equipped with electromagnetic brake, turn off the inverter output by turning on the inverter output stop terminals across MRS and SD. Otherwise, an overcurrent (E.OC3) may occur when the locked current flows to the motor at braking.

(3) When a motor with brake is used, rattle may be heard depending on the type of the brake during continuous operation at the low speed (30Hz or less). The motor can be used without trouble if used for the low-speed operation in a short time such as a positioning stop.

(4) When an inverter is used with the 400V power distribution system, the operation circuit is controlled by stepping down to 400V/100V or 400V/200V via a stepdown transformer.

(5) Seizing will occur if brake is applied during operation with a frequency higher than the permissible frequency. Check the permissible frequency beforehand if the operating frequency is expected to exceed 60Hz.

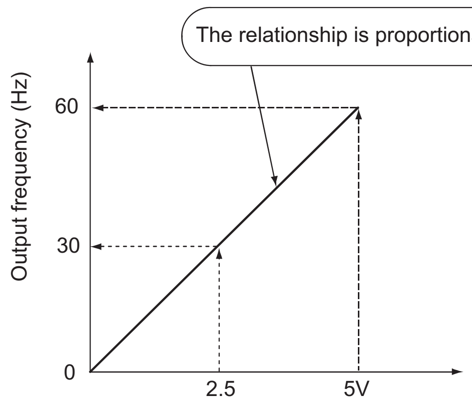
Remark

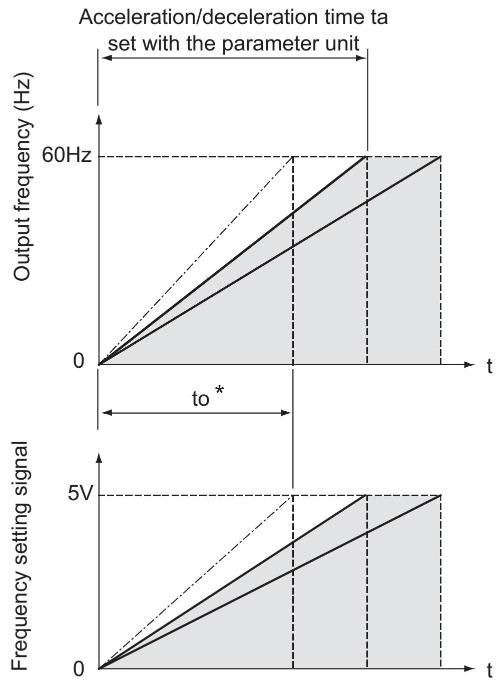
In FR-A800 series, the brake sequence function A100 (Pr. 278) to A106 (Pr. 285), A110 (Pr. 292), A108 (Pr.639) to A126 (Pr.648), A128 (Pr.650), A129 (Pr.651)) prevents load slippage at start due to poor brake timing and overcurrent alarm in stop status. (Refer to FR-A800 Instruction Manual (Detailed))

5.6.8 Frequency setting (select) signals and output frequency

The output frequency can be varied using the following methods.
·Continuously change the frequency setting signal (e.g. 0 to 5VDC, 4 to 20mA).
·Turn the setting dial to change the frequency. (Setting dial potentiometer mode)
(Hold down the ▲ or ▼ key to operate with the parameter unit.)
·Change the frequency step-by-step by switching the multiple frequency setting potentiometers or by switching the multi-speed selection terminals (RH, RM and RL).
(Directly enter the frequency when a parameter unit is used to control.)

(1) Changing the frequency setting value (0 to 5VDC, 4 to 20mA, etc.) continuously





* If the frequency setting signal is started earlier than the acceleration/deceleration time setting value (ta), the acceleration/deceleration time does not become shorter than ta.

Fig.5.14 Variable time of frequency setting signal

(2) Switching among multi-speed selection signals (RH, RM, RL)

·When switched simultaneously ·When switched at some interval

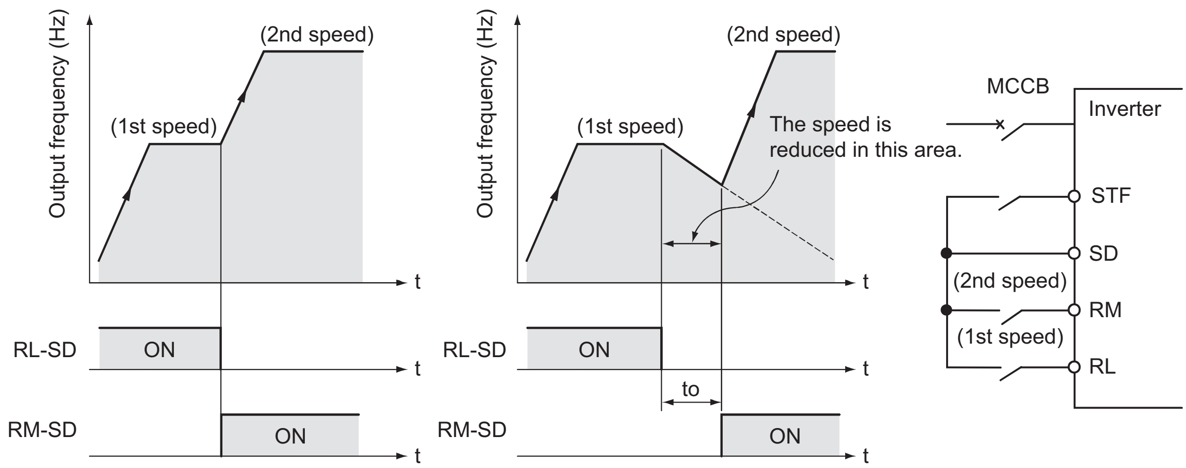
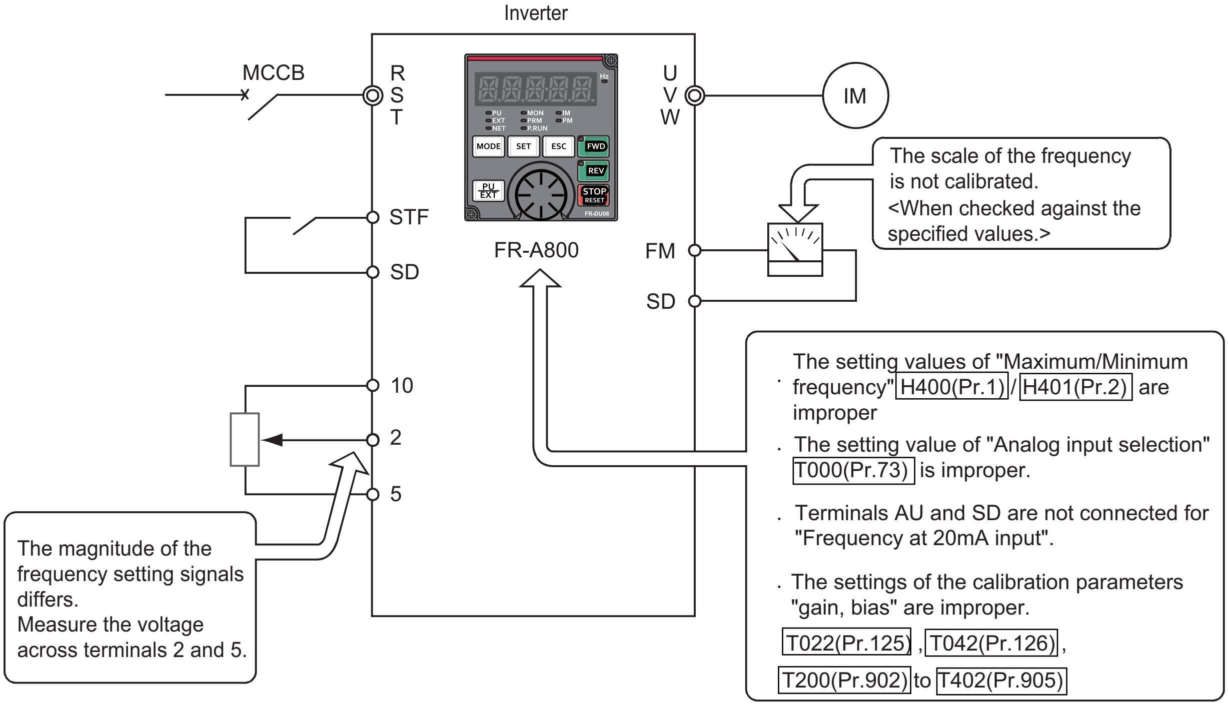


Fig.5.15 Change of output frequency at switching

☒ Useful information

When the motor speed does not reach the set value, the following causes are possible.



When the motor remains stopped with the start signal turned on

(1) Check the main circuit.
  1) Check that the power is supplied.
  2) Check that the R or S phase of the power supply is not opened.
  3) Check that the motor is securely connected to the inverter.

(2) Check the input signal.
  1) Check that the frequency setting signal is being input or not set to the zero level.
  2) Check that the start signals of both forward and reverse rotation are not input.
  3) Check that the "Reset" or "Output stop" signal is not input.
  4) Check that the terminals across AU and SD are ON while 4 to 20mA is input.

(3) Check the function setting values.
  1) Check that "Reverse rotation prevention" is not set. D020(Pr.78)
  2) Check that "Operation mode" is not set to the PU operation.
  3) Check that each operation function is not set to 0 when used.
     "Multi-speed setting"
     D301 to D303(Pr.4 to Pr.6)
     D304 to D307(Pr.24 to Pr.27)
     "JOG frequency" D200(Pr.15)
  4) Check that "Starting frequency" is not larger than the operation frequency.
     F102(Pr.13)
  5) Check that the "Bias" setting is proper.
     T200,T201,T400,T401(Pr.902,Pr.904)

(4) Others
  · Check that the alarm lamp is not lit.

5.6.9 Other operation methods

(1) Three-wire type (terminal STF, STR, STOP)

The three-wire type connection is shown in Fig.5.17.

1) Short the terminals STOP and SD to enable the start self-holding function.
   In this case, the forward/reverse rotation signal functions only as a start signal.
2) If the start signal terminals STF (STR) and SD are once shorted and then opened, the start signal is kept on. The terminal which is shorted earlier is enabled to start the inverter.
3) The inverter is decelerated to stop by opening between the start signal terminals of STOP and SD once. For the frequency setting signal and the operation of DC injection brake at stop, refer to Section 3.8.2.
4) When the terminals JOG and SD are shorted, the signal of terminal STOP is disabled and the JOG operation has a priority.
5) Short the output stop terminals MRS and SD to deactivate the self-holding function.

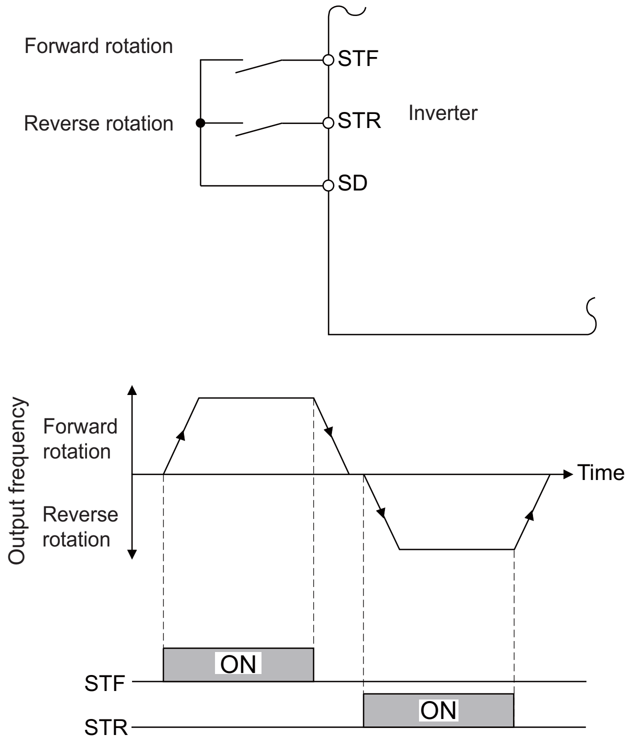


Fig.5.16 Two-wire type connection example

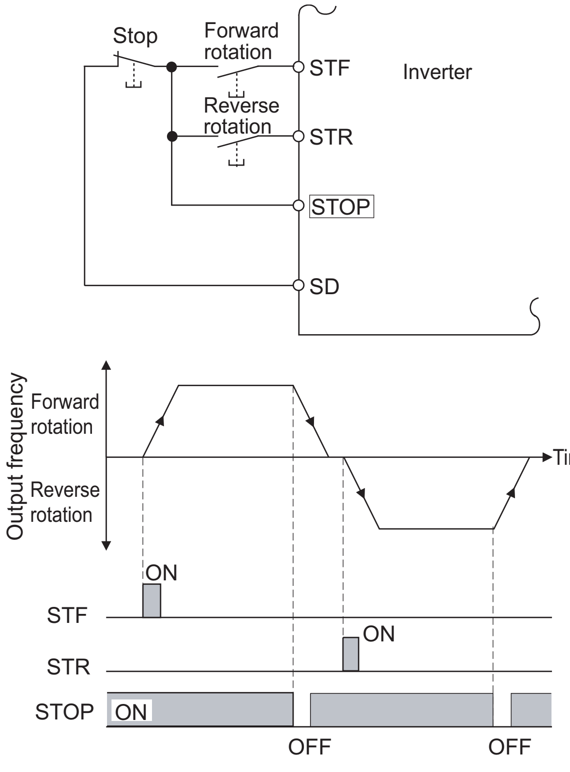


Fig.5.17 Three-wire type connection example

(2) With pairs of inverters and motors

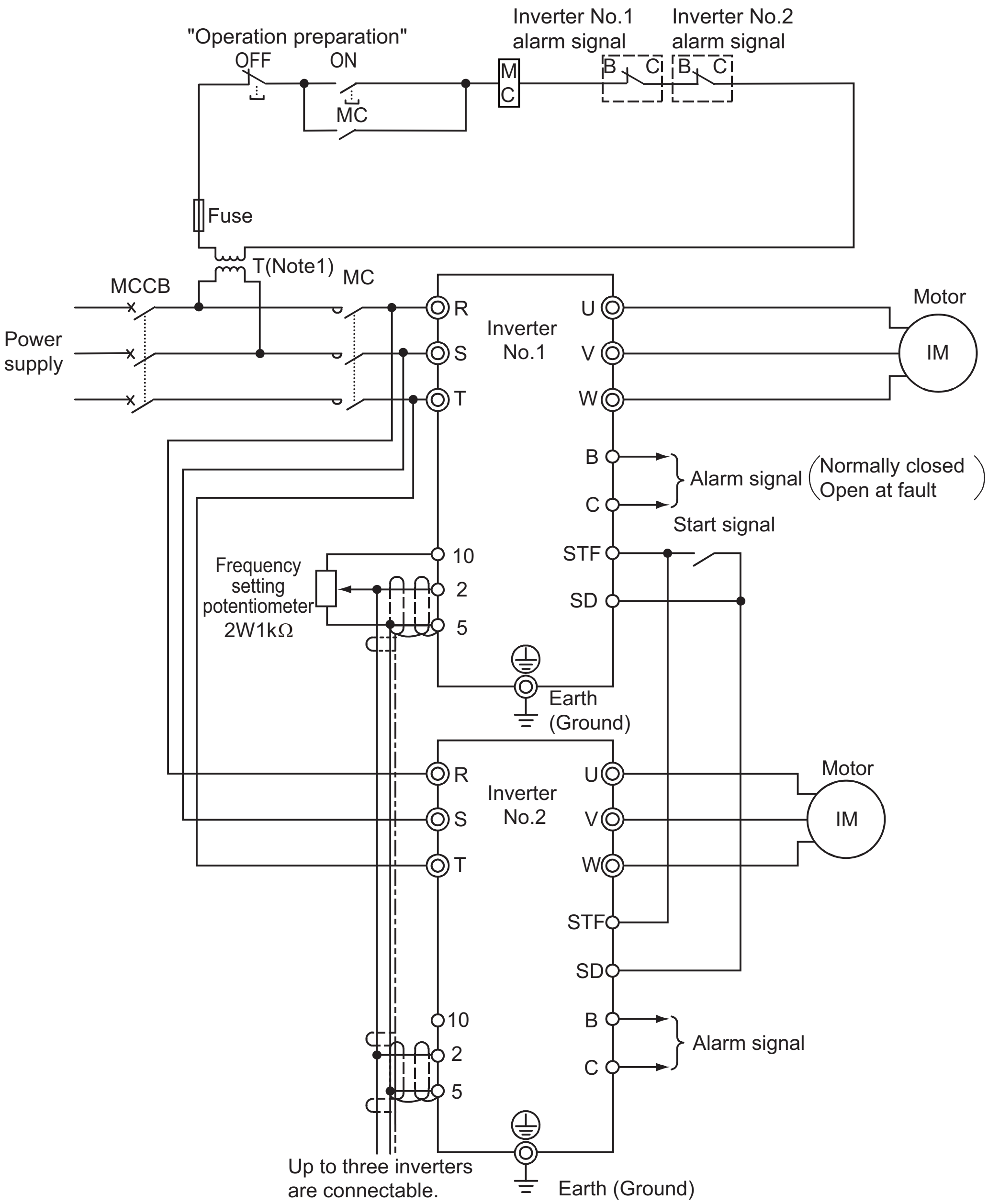
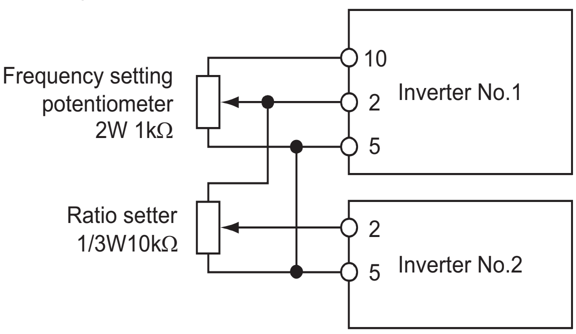


Fig.5.18 With pairs of inverters and motors



The ratio setting can be skipped by setting the gain/bias of the parameter unit calibration functions.

Fig.5.19 For ratio operation

(Note) 1. When the power supply is 400V class, install a control transformer.
2. Using the parameter unit calibration functions, the output frequency of three inverters corresponding to a common command voltage value from the frequency setting potentiometer can be adjusted to match.
3. When more than two motors are mechanically connected, the load may be applied to one motor and an overload may occur.

Chapter 6 PRECAUTIONS WHEN USING INVERTERS

This chapter describes the reliability and life of inverters according to the installation environment and operating conditions in addition to the precautions when using inverters.
This chapter also describes the circuit designs, precautions for wiring and operation procedures to use inverters.

6.1 Environment and Installation Conditions

6.1.1 Reliability of the inverter and temperature

The life of an inverter is influenced by the ambient temperature. The use in high surrounding air temperature, improper installation, or inadequate installation location may cause the inverter's internal temperature to rise, and may bring failure, damage, and other unexpected troubles. Those troubles are caused by the following factors.

Factors

High surrounding air temperature ⇒
- · Heat stagnation in the enclosure
- · Heat dissipation of the enclosure is insufficient. (e.g. The size is small; ventilation is not enough.)
- · Ventilation slits of the inverter are narrow.
- · The inverter is installed in an improper place.
- · An exothermic body is near the inverter.

High internal temperature of an inverter ⇒
- · The inverters mounting orientation is improper.
- · The clearance above the inverter is insufficient.
- · The inverter fan is faulty.

6.1.2 Surrounding air temperature

The surrounding air temperature of an inverter is the temperature in the immediate proximity of an installed inverter.

1) Measure the temperature at the positions indicated in Fig.6.1.
2) The permissible temperature between -10°C and +50°C.
   (Temperatures that are too high or too low may cause troubles.)
3) "In-enclosure temperature +50°C or less" means that the surrounding air temperature of the enclosure must be 40°C or less.

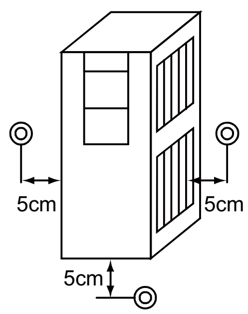


Fig.6.1 Measurement of ambient temperature

☒ Useful information

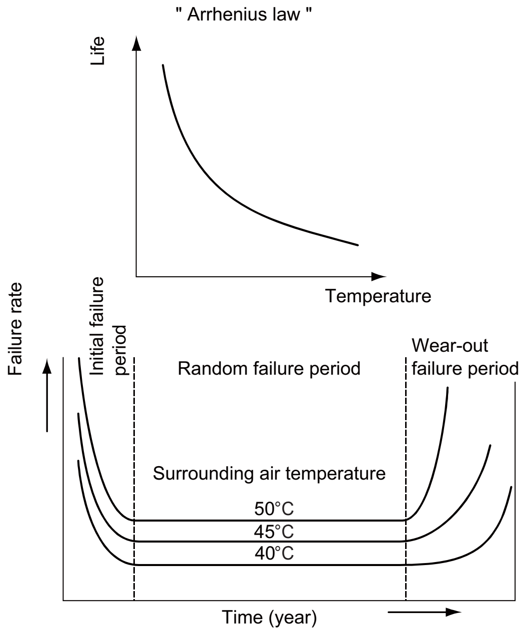
Life

The life of an inverter's electrolytic capacitor for smoothing decreases to half if the surrounding air temperature increases by 10°C (18°F) (and doubles if decreases by 10°C (18°F)) in accordance with the Arrhenius' law.

The service life of the other parts also highly depend on the temperature.

Failure rate and temperature

An inverter consists of many electronic parts such as semiconductor devices. The failure rate of these parts is closely related to the surrounding air temperature. Using them in the temperature as low as possible decreases the failure rate.



6.1.3 Heat generation of the inverter

The heat amount generated by an inverter varies depending on the inverter's capacity and the motor load factor.

In addition, the optional parts enclosed with an inverter such as an AC reactor, DC reactor, or brake unit (including a resistor) generate a relatively large heat amount. This should be taken into consideration when designing an enclosure. Table 6.1 lists the generated heat amount.

Externally installing the semiconductor heatsink and built-in break resistor using a heatsink outside attachment can radiate approximately 70% of the heat amount generated by the inverter to the outside of the enclosure.

Refer to Fig.6.2 for how to use the heatsink outside attachment.

Table 6.1 Heat amount generated from the inverters and reactors at rated inverter current output

Motor capacity (kW)	Heat amount generated from FR-A800 (W)		Heat amount generated from reactors (W)			
			FR-HEL		FR-HAL	
	200V	400V	200V	400V	200V	400V
0.4	50	50	6	6	10	16
0.75	70	65	7	7	14	23
1.5	110	75	8	8	20	30
2.2	140	100	11	11	24	43
3.7	190	150	13	13	33	46
5.5	260	200	17	17	40	52
7.5	360	250	19	19	46	52
11	520	300	23	23	60	60
15	670	400	26	26	75	60
18.5	770	550	29	29	74	76
22	940	650	34	34	82	74
30	1050	800	38	38	97	91
37	1270	1100	47	47	120	97
45	1610	1300	47	47	140	140
55	1880	1550	52	52	140	150
75	2530	1900	130	130	170	180
90	3110	2400	130	130		
110		2500	160	140	280	200
132		3000		140		
160		4000		170		
185		4200		230		400
220		5000		240		
250		5500		270		
280		6500		300		490
315		7000		360		
355		8000		360		530
400		9000		450		
450		10500		450		
500		11500		470		
560				500		1080

(Note) The heat amount generated by built-in brake resistors of 7.5K or lower is not included.

6.1.4 Interference of heat in the enclosure and ventilation

The inverter and ventilation fan placement is another point to be noted when they are installed in an enclosure.

When multiple inverters are installed in an enclosure or a ventilation fan is installed, the surrounding air temperature of the inverters may rise and the ventilation effect may be reduced depending on the installation position.

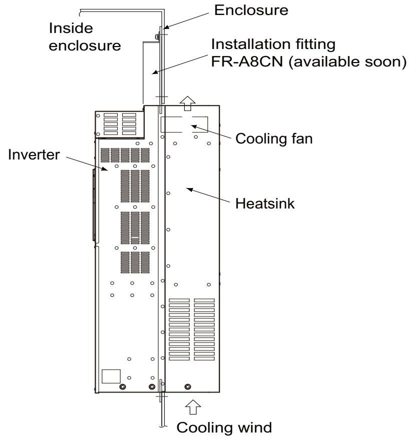


Fig.6.2 How to use the heatsink protrusion attachment

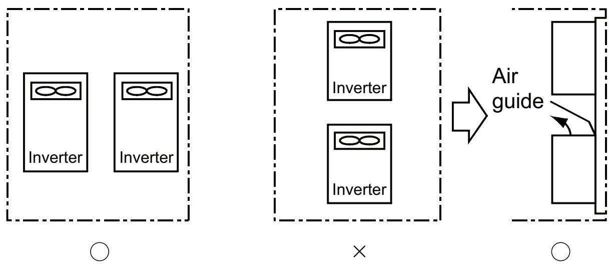


Fig.6.3 Installation of multiple inverters

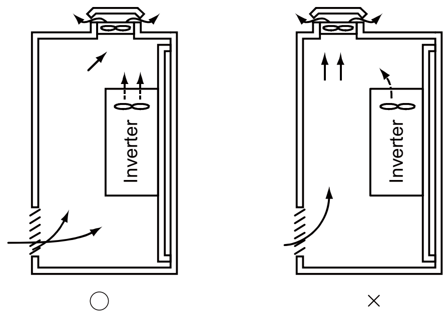


Fig.6.4 Position of a ventilation fan

6.1.5 Placement of electrical-discharge resistor

When an electrical-discharge resistor or externally-installed high-duty brake resistor (FR-ABR type) is used, sufficient measures against heat generated from the resistors must be taken.
Consider a resistor to be a heater for cooling.
It is recommended to install electrical-discharge resistors outside the enclosure.

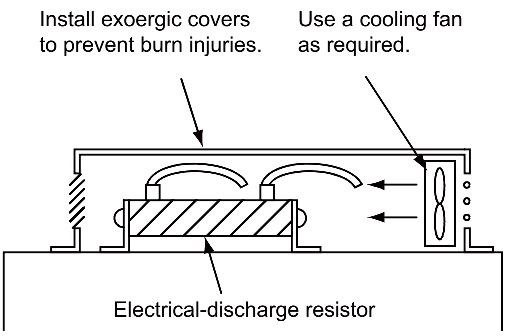


Fig.6.5 Installation method of the resistor

Caution: The surface of the electrical-discharge resistors sometimes becomes as high as 300°C. Caution must be taken for the material of the installing surface and the layout for the use of multiple resistors.

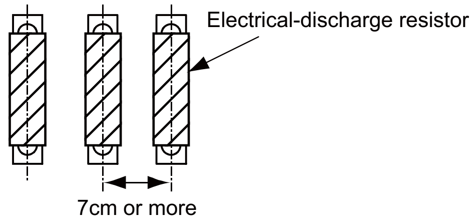


Fig.6.6 Layout of the resistors

6.1.6 Inverter mounting orientation

When an inverter is not mounted with a proper orientation, the inverter's heat dissipation extremely deteriorates. (The printed board of the control circuit is not cooled by a cooling fan.)

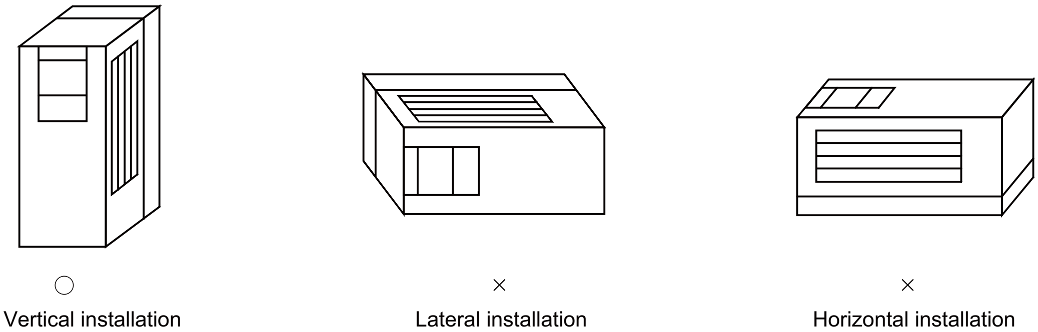


Fig.6.7 Inverter mounting orientation

6.1.7 Standard specifications of installation environment (FR-A800 series 200V class)

Item		Description
Surrounding air temperature	LD, ND (initial setting), HD	-10°C to +50°C (non-freezing)
	SLD	-10°C to +40°C (non-freezing)
Ambient humidity		With circuit board coating: 95%RH or less (non-condensing) Without circuit board coating: 90%RH or less (non-condensing)
Ambience		Indoors (Free from corrosive gas, flammable gas, oil mist, dust and dirt)
Altitude		1,000m or less above sea level
Vibration		5.9m/s^2 or less at 10 to 55Hz (directions of X, Y, Z axes)
AC voltage/frequency		Three-phase, 200 to 220V 50Hz, 200 to 240V 60Hz
Permissible voltage fluctuation		170 to 242V 50Hz, 170 to 264V 60Hz
Permissible frequency fluctuation		±5%

●Temperature

(1) Measures against high temperature
  (a) Use a forced ventilation system or similar cooling system. (Refer to Section 6.1.4)
  (b) Install the enclosure in an air-conditioned electrical chamber.
  (c) Block direct sunlight.
  (d) Provide a shield or similar plate to avoid direct exposure to the radiated heat and wind of a heat source.
  (e) Ventilate the area around the enclosure well.

(2) Measures against low temperature
  (a) Provide a space heater in the enclosure.
  (b) Keep the inverter power ON. (Keep the start signal of the inverter OFF.)

(3) Sudden temperature changes
  (a) Select an installation place where temperature does not change suddenly.
  (b) Avoid installing the inverter near the air outlet of an air conditioner.
  (c) If temperature changes are caused by opening/closing of a door, install the inverter away from the door.

●Humidity

Normally operate the inverter within the 45 to 90% range of the ambient humidity. Humidity that is too high will pose problems of reduced insulation and metal corrosion. On the other hand, humidity that is too low may produce a spatial electrical breakdown.
The insulation distance specified in JEM1103 "Control Equipment Insulator" is defined as humidity 45 to 85%.

(1) Measures against high humidity
  (a) Close the enclosure, and provide it with a hygroscopic agent.
  (b) Take dry air into the enclosure from outside.
  (c) Provide a space heater in the enclosure.

(2) Measures against low humidity
  Besides flowing air of proper humidity in to the enclosure from outside, make sure to discharge your body of static electricity before fitting and inspections, and avoid contact with the parts and patterns.

(3) Measures against condensation
  Condensation may occur if frequent operation stops change the in-enclosure temperature suddenly or if the outside-air temperature changes suddenly.
  Condensation causes faults such as reduced insulation and corrosion.
  (a) Take the measures against high humidity in (1).
  (b) Keep the inverter power ON. (Keep the start signal of the inverter OFF.)

6.1.8 Precautions for encasing the inverter in an enclosure

Refer to Fig.6.8 for precautions for encasing the inverter in an enclosure.

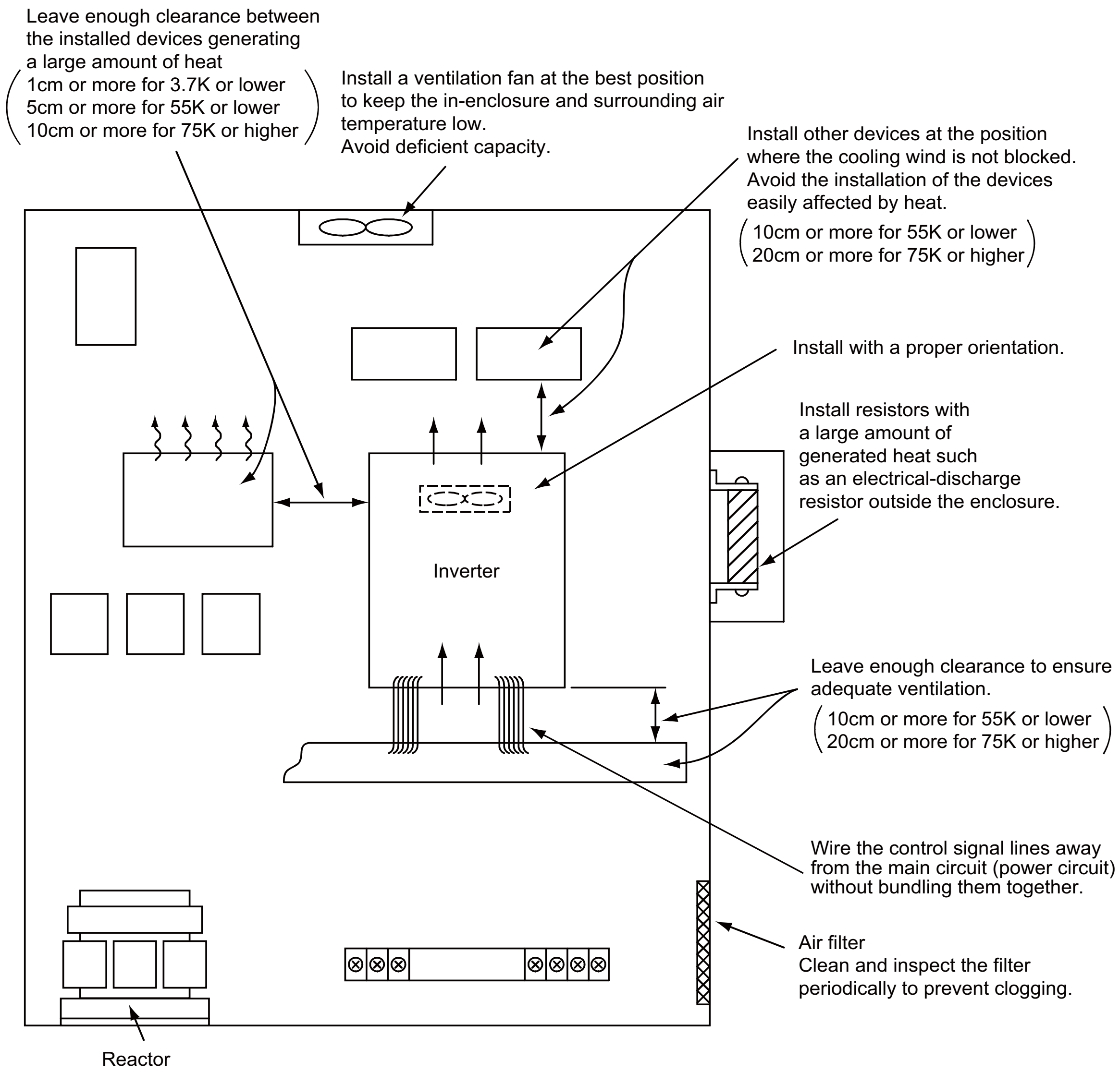


Fig.6.8 Precautions for encasing the inverter in an enclosure

●Dust, dirt, oil mist

Dust and dirt will cause faults such as connection errors of contacts, reduced insulation resulting from moisture absorption of deposits, reduced cooling effects and in-enclosure temperature rise by filter clogging.
In an atmosphere where conductive powder floats, dust and dirt will cause faults such as malfunctions, deteriorated insulation and short circuit in a short time.
Since oil mist will cause similar conditions, it is necessary to take adequate measures.

Corrective action
(a) Place in a totally enclosed enclosure.
Take measures if the in-enclosure temperature rises.
(b) Purge air.
Pump clean air from outside to make the in-enclosure pressure higher than the outside air pressure.

●Corrosive gas, salt damage

If the inverter is exposed to corrosive gas or to salt from nearby ocean, the printed board patterns and parts will corrode and the relays and switches will result in poor contact.
In such places, take the measures for dust, dirt, and oil mist, which are given in (a) and (b) above.

●Explosive, flammable gases

As the inverter is non-explosion proof, it must be contained in an explosion proof enclosure. In places where explosions may be caused by explosive gas, dust or dirt, an enclosure cannot be used unless it structurally complies with the guidelines and has passed the specified tests. This makes the enclosure itself expensive (including the test charges).
The best way is to avoid installation in such places and install the inverter in a non-hazardous place.

●High altitude

Use the inverter at the altitude of 1000m or less.
If it is used at a higher place, it is likely that thin air will reduce the cooling effect and low air pressure will deteriorate dielectric strength.

●Vibration, impact

The permissible vibration level for inverters are 10 to 55Hz (directions of X, Y, Z axes) with the acceleration rate of 5.9m/s^2 at maximum*.
Applying vibrations and impacts for a long time may loosen the structures and cause poor contacts of connectors, even if those vibrations' and impacts' levels are within the specified values.

* 2.9m/s^2 according to the capacity

Especially when impacts are imposed repeatedly, caution must be taken as the part pins are likely to break.

Corrective action
(a) Provide the panel with rubber vibration isolators.
(b) Strengthen the structure to prevent the panel from resonance.
(c) Install the enclosure away from sources of vibration.

6.1.9 When driving an explosion-proof motor with the inverter

When an explosion-proof motor is used with the inverter for drive, they must pass the specified exam. Please note the following for installation.

(1) The existing commercial power-driven pressure-resistant explosion-proof motor or increased-safety explosion-proof motor cannot be driven by the inverter.
The motor must pass the explosion-proof test by the Ministry of Health, Labour and Welfare in combination with its driving inverter. The Technology Institution of Industrial Safety (TIIS) organizes the test.
A pressure-resistant explosion-proof motor which has acquired TIIS Certification of Conformity beforehand in combination with an inverter drive can be used with another inverter.
However, that inverter must be the same model (up to the model’s capacity) used when the certification has been approved and the operation is limited to the range under the certified conditions.
Mitsubishi Electric offers pressure-resistant explosion-proof motors dedicated to an inverter drive and inverters for them. Refer to a catalog for details.

(2) When the rating to be used is out of the certified range or the model which has not passed TIIS Certification of Conformity needs to be used, a new certification must be acquired for it.

(3) Refer to the instruction manual of the inverter when using options.

(4) Using an increased-safety explosion-proof motor with an inverter is not economical because of the strict restrictions against the operation conditions (loss reduction, cooling effect improvement, etc.) and also because of the costs to take the test.
Using a pressure-resistant explosion-proof motor which has passed TIIS Certification of Conformity is recommended.

(5) The inverter is a non-explosion proof structure. Always install it in a non-hazardous place.

6.2 Wiring of Inverter

6.2.1 Terminal connection diagram

Catalogs describe the connection condition of each terminal for the inverter drive. The specifications of these terminals and precautions for use are given below using FR-A800 series as an example.

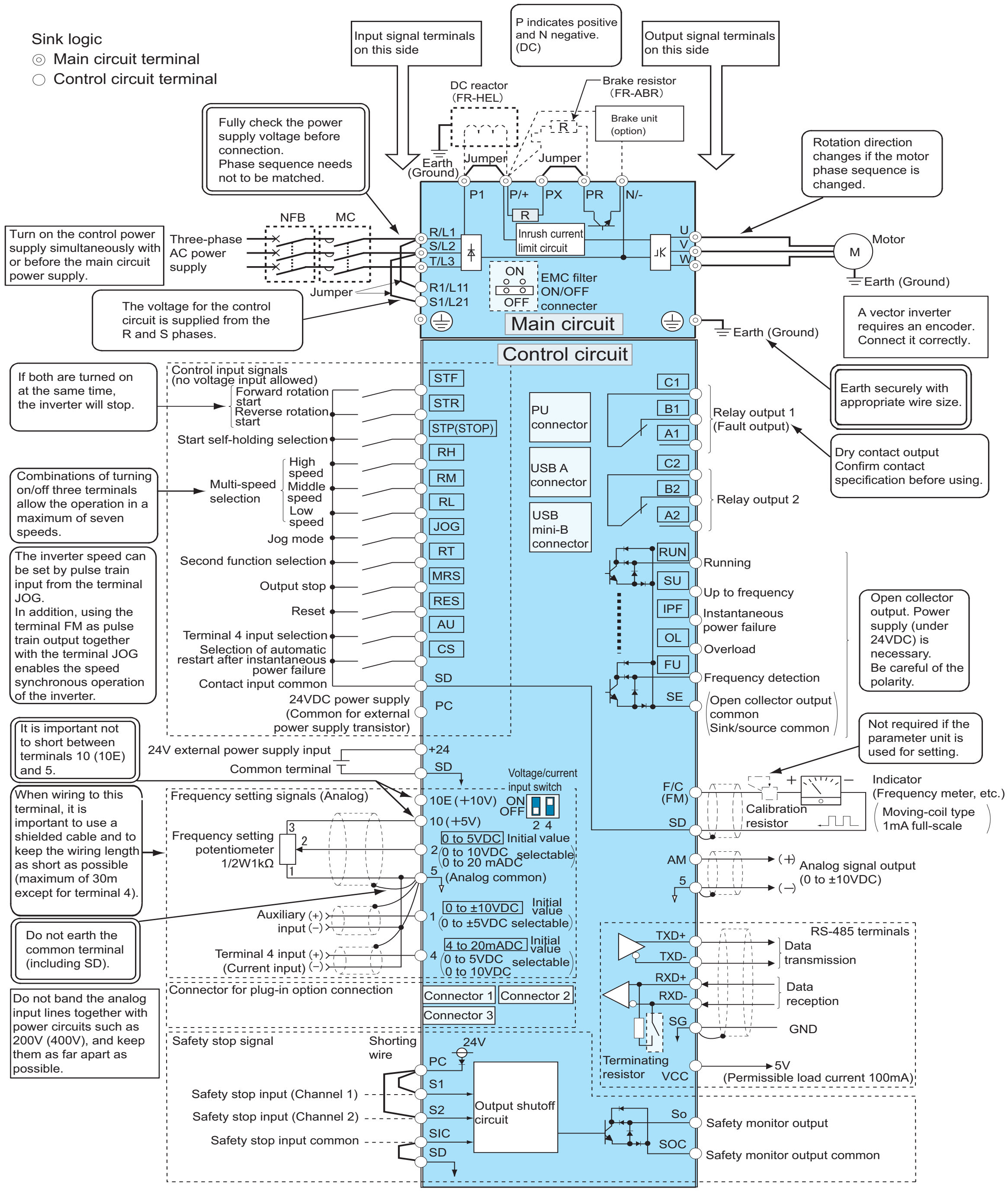


Fig.6.9 Terminal connection diagram (FM type)

6.2.2 Wiring of the main circuit

The main circuit is the power circuit (high voltage in lines). Incorrect wirings may damage the inverter and also jeopardize the operators. The following shows the points that easily cause miswiring.

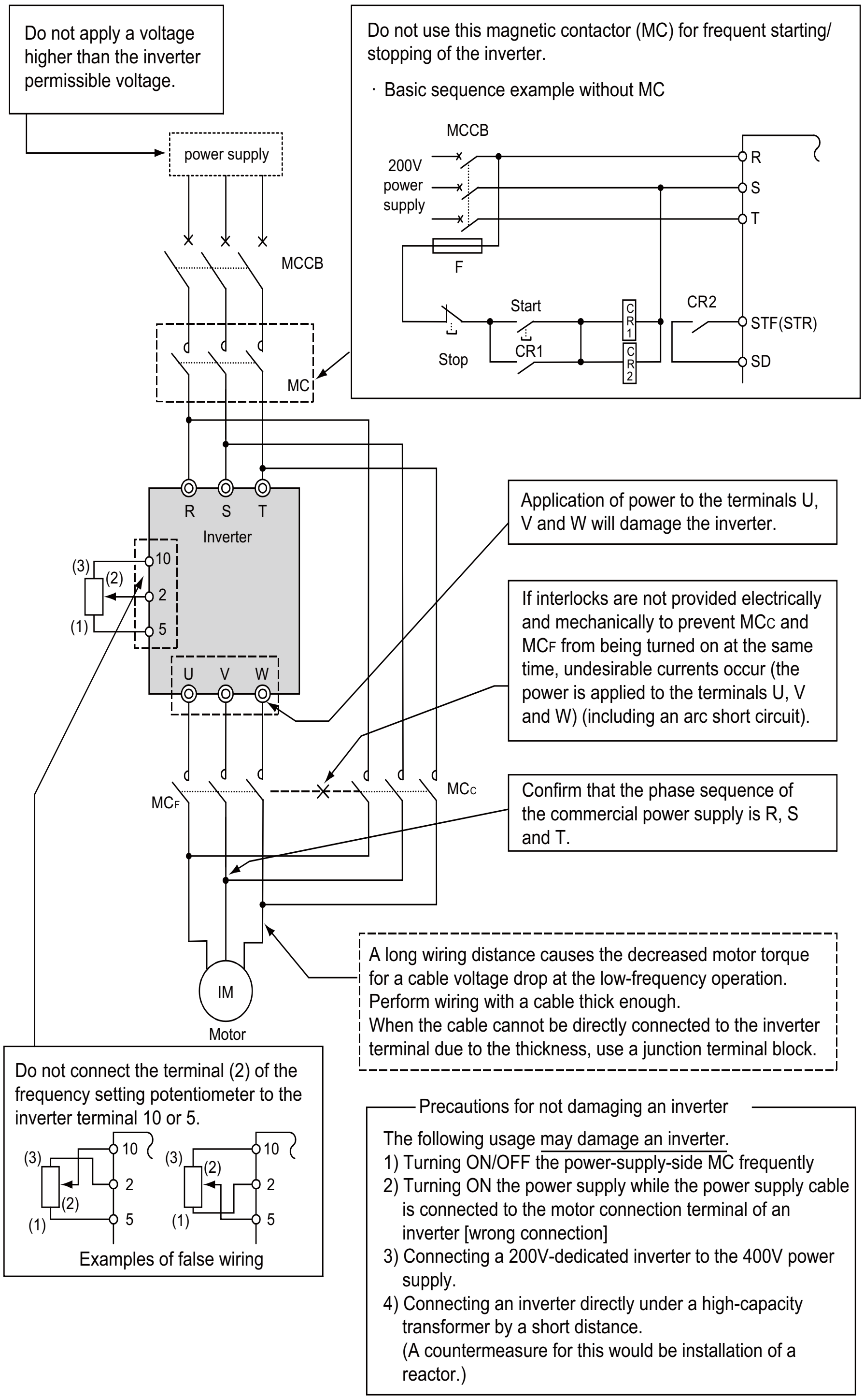


Fig.6.10 Main circuit wiring

6.2.3 Wiring of the control circuit

The following table lists the I/O terminal types and common terminals equipped with the inverter. Spring clamp terminals are used for control circuit terminals of the FR-A800 series.

Terminal	Type	Terminal example	Common terminal
Input terminals	Contact (or open collector)	Start signal (STF, STR) Select signal (RH, RM, RL, AU, etc.)	SD or PC (Power common ⊕)
	Analog	Frequency setting signal (2, 1, 4, etc.)	5
Output terminals	Contact	Alarm output (A, B)	C
	Open collector	Running signal (RUN, SU, OL, IPF, FU)	SE
	Pulse train	For indicator (frequency meter (FM))	SD
	Analog	For analog voltage output (AM)	5

(1) Connection to input terminals

1) Contact or open collector input terminal (Isolated from the inverter internal circuit)
Each terminal operates its function by causing a short circuit to the common terminal SD. The carry current for the input signals is micro-current (4 to 6mADC). Therefore, switches or relays for micro-current (twin contacts, etc.) must be used to prevent contact faults.

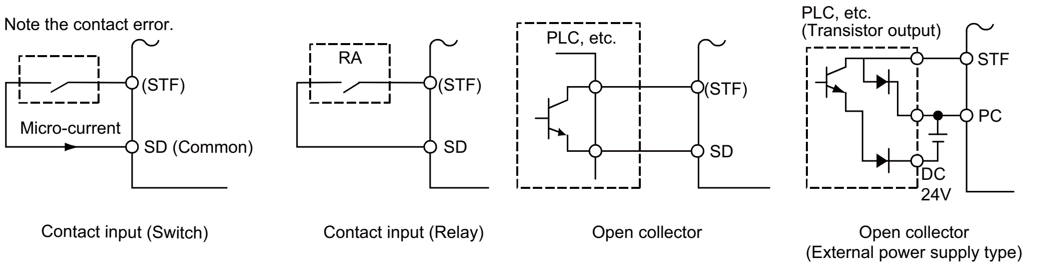


Fig.6.11 Connection for input signals

2) Analog input terminals (Non-isolated from the inverter internal circuit)
Perform the wiring fully away from the 200V (400V) power circuit lines without bundling them together.
A shielded cable should be used to avoid the influence of external noises.

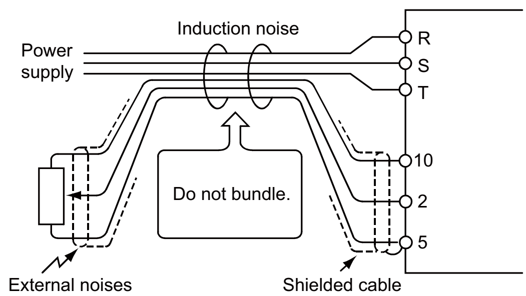


Fig.6.12 Connection example of frequency setting input terminals

3) Proper connection of frequency setting potentiometer
Improper connection of the frequency setting potentiometer terminals without referring to the terminal symbols will affect the operation of the inverter.
The resistance value is an important factor in selecting a frequency setting potentiometer.
<Specification> 2W 1kΩ coil-type variable resistor B characteristics

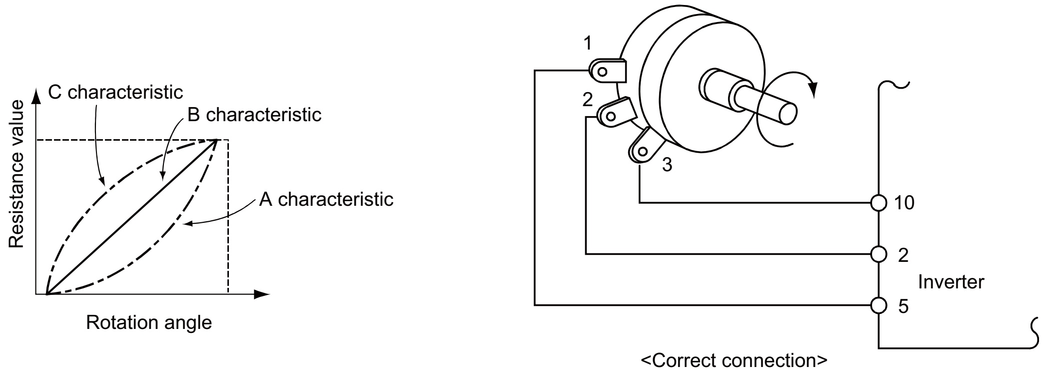
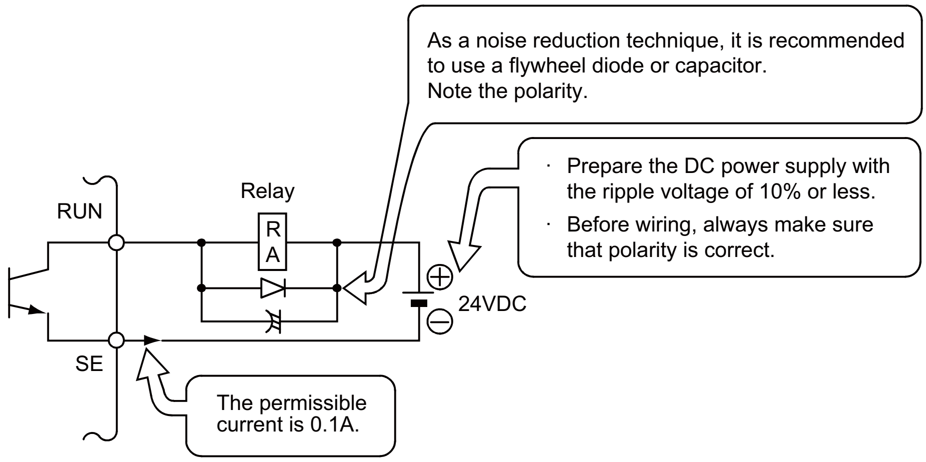


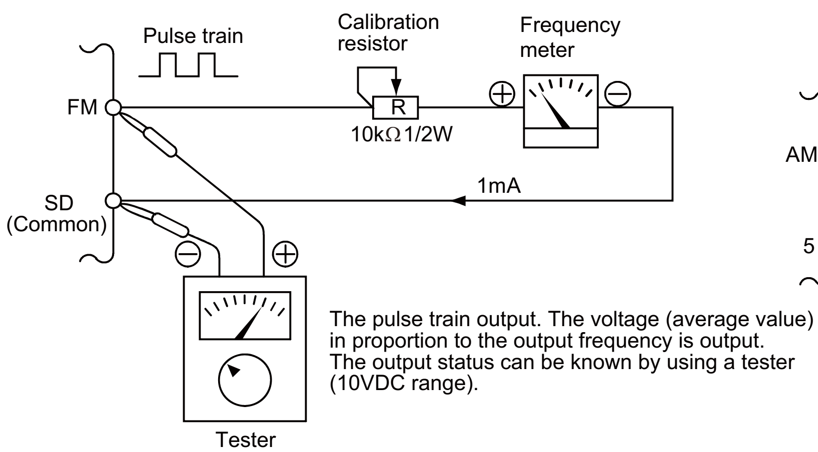
Fig.6.13 Connection of frequency setting potentiometer

(2) Connection to output terminals

1) Open collector output terminal



2) Pulse train output terminal



3) Analog signal output (0 to 10VDC)

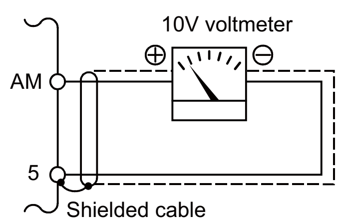


Fig.6.14 Connection of output signal terminals

6.2.4 Wiring length of I/O cables

The restriction varies according to each I/O terminal. Especially for control signals, the input part is isolated by photocoupler for improving noise resistance. However, the isolation measure is not taken for the analog input.
Therefore, the special caution must be taken for the wiring for the frequency setting signal by taking a measure such as making the cable length as short as possible to protect the signal from the external noise. The permissible cable length for each signal and the measures taken when the length is exceeded are shown in Fig.6.15.

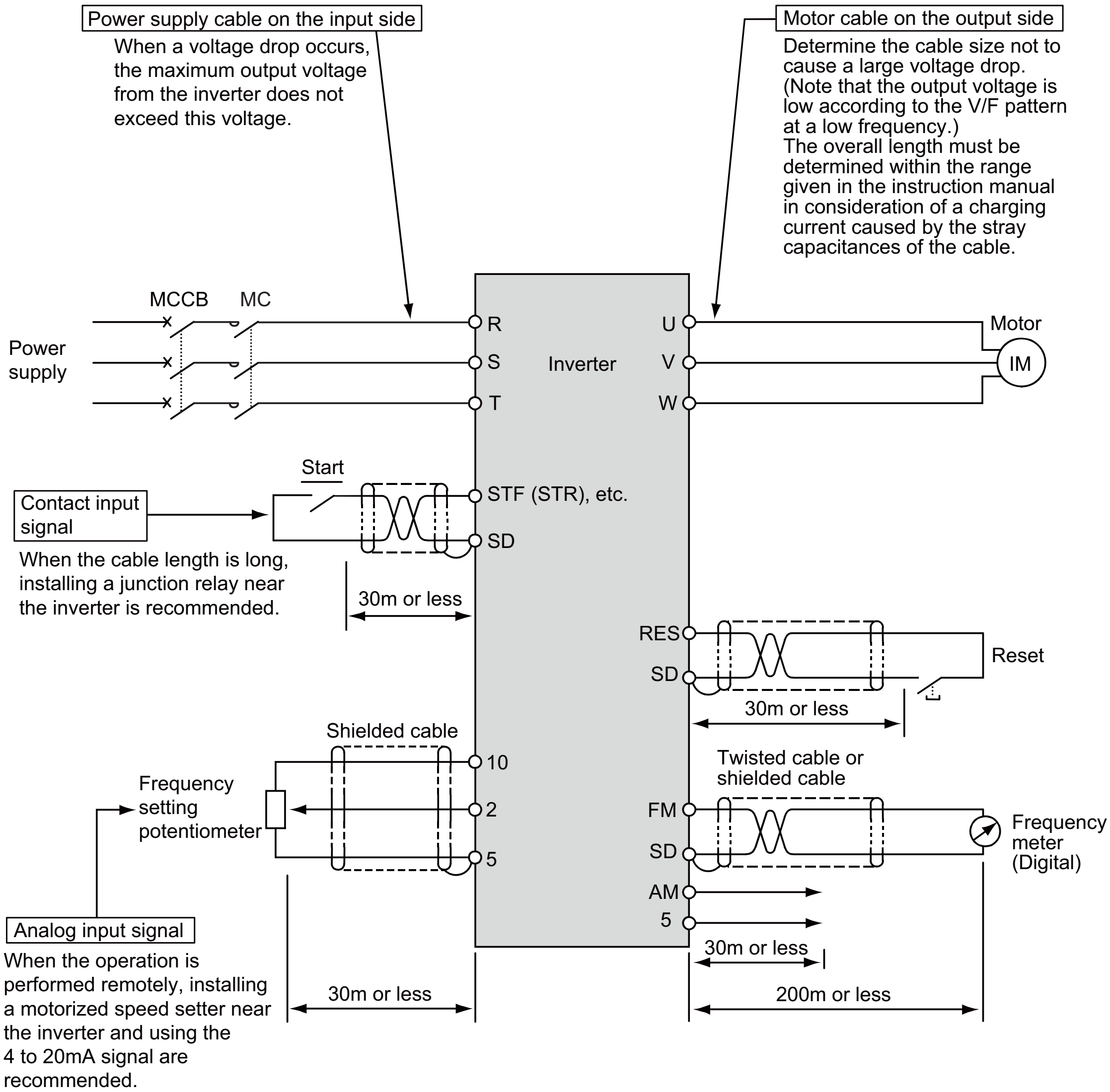
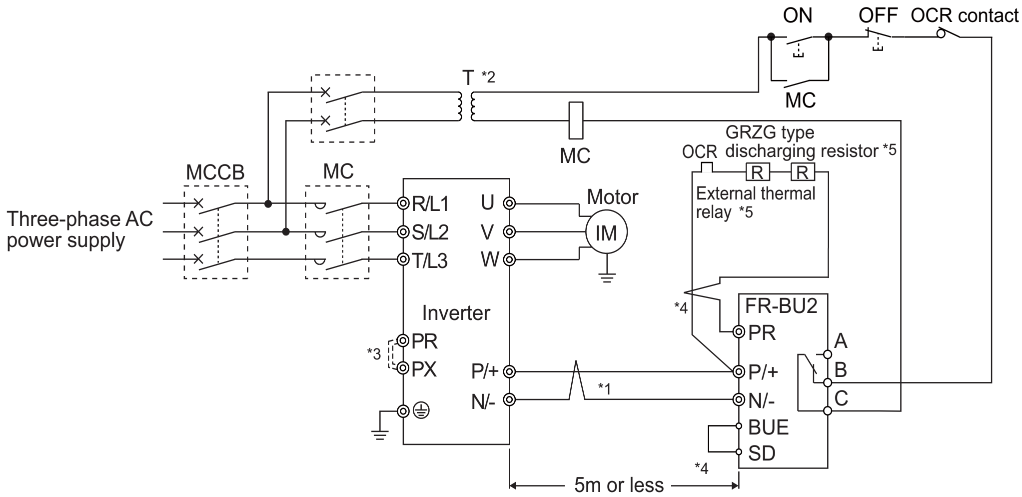


Fig.6.15 Wiring length of I/O cables

6.2.5 Connection of the brake unit (FR-BU2)

Handle an FR-BU2 brake unit, and discharging resistors or a resistor unit as a pair, and connect the pair to the terminals P/+ and N/- of an inverter.

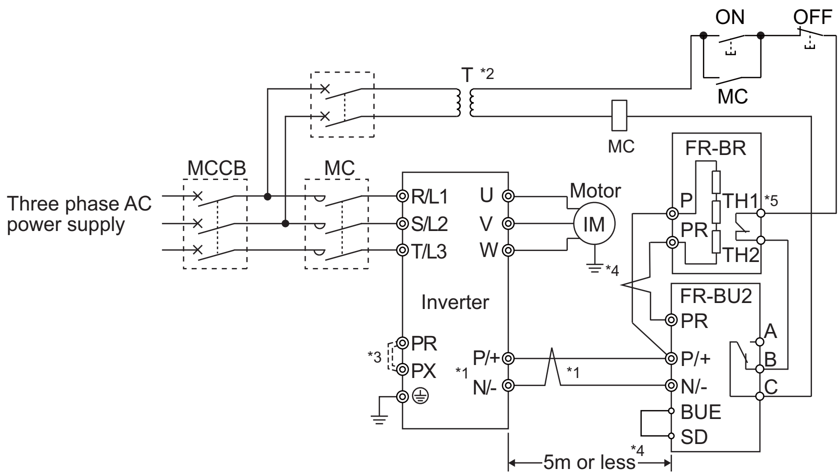
(1) An FR-BU2 brake unit and discharging resistors



*1 Connect the inverter terminals (P/+, N/-) and brake unit (FR-BU2) terminals so that their terminal names match with each other. (Incorrect connection will damage the inverter and brake unit.)
*2 When the power supply is 400V class, install a step-down transformer.
*3 Be sure to remove the jumper across terminals PR and PX when using the FR-BU2 with the FR-A800 of 7.5K or lower or FR-V500 of 5.5K or lower.
*4 Keep the wiring distance within 5m between the inverter, brake unit (FR-BU2) and discharging resistor. Even when the wiring is twisted, the cable length must not exceed 10m.
*5 It is recommended to install an external thermal relay to prevent overheat of discharging resistors.

Fig.6.16 Wiring method of a brake unit (with GRZG discharging resistors)

(2) An FR-BU2 brake unit and FR-BR resistor unit



*1 Connect the inverter terminals (P/+, N/-) and brake unit (FR-BU2) terminals so that their terminal names match with each other. (Incorrect connection will damage the inverter and brake unit.)
*2 When the power supply is 400V class, install a step-down transformer.
*3 Be sure to remove the jumper across terminals PR and PX when using the FR-BU2 with the FR-A800 of 7.5K or lower or FR-V500 of 5.5K or lower.
*4 Keep the wiring distance within 5m between the inverter, brake unit (FR-BU2) and resistor unit (FR-BR). Even when the wiring is twisted, the cable length must not exceed 10m.
*5 The contact between TH1 and TH2 is closed in the normal status and is open at a fault.
*6 For the MT-BR5 resistor unit, refer to the Option Catalog.

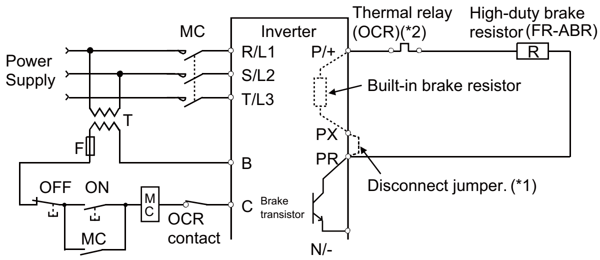
Fig.6.17 Wiring method of a brake unit (with FR-BR resistor unit)

6.2.6 Wiring of a high-duty brake resistor (FR-ABR)

A built-in brake resistor is connected to the terminals P and PX. If the built-in brake resistor does not provide enough thermal capacity in the required high-duty operation, remove the jumper between terminals PR and PX, and connect a high-duty brake resistor across the terminals P and PR.

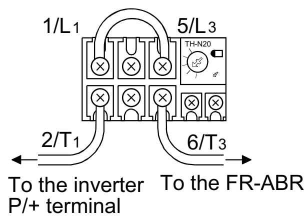
(Note) · No other resistor other than the dedicated brake resistor should be connected.
· The terminal PX is only provided for an inverter that has a built-in brake resistor.
· A high-duty brake resistor is only connectable to a model that has a built-in brake transistor.

When the regenerative brake transistor is damaged, the following sequence is recommended to prevent overheat and burnout of the brake resistor.



*1 The terminal PX is not equipped in the inverters that do not have built-in brake resistors.
For those inverters, it is not necessary to take out the jumpers.
*2 Refer to the table below for the type number of each capacity of thermal relay and the diagram below for the connection.
(Always install a thermal relay when using the 11K or higher brake resistor.)

Power Supply Voltage	High-Duty Brake Resistor	Thermal Relay Type (Mitsubishi Electric product)	Contact Rating
200V	FR-ABR-0.4K	TH-N20CXHZ-0.7A	110V 5AAC, 220V 2AAC(AC-11 class) 110V 0.5ADC, 220V 0.25ADC(DC-11 class)
	FR-ABR-0.75K	TH-N20CXHZ-1.3A	
	FR-ABR-2.2K	TH-N20CXHZ-2.1A	
	FR-ABR-3.7K	TH-N20CXHZ-3.6A	
	FR-ABR-5.5K	TH-N20CXHZ-5A	
	FR-ABR-7.5K	TH-N20CXHZ-6.6A	
	FR-ABR-11K	TH-N20CXHZ-11A	
	FR-ABR-15K	TH-N20CXHZ-11A	
	FR-ABR-22K	TH-N60-22A	
400V	FR-ABR-H0.4K	TH-N20CXHZ-0.24A	
	FR-ABR-H0.75K	TH-N20CXHZ-0.35A	
	FR-ABR-H1.5K	TH-N20CXHZ-0.9A	
	FR-ABR-H2.2K	TH-N20CXHZ-1.3A	
	FR-ABR-H3.7K	TH-N20CXHZ-2.1A	
	FR-ABR-H5.5K	TH-N20CXHZ-2.5A	
	FR-ABR-H7.5K	TH-N20CXHZ-3.6A	
	FR-ABR-H11K	TH-N20CXHZ-6.6A	
	FR-ABR-H15K	TH-N20CXHZ-6.6A	
	FR-ABR-H22K	TH-N20-9A	



6.3 Measures against Noise

The following shows measures that are most effective against inverter noise.

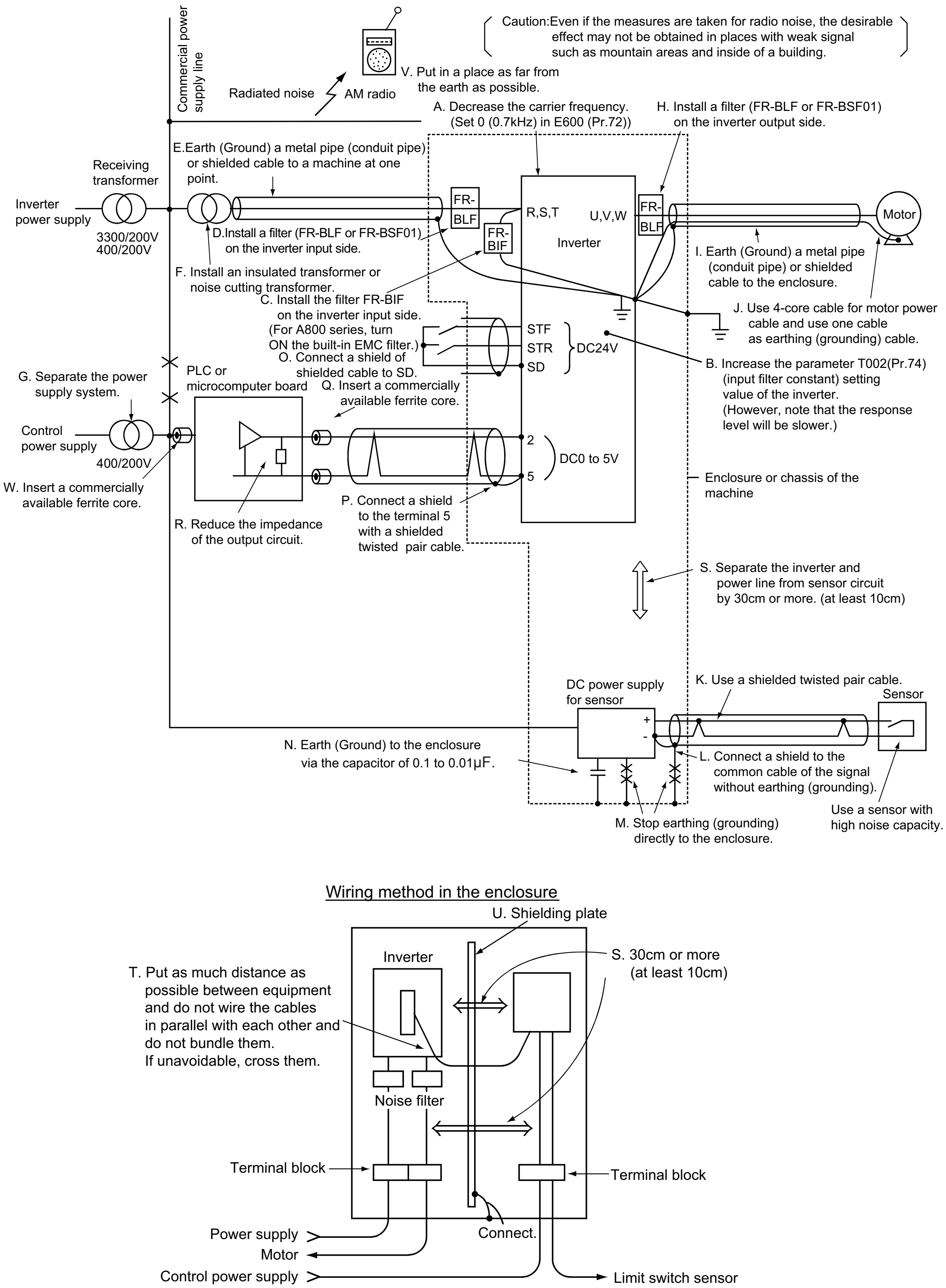


Fig.6.18 Examples of measures against noise of the inverter

The effectiveness against noise for the measures on the previous page are shown below. Refer to this chart when prioritizing which measures to take against noise.

Definition of symbols
⊙: Substantially effective
○: Effective
Δ: Slightly effective
—: Not effective

Table 6.2 Effect of measures against noise

Location	Symbol	Corrective action	Noise propagation method: Air-propagated noise: Inverter radiation	Air-propagated noise: Power supply cable radiation	Air-propagated noise: Motor cable radiation	Electro magnetic induction noise	Electrostatic induction noise	Cable-propagated noise: Power supply cable	Cable-propagated noise: Undesirable path of earthing (grounding) cable
Inverter	A	Reduce the carrier frequency (E600(Pr.72))	⊙	⊙	⊙	⊙	⊙	⊙	⊙
Inverter	B	Increase the input filter constant (T002(Pr.74))	Δ	Δ	Δ	○	Δ	—	—
Input side	C	Install the radio noise filter FR-BIF(-H). (For A800 series, turn ON the built-in EMC filter.)	—	⊙	—	—	—	⊙	—
Input side	D	Install the line noise filter FR-BSF01 or FR-BLF.	—	⊙	—	—	—	⊙	Δ
Input side	E	Wire the power supply cable with a metal pipe or shield cable	—	⊙	—	—	—	⊙	—
Input side	F	Install an insulated transformer or noise cutting transformer.	—	Δ	—	—	—	⊙	—
Input side	G	Separate the power supply system.	—	—	—	—	—	⊙	⊙
Output side	H	Install the line noise filter FR-BSF01 or FR-BLF.	—	—	⊙	Δ	Δ	—	⊙
Output side	I	Wire the output cable with a metal pipe or shield cable	—	—	⊙	○	○	—	—
Output side	J	Use 4-core cable for motor power cable and use one cable as earth (ground) cable.	—	—	Δ	Δ	Δ	—	⊙
External device	K	Use a twisted pair shielded cable for the sensor signal.	○	○	○	⊙	⊙	—	—
External device	L	Connect a shield to the common cable of the sensor signal.	—	—	—	⊙	⊙	—	⊙
External device	M	Do not ground the power supply unit for sensor directly to the enclosure, etc.	—	—	—	—	—	Δ	⊙
External device	N	Ground the power supply unit for sensor with a capacitor.	—	—	—	—	—	Δ	○
External device	O	Use a shielded cable for the signal input and connect a shield to the common (input terminal) SD.	Δ	Δ	Δ	○	⊙	—	Δ
External device	P	Use a twisted pair shielded cable for the speed input and connect a shield to the terminal 5.	○	○	○	⊙	⊙	—	Δ
External device	Q	Insert a commercially available ferrite core to the speed input cable (on the output side of the external device).	Δ	Δ	Δ	○	—	—	—
External device	R	Reduce the impedance in the output circuit of the external device.	Δ	Δ	Δ	○	—	—	—
External device	S	Separate the external device from the inverter and power line by 30cm or more.	⊙	⊙	⊙	⊙	⊙	—	—
External device	T	Do not wire the cables in parallel with each other and do not bundle them.	Δ	Δ	Δ	⊙	⊙	—	—
External device	U	Install a shielding plate.	○	Δ	Δ	Δ	Δ	—	—
External device	V	Keep away from the ground.	Δ	○	○	Δ	Δ	—	—
External device	W	Insert a commercially available ferrite core on the input side of the external device.	—	—	—	—	—	○	Δ

Remark

For "inverter power supply (harmonics and instantaneous power failure)", "noise", and "maintenance and inspection", refer to Appendices 4 to 6.

Chapter 7 PERIPHERAL DEVICES AND OPTIONS

7.1 Types of Peripheral Devices and Points of Understanding

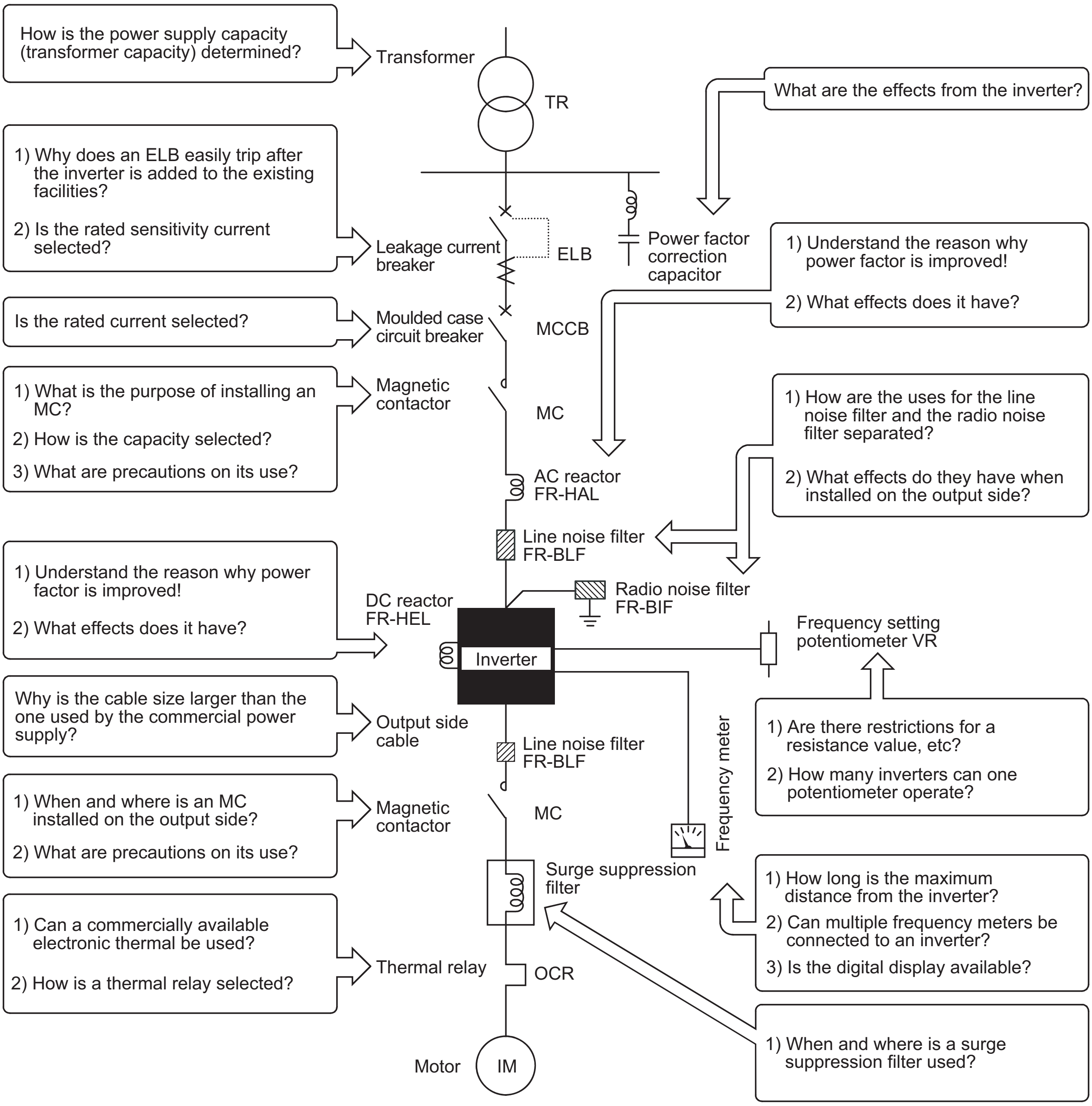


Fig.7.1 Peripheral devices

7.2 Inverter Options

To use a general-purpose inverter more effectively, various options can be used for improving the characteristics of an applied operation, etc.

Table 7.1 Types and applied examples of FR-A800 series inverter options

Classification	Requested specifications	Examples of applied options
Operation	•To set the operation frequency with a digital switch	FR-A8AX (16-bit digital input)
	•To set the operation frequency with a PLC •To monitor the output frequency, output voltage and output current simultaneously •To perform the remote operation of the inverter •To perform the automatic operation of the inverter •To perform the inverter operation with a personal computer or PLC •To change a parameter remotely	FR-A8NC (CC-Link)
	•To start the inverter easily •To set a parameter with a PC easily	FR Configurator2 (SW1DND-FRC2-E) (Inverter setup software)
	•An operation panel that displays English is required.	FR-LU08 (LCD operation panel)
	•To install the inverter in an enclosure and mount the parameter unit to a door •To operate near the inverter	FR-CB201, 03, 05 (Connection cable)
Output signal	•To drive the AC relay and a contactor with the inverter output signal	FR-A8AR (Relay output)
Power factor improvement	•The power supply capacity must be larger if the inverter power factor is low. •The inverter is installed near a large-capacity power supply.	FR-HAL, FR-HEL * (AC reactor, DC reactor)
Harmonic suppression	•Effects of harmonics on the power supply is worrying.	FR-HC2 (High power factor converter)
Measures against noise	•It is harder to hear a radio due to noise if the inverter is installed.	FR-BIF (Radio noise filter) FR-BLF (Line noise filter)
Enhance braking capability	•To decelerate quickly even if the inertia moment of a machine is large •Enough braking capacity is required since acceleration/deceleration is frequently performed.	FR-BU2 brake unit GRZG type discharging resistor, FR-BR, and MT-BR5 resistor unit. (brake unit + brake resistor) FR-CV power regeneration common converter
Applied operation	•To make various settings •To perform the line control and synchronous operation	FR series manual controller
Installation	•To place the exothermic section of the inverter outside the enclosure and make the panel size smaller.	FR-A8CN Heatsink protrusion attachment

* Be sure to connect the DC reactor when combining 75K or higher inverter and 75kW or higher motor.

7.3 Power Supply Capacity

The power supply capacity (transformer capacity) on the inverter input side can be calculated by Formula (7.1).

$$\text{Power supply capacity} = \frac{\text{Motor output (kW)}}{\text{Total efficiency of the inverter} \times \text{Inverter power factor}} \text{[kVA]} \cdots\cdots\cdots\cdots\cdots (7.1)$$

(Total efficiency of the inverter = Motor efficiency × Inverter efficiency)

The inverter power factor varies depending on the load and power supply conditions. Therefore, set the power supply capacity (transformer capacity) to 1.2 to 1.5 times as large as the inverter output kVA with the assumption that the inverter efficiency is 0.6 to 0.8 and in consideration for the influence of a voltage drop at a power-on of the inverter. The power factor of the inverter with AC/DC reactor is calculated with FR-HEL: 0.93 and FR-HEL: 0.88. (For the details of FR-HAL and FR-HEL, refer to page 72.)
The power supply capacity (kVA) is described in a catalog.

7.4 Moulded Case Circuit Breaker (MCCB)

MCCB is used to prevent the power supply side distribution line from being damaged due to an overload and a current at short-circuit.

1) Selecting the rated current
For selecting the MCCB breaking capacity, refer to "Mitsubishi Electric No-Fuse Breaker Instruction Manual".
2) Selecting the rated current
The size of the inverter input current (effective value) varies depending on the input current form factor. The input current form factor is affected by the power supply impedance.
Therefore, set the rated current to 1.4 times or more as large as the input current effective value in consideration for the influence of the harmonic components as well as for the size of the effective value.
3) For selecting the MCCB type and the rated current to avoid the false tripping at the peak value of the inrush current at power on, refer to "Selection of peripheral devices" in the catalog.

7.5 Earth Leakage Current Breaker (ELB)

1) Leakage current of cable path
Since the inverter output waveform includes high frequency components, the leakage current of the cable path from the inverter to the motor during the inverter operation becomes larger than that during the commercial power supply operation.
Therefore, if the inverter is used for existing facilities, the ELB may trip.
2) Selecting the rated sensitivity current
Calculate the rated sensitivity current from the continuous leakage current of the cable and motor. The size of the continuous leakage current varies according to conditions such as the motor capacity, cable length, insulation type and cable laying.

The output side leakage current during the inverter operation is approximately 3 times as large as that with the commercial power supply.
In addition, if Mitsubishi Electric New Super NV is used, the same sensitivity current as for the commercial power supply operation can be selected.

7.6 Input Side Magnetic Contactor (MC)

(1) Necessity of installation

The purposes of installing the magnetic contactor (MC) on the input side are described as follows.

1) To avoid restarting by power restoration at an occurrence of the instantaneous power failure
2) To disconnect the inverter from the power supply at inverter fault or maintenance
If a regeneration brake transistor fails due to thermal capacity shortage of the brake resistor or excessive operation of the regenerative brake, etc. during cyclic operation or harsh condition operation with an optional brake resistor, an MC prevents the brake resistor from overheating or burning.
3) To rest the inverter for an extended period of time (Use MC to save power.)

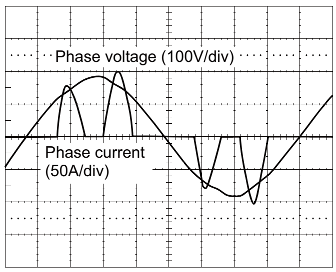
For cautions for turning on/off the input side magnetic contactor (MC), refer to Section 5.6.5.

(2) Capacity selection method

Since installing the input side magnetic contactor (MC) is not for the start/stop of the inverter, the electrical life does not lead to problems. Select a capacity which meets the inverter input current. Refer to "Selection of peripheral devices" in the catalog for selecting the input side magnetic contactor (MC).

Useful information

Since the inverter has a large-capacity smoothing electrolytic capacitor on the converter circuit, it is seen as a capacitor input type rectifier from the power supply side.
Therefore, the pulsed current for charging the capacitor flows to the inverter input side. This current form factor is reduced greater than the sine wave current for the commercial power supply, and the power factor becomes lower.



Inverter stop

Inverter stop is made by the base shutoff of a transistor. The inverter does not stop until the deceleration time elapses even if the start terminal (STF or STR) is turned off. Also, the inverter continues to operate, though the motor stops if the output side MC is turned off. Therefore, turn off the start terminal or turn on the output stop terminal (MRS or reset terminal RES) to shut off he base circuit for the transistor.
When the inverter power supply is turned OFF, the base of a transistor is shut off, and that brings the inverter to a stop. Even if the power supply to the inverter is turned ON, the inverter outputs are withheld until a start command is input.

7.7 Surge Suppression Filter

With a PWM type inverter, a surge voltage attributable to wiring constants is generated at the motor terminals. Especially for a 400V class motor, the surge voltage may deteriorate the insulation.

7.7.1 What is a micro surge?

When a motor is driven with an inverter, surge voltage, which is caused by inverter switching, is superpositioned to the inverter's output voltage and applied to the motor.
Whisker-shaped high voltage is added to normal output voltage, and this whisker-shaped voltage is called a micro surge. (Refer to Fig.7.2.)
This whisker-shaped peak voltage is larger when the motor's wiring length is longer. In theory, the whisker-shaped voltage can be twice as large as the DC bus voltage.

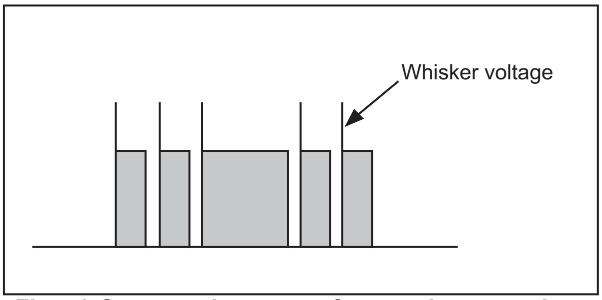


Fig.7.2 Output voltage waveform and surge voltage

7.7.2 Effects of micro surges

Micro surges affect insulation of motors.
The micro surge voltage exceeding the motor's permissible voltage of 850V (reference value by the Japan Electrical Manufacturer's Association) may deteriorate the motor insulation and cause burning in the worst case.

Supplemental information

1) There are few instances of motor burnouts that are caused by surge voltage.
If you look at the burnout cases, all of the burnouts occurred in the early stage of the operation with 40m or longer (reference) wiring. The use under the following condition probably do not require any special measure as the probability of burnout is low. (Not an absolute standard.)
   - When the wiring length between the inverter and motor is 20m or less (as a reference).
   - When the motor and the inverter have been operated for several months.
2) DC voltage is as low as 300V for the 200V-class inverters. Because of this, the superpositioned micro surge voltage does not exceed the permissible terminal voltage of 850V, even if the terminal voltage becomes the twice as high. Thus, a problem is unlikely to occur with a 200V-class inverter.

7.7.3 Corrective action

Consider taking the following measures when driving a 400V class motor with an inverter.

(1) Rectifying the motor insulation

For the 400V class motor, use an insulation-enhanced motor.

Specifically,

1) Specify the "400V class inverter-driven insulation-enhanced motor".
2) For the dedicated motor such as the constant-torque motor and low-vibration motor, use the "inverter-driven dedicated motor".

(2) Suppressing the surge voltage on the inverter side

Connect a filter on the secondary side of the inverter to suppress the surge voltage so that the terminal voltage of the motor is 850V or less.
When using a Mitsubishi Electric inverter to drive the motor, connect an optional surge voltage suppression filter on the secondary side of the inverter.
For the surge voltage suppression filter, FR-ASF-H□□K or FR-BMF-H□□K is selectable.
FR-BMF-H□□K can be installed on the rear panel (up to 22K) or side panel of the inverter and is available for designing in various enclosures.
For using the surge voltage suppression filter, the maximum wiring length must be within 100m, and the carrier frequency within 2kHz.

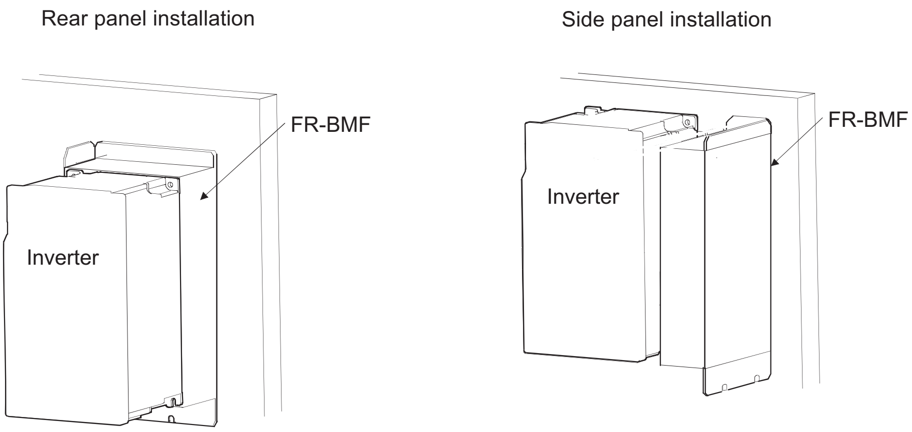


Fig.7.3 Installation method of FR-BMF

Useful information

For a 75K or higher capacity inverter, installing a sine-wave filter at the output side will shape the motor voltage and current waveforms to be almost identical to the sine wave.
Doing this will produce characteristics equivalent to when the motor is driven by a sine wave power supply. Providing the following benefits.

1) Low noise
2) No surge current
3) Small motor losses (for a standard motor)

7.8 Output Side Magnetic Contactor (MC)

As a general rule, the magnetic contactor (MC) installed on the inverter output side must not be turned on during the inverter operation. When the output side magnetic contactor (MC) is turned on during the operation, an overcurrent trip occurs in the inverter due to the large start current.
The output side magnetic contactor (MC) can be shut off during the operation. However, the motor coasts to stop at that time.

The purposes of installing the magnetic contactor (MC) on the output side are described as follows:

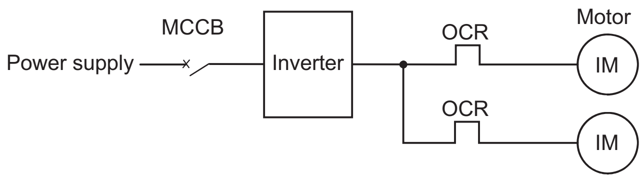
1) To configure the commercial power supply-inverter switch-over circuit
2) To switch multiple motors with one inverter (Switch the motors during an inverter stop.)
3) To need to disconnect the motor from the cable path in the operation cycle while the motor is at a stop.

For cautions on turning on/off the output side magnetic contactor (MC), refer to Section 5.6.4.

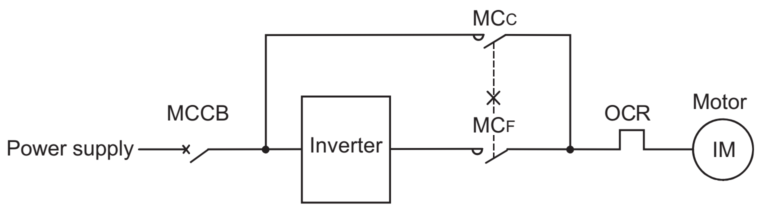
7.9 Thermal Relay (OCR)

(1) The overload protection of the standard motor is performed with the inverter built-in electronic thermal. However, because the protection cannot be performed for the following cases, install a thermal relay between the motor and the inverter.

1) To drive multiple motors with a single inverter



2) To drive a special motor whose thermal characteristic differs from that of a standard motor
[Example] Submersible motor, multi-pole motor (8 poles or more) or other motors
3) To perform the commercial power supply-inverter switchover operation



(2) For the thermal relay setting, set the current value at 50Hz, which is written on the motor's rating plate.
For dedicated motors, set the values on their rating plates.

(3) Since the inverter output waveform is not a sine wave and includes high frequency components, a commercially available <u>electronic</u> thermal relay cannot be used.

7.10 Cable Size of Main Circuit

Select the cable size of the main circuit according to the voltage, current, surrounding air temperature and wiring distance.

(1) Inverter input side
Select a cable size which is appropriate for the input current. (Refer to the size shown in a catalog.)

(2) Inverter output side
Select a cable size which is appropriate for the motor current likewise on the input side. Especially, if the wiring distance between the inverter and motor is long, the decrease of motor output torque and the increase of heat generation may occur due to the voltage drop. Select an adequate size. The size shown in a catalog is selected for the distance of 20m.

Useful information

Inverter's output voltage is mostly proportional to the output frequency. Because of this, output voltage is smaller in the lower-frequency operation range. Voltage drop rate [%] also differs between 50Hz and 60Hz (larger at 50Hz) while the voltage drop [V] in a cable is the same.

7.11 Power Factor Improving Reactor (Either FR-HAL or FR-HEL)

(1) Purpose for use
Since the power factor on the inverter input side is low, connect the power factor improving reactor to the inverter input side (for FR-HAL) or the inverter DC side (for FR-HEL) to improve the power factor.

(2) Effects
The power factor is approximately 88% for the AC reactor (FR-HAL), and approximately 93% for the DC reactor (FR-HEL). (For the details of FR-HAL and FR-HEL, refer to page 72.) The following effects are obtained in addition to the power factor improvement.
1) The power supply capacity can be decreased. <<Since the power factor improves>>
2) Rated values of the equipment used on the inverter input side can be reduced. <<Since the input current becomes lower>>
3) The harmonic components included in the input side current decrease.
4) It suppresses the voltage increase on the capacitor terminal (surge voltage), which is caused by an instantaneous increase of power supply. It also prevents an overvoltage trip (OV1 to OV3).

(3) Capacity selection
Select the capacity according to the motor capacity and the voltage specification.
For the AC reactor (FR-HAL), a voltage drop of approximately 2% occurs (at the rated load). Caution is required for the insufficient torque.
Be sure to connect the DC reactor (FR-HEL) when combining 75K or higher inverter and 75kW or higher motor.

7.12 Inverter Setup Software

FR Configurator2 (SW1DND-FRC2-E)
This software is an effective support tool for startup and maintenance of the Mitsubishi Electric transistorized inverter.
Parameter setting and monitoring are easily performed on Windows personal computer screen.

7.12.1 Functions

- FR Configurator2 is an effective support tool for startup and maintenance of the Mitsubishi Electric general-purpose inverter. The following functions can be performed efficiently on a personal computer.

Function	Description
Parameter List	Displaying parameter list, functional list, initial value change list and editing and setting of the parameters are available.
Diagnosis	Displays alarm history.
Graph	Displays the values monitored by the high speed or monitor sampling and the USB trace file in a graph format.
Batch Monitor	Displays the monitored items of the inverter in a batch.
Test operation	"Test operation" allows the selected inverter's frequency to be displayed, operation mode to be switched and displayed, forward and reverse operation commands to be sent, setting frequency to be written, and other functions to be done.
Developer	Used for creating sequence programs and writing them to the inverter to enable the use of the PLC function of the inverter.
USB memory parameter copy file edit	Used for editing the parameter setting values (USB memory parameter copy file) read from the inverter to the USB memory.
Help	Displays the contents of the instruction manuals of the inverter and software.

- Graph
  The inverter output frequency, current, and other data are sampled, and the results are displayed in a graph (waveform). Sampled data can be saved to a file (*.jpg, *.emf, *.gp4, or *.csv file), and sampling data saved to a file can be read (by importing *.gp4 file, or *.st1) and displayed.

- Using the PLC function
  Developer is used for creating sequence programs and writing them to the inverter to enable the use of the PLC function of the inverter.
  PLC function is used for customizing inverter operation to meet the machine specifications. PLC function operates the inverter according the input signals, or outputs signals and monitored values according to inverter operation. Refer to the Instruction Manual of each inverter model for details of the inverter settings in Developer.

- USB memory parameter copy file edit function
  The USB memory parameter copy file editor is a dedicated software for editing setting values of USB memory parameter copy files of the models which support FR Configurator2.

Useful information

Various types of data of the inverter can be saved in a USB memory device.
The USB host communication enables the following functions.

Function	Description
Parameter copy	• Copies the parameter setting from the inverter to the USB memory device. A maximum of 99 parameter setting files can be saved in the USB memory device. • The parameter setting data copied in the USB memory device can be copied to other inverters. This function is useful in backing up the parameter setting or for sharing the parameter setting among multiple inverters. • The parameter setting file can be copied onto a personal computer from the USB memory device and edited using FR Configurator2.
Trace	• The monitored data and output status of the signals can be saved in the USB memory device. • The saved data can be imported to FR Configurator2 to diagnose the operating status of the inverter.
PLC function data copy	• This function copies the PLC function project data to a USB memory device when the PLC function is used. • The PLC function project data copied in the USB memory device can be copied to other inverters. • This function is useful in backing up the parameter setting and for allowing multiple inverters to operate by the same sequence programs.

7.12.2 Screen example

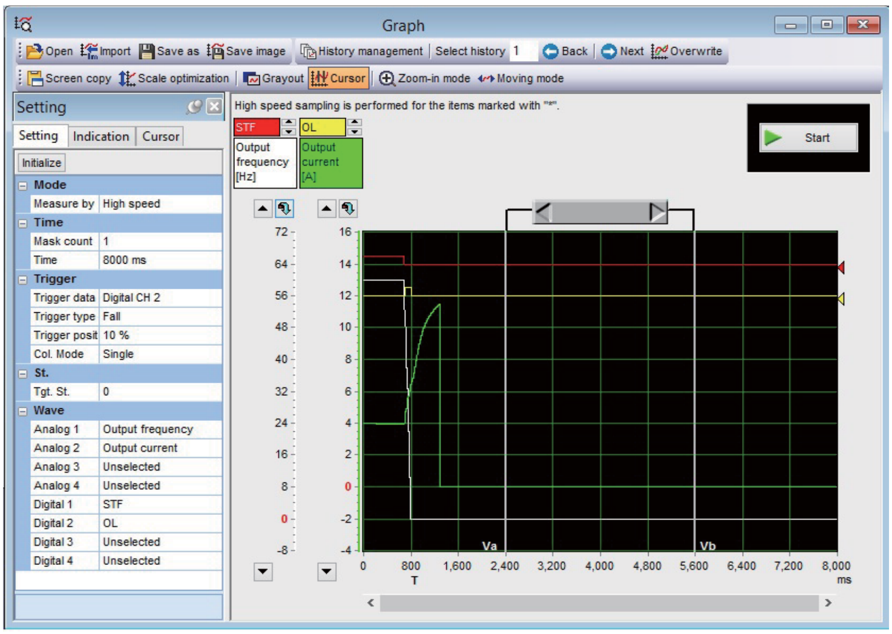
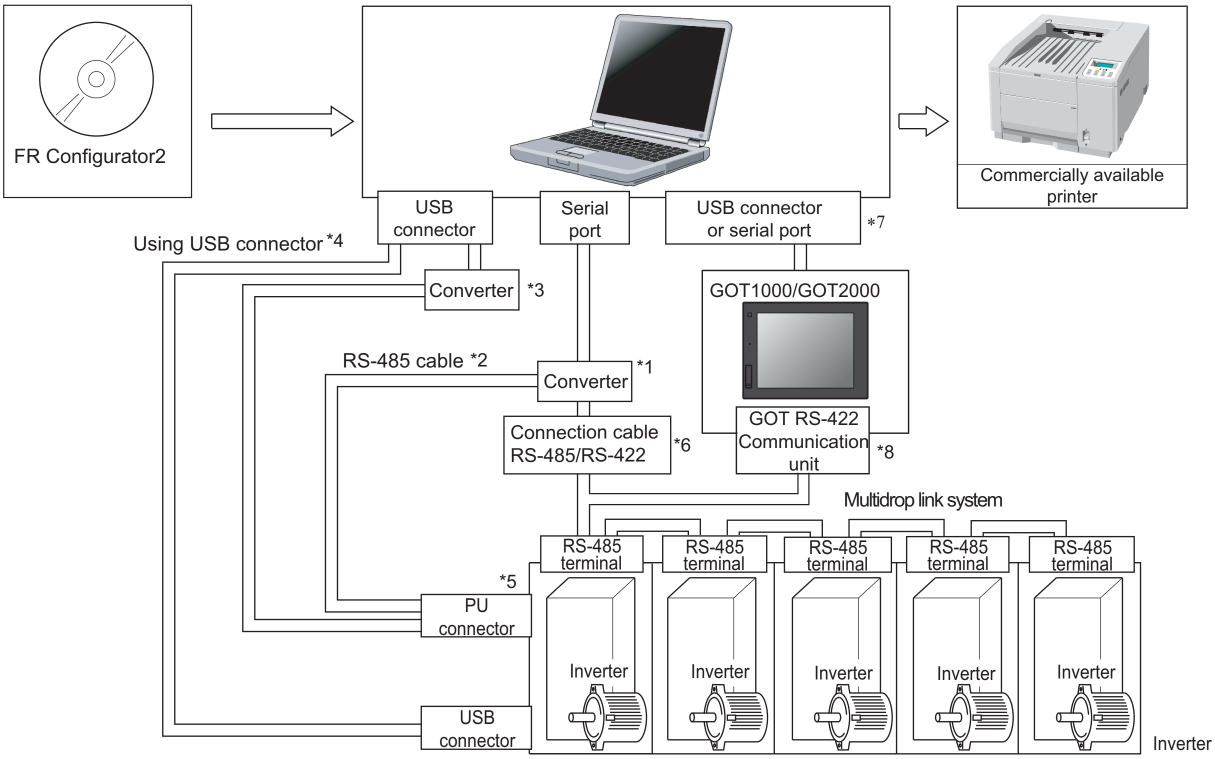


Fig.7.4 Screen example of the graph display

7.12.3 System configuration

The following devices are required to use FR Configurator2. Setup the system in accordance with the instruction manual of each device.



*1: When using serial port of a personal computer, a commercially available converter is required.
<Examples of product available on the market> (as of February 2012)
Model: DINV-CABV (with connectors and cable)
Diatrend Corp.

The converter cable cannot connect two or more inverters. (The computer and inverter are connected on a 1:1 basis). This is a RS-232C/RS-485 conversion cable with built-in converter. No additional cable or connector is required. Contact the maker for details of the product.

*2: Connection cable
<Examples of product available on the market> (as of February 2012)

Connector: RJ45 connector
Example: Tyco Electronics
5-554720-3

Cable: Cable in compliance with EIA568 (such as 10BASE-T cable)
Example: Mitsubishi Cable Industries, Ltd.
SGLPEV-T (Cat5e/300m) 24AWG x 4P

*3: USB/RS-485 convert cable
<Examples of product available on the market> (as of February 2012)

Model: DINV-U4
Diatrend Corp.

When using USB/RS-485 conversion cable, use the newest driver software. For product details or the newest driver software, contact the cable manufacturer.

*4: Recommended USB cable for computer-inverter connection
MR-J3USBCBL3M Cable length: 3m

*5: Communication with PU connector, RS-485 terminal, or USB connector is available.

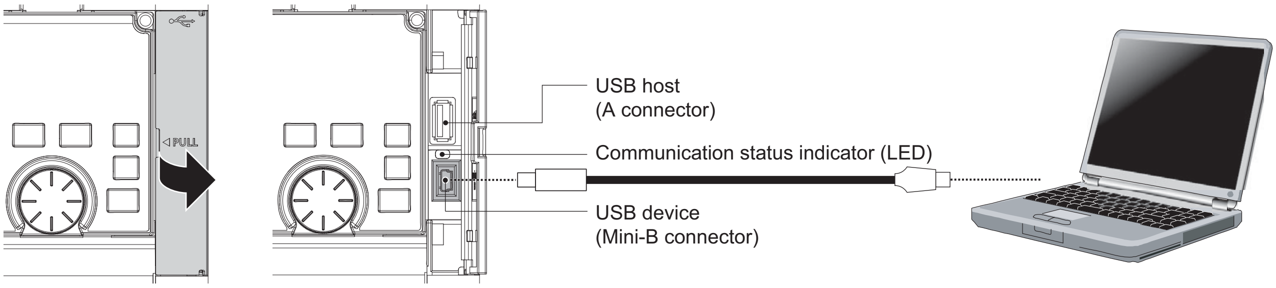
*6: Overall length of connection cable: 500m

*7: Available communication port is USB or serial port (one of port 1 to 63), and set in Communication settings screen of FR Configurator2. (Using multiple port at the same time is unavailable) Connection of a computer to GOT is 1:1 connection. When using USB for connecting with GOT, use dedicated cable GT09-C30USB-5P or GT09-C20USB-5P.
GTO 2000 series and a personal computer are connected only by USB.

*8: RS-422 communication unit (GT15-RS4-9S) is required for GOT1000 series. The number of connectable inverters depends on GOT. Refer to GOT1000 series or GOT2000 series connection manual for details of RS-422 connection and compatible version of GOT.

Product	Type	Maker
Communication cable	SGLPEV-T (Cat5e/300m) 24AWG x 4P	Mitsubishi Cable Industries, Ltd.
RJ-45 connector	5-554720-3	Tyco Electronics

[Connection examples of the USB cable and the USB connector]
On the inverter side, connect the USB cable to the USB device (mini-B connector).



7.13 Setting multiple parameters as a batch

Parameters including those for setting communication with Mitsubishi Electric human machine interface (GOT), rated frequency of 50Hz/60Hz and acceleration/deceleration time can be changed as a batch.
Multiple parameters are changed automatically. Users do not have to consider each parameter number. (Automatic parameter setting mode)
When the GOT is used, terms are displayed for the operator to understand better, and the parameters can be set easily with the touch panel.

7.14 Easy-to-read operation panel

Operation panel (FR-DU08) is capable of 5-digit, 12-seg display. To further improve the display function, optional operation panel (FR-LU08) adopting an LCD panel is also available.

FR-DU08(12 segment type)

FR-LU08(LCD type)(option)

7.15 PLC function

The PLC function will help you to provide the control sequence best suited for the machine specifications.
The following functions can be used in PLC function.

Item	Description
I/O	
General-purpose I/O	Sequence programs enable I/O signal transmission to/from the inverter and its plug-in options.
Analog I/O	Sequence programs enable analog input/ouput transmision of plug-in options and inverters.
Pulse train I/O	Sequence programs enable pulse train inputs (to terminal JOG) and pulse train outputs (from terminal F/C(FM)).
Inverter parameter read/write	Sequence programs enable inverter parameter write/read.
User parameter	50 user parameters (Pr.1150 to Pr.1199) are available and are linked with the data registers D206 to D255, which accept direct access by sequence programs.
CC-Link/CC-Link IE Field	A plug-in option (FR-A8NC or FR-A8NCE) enables data communication between PLC program and master unit.
Special function	
PID operation	Inverter's PID operations can be set (up to two loops).
User initiated fault	Up to five fault-initiating conditions can be set to activate a protective function.
Fault clear	The protective function occurring in the inverter can be reset.
Inverter operation lock	Inverters can start up while the PLC function is running.
Monitored item for the user	Desired data can be displayed on the operation panel.

(1) Inverter operation sequence customized for the machine

PLC function operates the inverter according the input signals, or outputs signals and monitored values according to inverter operation.
For example, the frequency of opening or closing of a shutter can be checked based on a signal from a sensor.
Control programs can be created in sequence ladders using FR Configurator2.

(2) Realizes the decentralized control

The control of the whole system is decentralized to inverters that manage their subordinating devices individually.
A group of dedicated sequence programs is created and saved in each inverter. The master controller no longer has to process all the sequence programs, and the decentralized system accepts program changes more flexibly.

(3) Automatic operation in accordance with the time

With the real-time clock, automatic operation can be performed at certain times (when the optional LCD operation panel (FR-LU08) is used).

(4) Optional parameter, protective functions and monitor setting are available

- **User parameter**

  Up to 50 parameters, which are linked with the data registers, can be set. The variables (data registers) used in the PLC function can be set as inverter parameters. Furthermore, parameter settings can be saved in the EEPROM of the inverter. When results of calculation using the PLC function are saved in the parameters, the data can be retained after the power is turned OFF.

- **User initiated fault**

  Output can be shut off under conditions other than those of the existing protective functions. Up to five specific fault-initiating conditions can be set to activate a protective function and shut off the inverter output.

- **Monitored item for the user**

  Special register values can be displayed for monitoring on the operation panel. User-designated data such as results of calculation using the PLC function can be displayed.

(5) Useful functions

- **Inverter parameter read/write**

  Parameter settings can be changed using sequence programs. The acceleration/deceleration time and patterns can be changed in accordance with operation statuses. You can choose RAM or EEPROM to save the parameter settings. Choose RAM if changing the settings frequently.

- **PID function**

  Two different loops of PID inverter operations can be pre-set, and those can be controlled using sequence programs.

- **Inverter operation lock**

  The inverter operation can be restricted for the command sources other than the sequence programs.

• Application example

<table>
<tr><th>Characteristic</th><th>Application example</th></tr>
<tr><td>

Crane control

• The traveled distance (total number of travel pulses) of each wheel is directly read from the encoder installed at the wheel. The pulses from the two wheels are then compared, and their speed is adjusted to synchronize the wheel positions. An external controller to offset speed is no longer needed, and system cost can be reduced.

User initiated fault

• Up to five protective functions operating under specific conditions can be set.

• Protective functions can be triggered to block inverter output at such times as when positional displacements are not eliminated even after offsetting speed over a fixed period of time, or pulses from the PLGs on both wheels are not input.

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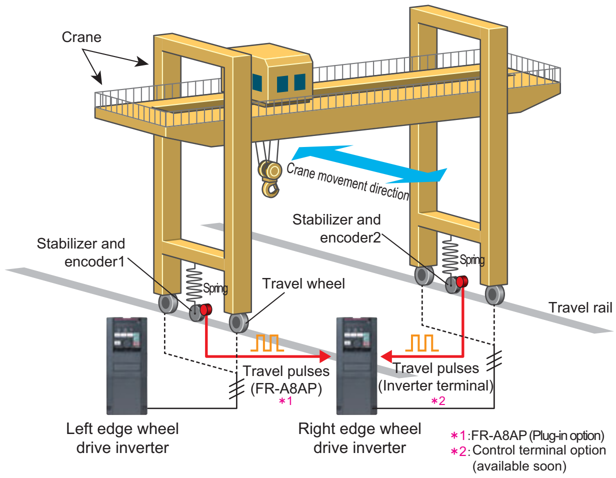

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Conveyor control

• The workpiece positions detected by sensors are directly reported to the inverter, and the inverter sends out the operation commands to the conveyor robot and to the extruding machine.

• Whole control can be performed by an inverter, and system cost can be reduced.

Inverter parameter read/write

• Changes can be made to inverter parameters from the sequence program.

• The acceleration/deceleration time and pattern can be set based on the type of workpiece.

Inverter operation lock

• Operation is possible only when the sequence function is enabled. Changes to settings caused by operator error can be avoided.

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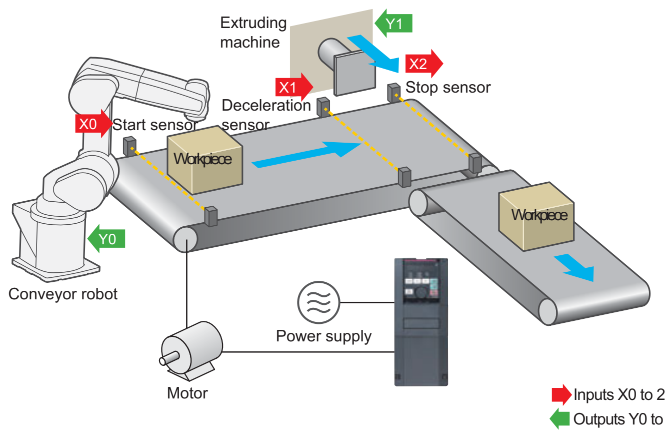

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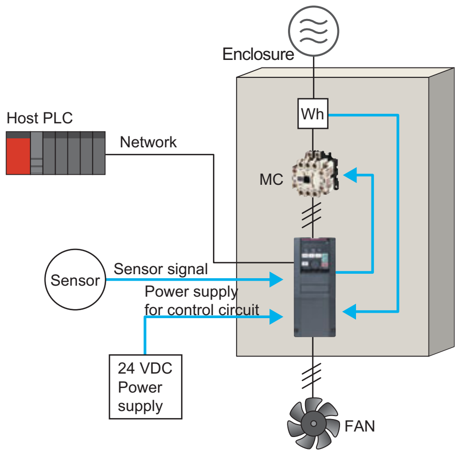
</table>

<table>
<tr><th>Characteristic</th><th>Application example</th></tr>
<tr><td>Fan control
• Signals sent via the enclosure (relay panel, etc.) such as input magnetic contactor signals, watt hour meter signals, and sensor signals can be read directly into the inverter and controlled.
• A fan can be controlled in accordance with the conditions without using relays, etc. Furthermore, by using an external 24 VDC power source for the control power supply, input machine signals can be turned ON and OFF regardless of whether there is an input power source. And by employing an external 24 VDC power supply for the control power, input machine signals can be turned ON and OFF, regardless of the existence of a main circuit power supply.
CC-Link/CC-Link IE Field
• A plug-in option (FR-A8NC/FR-A8NCE) enables the communication between sequence program and master unit.
• A variety of equipment inside the factory can be centrally controlled with a CC-Link Network.</td><td></td></tr>
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APPENDICES

APPENDIX 1 Required Power Calculation

The following section describes how to calculate the required power for different machines and devices.

(1) Basic formula

Calculate the required power P[kW] by

$$P=\frac{T \times N}{9550} \quad \text{.......(App. 1.1)}$$

T : Required torque [N•m]
N : Speed [r/min]

(2) General industrial machine

1) Pump

$$P=\frac{Q \times H}{6.12 \times \eta}\ [kW] \quad \text{.......(App. 1.2)}$$

Q : Discharge amount from the pump [m^3/min]
H : Lifting height [m]
η : Pumping efficiency (usually 0.55 to 0.85 although it changes by the model)

2) Fan and blower

$$P=\frac{Q \times H}{6120 \times \eta}\ [kW] \quad \text{.......(App. 1.3)}$$

Q : Air volume [m^3/min]
H : Wind pressure [mmHg]
η : Blowing efficiency of the fan (usually 0.5 to 0.8 although it changes by the model)

3) Compressor

$$P=\frac{5.83 \times Q \times (P^{0.286}-1)}{\eta}[kW] \quad \text{.......(App. 1.4)}$$

Q : Output air volume [m^3/min]
P : Absolute output pressure [kg/cm^2]
η : Compressing efficiency (0.5 to 0.8)

(3) Cargo-handling machine

1) For hoisting

$$P=\frac{(W+W_{CS}) \times V}{6120 \times \eta}\ [kW] \quad \text{.......(App. 1.5)}$$

W : Weight [kg]
Wcs : Hanger mass [kg]
V : Hoisting speed [m/min]
η : Machine efficiency (0.7 to 0.85)

2) For driving

$$P=\frac{\mu \times (W + W_{CS} + W_G) \times V}{6120 \times \eta}\ [kW] \quad \text{...(App. 1.6)}$$

W_G : Crane mass [kg]
μ : Driving resistance
V : Driving speed [m/min]

3) For turning

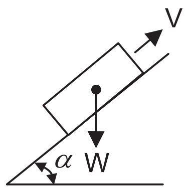
$$P=\frac{\mu \times (W+W_{G1}) \times V}{6120 \times \eta}\ [kW] \quad \text{.......(App. 1.7)}$$

W_{G1} : Mass of the crane's turning part [kg]
μ : Driving resistance
V : Driving speed [m/min]

4) When hoisting a load on the slope with α degree to the horizontal surface

$$P=\frac{W \times (\sin\alpha + \mu \times \cos\alpha) \times V}{6120 \times \eta}\ [kW] \quad \text{.....(App. 1.8)}$$

W : Mass [kg]
μ : Friction coefficient
η : Hoisting efficiency
V : Hoisting speed [m/min]



(4) Machine tool

Feeding a table

$$P=\frac{\mu \times (W + W_T) \times V}{6120 \times \eta}[kW] \quad \text{.......(App. 1.9)}$$

W : Work mass [kg]
W_T : Table mass [kg]
μ : Friction coefficient of the table and the base
V : Feeding speed of the table [m/min]

(5) Other

1) When driving an inertia body

$$P=\frac{1}{9550} \times \frac{J}{9.55} \times \frac{N^2}{t}\ [kW] \quad \text{.......(App. 1.10)}$$

N : Speed [r/min]
J : Flywheel effect [kg·m^2]
t : Acceleration time [s]

APPENDIX 2 Calculation Method of the Load Moment of Inertia

Table.2 shows typical calculation formulas for the load moment of inertia.
(Note) Conversion formula of $J\ [\mathrm{kg \cdot m^2}] = (1/4) \times GD^2\ [\mathrm{kgf \cdot m^2}]$.

Table.2 Calculation of load moment of inertia

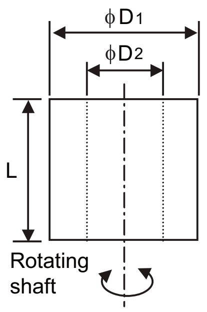
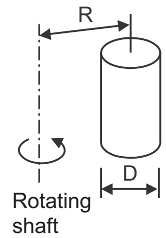
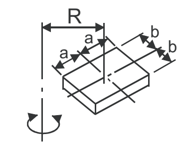
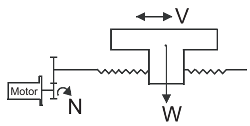
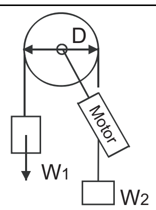
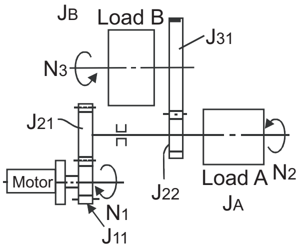
Type	Structure	Formula
Cylinder	Rotating shaft is the center of the cylinder 	$J_L = \frac{\pi \times \rho \times L}{32}(D_1^4 - D_2^4) \times 10^{-4} = \frac{W}{8}(D_1^2 + D_2^2) \times 10^{-4}$ ....(App. 2.1) J_L : Load moment of inertia [kg•m²] ρ : Density of cylinder material [kg/cm³] L : Cylinder length [cm] D_1 : Cylinder outer diameter [cm] D_2 : Cylinder inner diameter [cm] W : Cylinder mass [kg] Reference data Density of material Iron ....7.8 × 10^{-3} [kg/cm³] Aluminium ....2.7 × 10^{-3} [kg/cm³] Copper ....8.96 × 10^{-3} [kg/cm³]
	When rotating shaft and cylinder shaft are misaligned 	$J_L = \frac{W}{8}(D^2 + 8R^2) \times 10^{-4}$ ....(App. 2.2) J_L : Load moment of inertia [kg•m²] D, R : See the left figure [cm]
Prism		$J_L = W\left(\frac{a^2 + b^2}{3} + R^2\right) \times 10^{-4}$ ....(App. 2.3) J_L : Load moment of inertia [kg•m²] a, b, R : See the left figure [cm]
Linearly moving object		$J_L = \frac{W}{4} \times \left(\frac{V}{\pi N}\right)^2 = W \times \left(\frac{\Delta S}{20\pi}\right)^2 \times 10^{-4}$ ....(App. 2.4) J_L : Load moment of inertia at motor shaft [kg•m²] V : Speed of the linearly moving object [m/min] N : Motor speed [r/min] ΔS : Travel amount in one motor rotation [mm/rev] W : Mass of the linearly moving object [kg]
Hanging object		$J_L = \frac{W \times D^2}{4} + J_P$ ....(App. 2.5) W : Total mass (W_1 + W_2) [kg] J_P : Moment of inertia of the pulley [kg•m²] D : Diameter of the pulley [m]

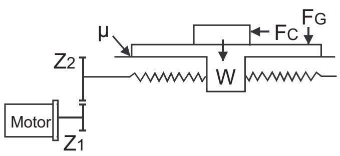
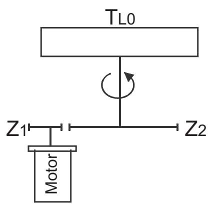
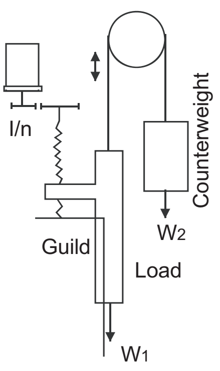
Table.2 Calculation of load moment of inertia

Type	Structure	Formula
Load of which speed is changed		$J_L = J_{11} + (J_{21} + J_{22} + J_A) \times \left(\frac{N_2}{N_1}\right)^2 + (J_{31} + J_B) \times \left(\frac{N_3}{N_1}\right)^2$ .... (App. 2.6) J_A, J_B : Moment of inertia of the loads A and B [kg•m²] J_{11} to J_{13} : Moment of inertia of gear [kg•m²] N_1 to N_3 : Rotation speed of each axis [r/min]

APPENDIX 3 Calculation Method for Load Torque

The following table shows typical calculation formulas for the load torque.

Table.3 Calculation of load torque [N•m]

Type	Structure	Formula
Linear movement		$T_L = \frac{F}{2\pi\eta} \times \left(\frac{V}{N}\right) = \frac{F \times \Delta S}{2 \times 10^3 \pi\eta}$ [N·m] ....(App. 3.1) F : Force toward the shaft of the linearly moving object [N] η : Efficiency of driving parts V : Travel speed [m/min] N : Motor speed [r/min] ΔS : Travel amount in one motor rotation [mm/rev] When moving a table as shown left, F in the above formula can be calculated in the next formula (App. 3.2). $F = F_C + \mu \times (W \times g + F_G)$ [N] ....(App. 3.2) F_C : Moving-part force towards the shaft [N] F_G : Tightening force of the table guiding surface [N] W : Total mass of the moving part [kg] g : Gravitational acceleration [9.8m/s^2] μ : Friction coefficient
Circular movement		$T_L = \frac{1}{n} \times \frac{1}{\eta} \times T_{L0} + T_F$ [N · m] ....(App. 3.3) T_{L0} : Load torque on the load axis [N•m] T_F : Frictional load torque at motor shaft [N•m] $\frac{1}{n}$: Reduction ratio $\left(\frac{Z_1}{Z_2}\right)$ η : Efficiency of driving parts
Lift movement		For ascending $T_L = T_U + T_F$ [N·m] ....(App. 3.4) For descending $T_L = -T_U \times \eta^2 + T_F$ [N·m] ....(App. 3.5) T_U : Unbalanced torque [N•m] T_F : Frictional torque of the moving part [N•m] η : Efficiency of driving parts $T_U = \frac{(W_1 - W_2) \times g}{2\pi\eta} \times \left(\frac{V}{N}\right) = \frac{(W_1 - W_2) \times g \times \Delta S}{2 \times 10^3 \pi\eta}$ ....(App. 3.6) $T_F = \frac{\mu \times (W_1 + W_2) \times g \times \Delta S}{2 \times 10^3 \pi\eta}$ ....(App. 3.7) W_1 : Load mass [kg] W_2 : Counterweight mass [kg] η : Efficiency of driving parts μ : Friction coefficient V : Travel speed [m/min] ΔS : Travel amount in one motor rotation [mm/rev]

APPENDIX 4 Power Supply of Inverter (Harmonics and Instantaneous Power Failure)

This chapter describes how the power source and its system to which an inverter is connected are affected by the harmonics generated by the inverter. The effect on the peripheral devices can be assumed based on the harmonic amount generated from the inverter. With the assumed value, specific harmonic measures can be examined.
This chapter also describes how the fluctuation of the power supply (instantaneous power failure, voltage drop, etc.) affects an inverter. It is important to understand how an inverter and motor work.

POINTS for understanding !

1.Difference between harmonics and noise
2.Influx path and magnitude of the harmonic current
3.Harmonic suppression measure guideline and the measures
4.Movement of an inverter and motor at an instantaneous power failure (including the instantaneous voltage drop)

Appendix 4.1 Harmonics

The harmonics are defined as a fundamental wave (generally, power supply frequency) with an integral multiple frequency. One fundamental wave combined with multiple harmonics is called a distortion. (Refer to Fig.4.2 in this section).
Distorted waves generally include the harmonics of high frequency band (kHz to MHz order). The frequency band handled as the harmonics of a power distribution system is 40th to 50th (until 3kHz), and it should be regarded as a different problem from a high frequency band with a random aspect. For example, the radio disturbance or noise (Refer to APPENDIX 5) caused by a personal computer should be treated as a local problem of the hardware. Therefore, its influences and measures are different from those of the harmonics generated from an electrical circuit network. This point must be made clear.

$$i = i_o + \sum_{n=1}^{\infty} i_n \cdot \sin(2\pi fnt + \phi n) \quad \cdots \text{(App. 4.1)}$$

n = 1, 2, 3, ...
f = Fundamental frequency

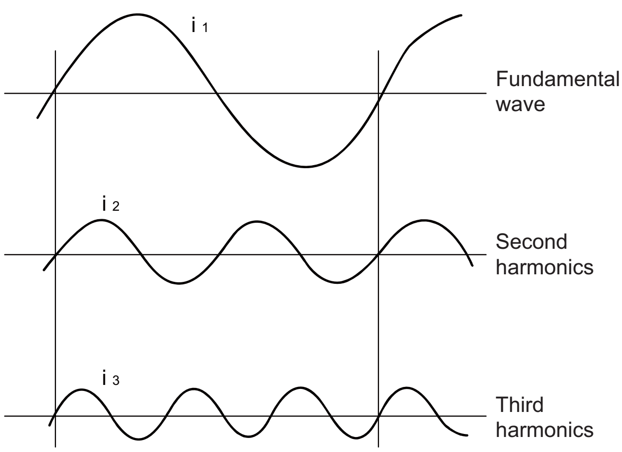


Fig.4.1 Fundamental wave and harmonics

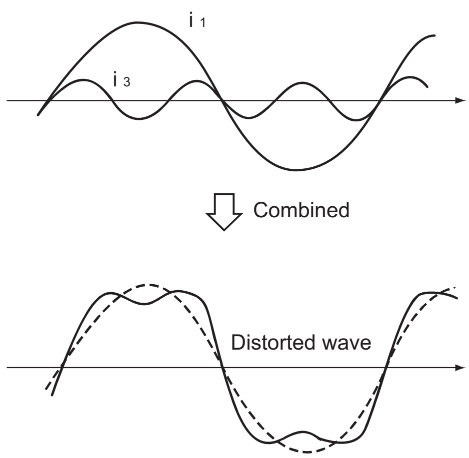


Fig.4.2 Distorted wave

1 BASICS OF INVERTERS
2 MOTOR CHARACTERISTICS AT INVERTER DRIVE
3 INVERTER PRINCIPLES AND ACCELERATION/DECELERATION CHARACTERISTICS
4 ENERGY SAVING WITH INVERTERS
5 CAPACITY SELECTION AND OPERATION METHOD FOR MOTOR AND INVERTER
6 PRECAUTIONS WHEN USING INVERTERS
7 PERIPHERAL DEVICES AND OPTIONS
APP APPENDICES

Table.4.4 Difference between harmonics and noise

Item	Harmonics	Noise
Frequency	Normally 40th to 50th or less, 3kHz or less	High frequency (Several tens of kHz to MHz order)
Source	Converter part	Inverter part
Cause	Commutation of rectifying circuits	Switching of transistors
Environment	To wire paths, power impedance	Across spaces, distance, laying paths
Quantitative understanding	Logical computation is possible	Occurs randomly, quantitative understanding is difficult.
Generated amount	Approximately proportional to load capacity	According to current fluctuation rate (larger with faster switching)
Immunity of affected device	Specified in standards for each device.	Differs according to maker's device specifications.
Examples of safeguard	Install a reactor (L).	Increase the distance (ℓ)

Appendix 4.2 Rectifying Circuit and Characteristics of Generated Harmonics

The sources of the generated harmonics are rectifiers, AC power regulators, etc. The converter in a general-purpose inverter consists of rectifying circuits, which generate many harmonics current. There are several types of rectifier circuits based on the main circuit types. The three-phase bridge type is most commonly used in general-purpose inverters. (Refer to Section 3.2)
The ordinal number "n" of the generating harmonic current can be theoretically calculated as "n = PK ± 1" (P= pulse number, K= 1, 2, 3 ...). Thus, the generating harmonic current of a three-phase bridge type inverter (P= 6 for the 6-pulse converter) will be 6K ± 1st order (5, 7, 11 or 13th ...). The magnitude of harmonics (harmonic contents) is 1/n, which means that the generated amount becomes smaller as the harmonic order becomes larger. Single-phase power input inverters generate the harmonics current with the order of 4K±1 (3rd, 5th, 7th, 9th...).

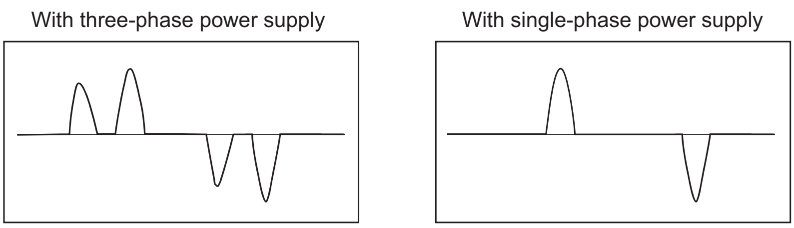


Fig.4.3 Waveform of the current input to the inverter (harmonic current)

Appendix 4.3 Shunt of Harmonic Current

When the harmonics are considered in the power distribution system, <u>the power source of the harmonics</u> is not the commercial power supply but the harmonic occurrence source (converter for general-use inverters). The commercial power supply (low and high-voltage power transformers) becomes a part of the load for the harmonics. Inverter-radiating harmonic current In (n as an ordinal number, $I_n = I_2 + I_3 + I_4 + ...$) is inversely proportional to the impedances of the power stepdown transformer ($\dot{Z}_L = R_L + j_nX_L$) and of the devices connected in parallel with the transformer. As for the Fig.4.4, the inverter-radiating harmonic current In is inversely proportional (1/Z) to the impedances of the motor B ($\dot{Z}_M = R_M + j_nX_M$) and of the capacitor ($\dot{Z}_C = j_nX_r - jX_C/n$). The harmonic current diverges in proportion to impedances (1/Z).
When harmonic frequency, which is much higher than the power supply frequency, flows, the impedance becomes small in the capacitor, and the low-impedance capacitor receives a large amount of harmonic current.
As the result, the capacitor may overheat or break.

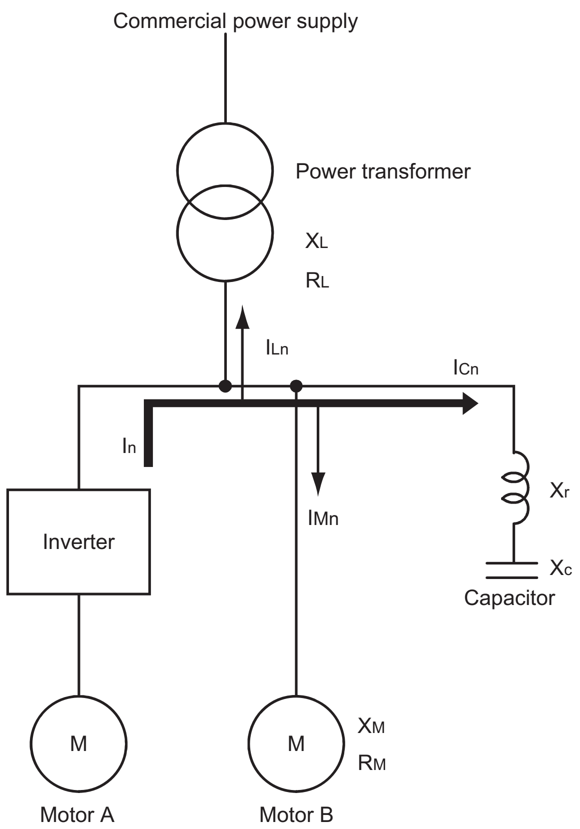


Fig.4.4 Power distribution system diagram

Useful information

- A current tends to flow to the smaller impedance, and a capacitive impedance element (power factor correction capacitor) may magnify the harmonics. When the harmonics are considered as a problem, the following can be said from the above:

1) The impedance on the power supply side $\dot{Z}s$ is represented by the short-circuit capacity on the power supply system and is not less affected by other factors as the power capacity is larger.
2) The inductive loads can be neglected since they have higher impedance than the harmonics.
3) What should be considered is only capacitive loads such as a power factor correction capacitor.

Appendix 4.4 Harmonic Suppression Guideline

Harmonic currents flow from the inverter to a power receiving point via a power transformer. The Harmonic Suppression Guidelines were established to protect other consumers from these outgoing harmonic currents.
The three-phase 200V input specifications 3.7kW or less were previously covered by "Harmonic Suppression Guidelines for Household Appliances and General-purpose Products" and other models were covered by "Harmonic Suppression Guidelines for Consumers Who Receive High Voltage or Special High Voltage". However, the general-purpose inverter has been excluded from the target products covered by "Harmonic Suppression Guidelines for Household Appliances and General-purpose Products" in January 2004. Later, this guideline was repealed on 6 September 2004. All capacities of all models are now target products of "Harmonic Suppression Guidelines for Consumers Who Receive High Voltage or Special High Voltage" (hereinafter referred to as "Specific Consumer Guidelines").

"The Harmonic Suppression Guidelines for Consumers Who Receive High Voltage or Special High Voltage"

This guideline sets forth the maximum values of harmonic currents outgoing from a high-voltage or especially high-voltage consumer who will install, add or renew harmonic generating equipment. If any of the maximum values is exceeded, this guideline requires that consumer to take certain suppression measures.

The users who are not covered by the above guidelines are not forced to follow the guidelines but advised to connect a DC reactor and an AC reactor.

Compliance with "the Harmonic Suppression Guidelines for Consumers Who Receive High Voltage or Special High Voltage"

Input power	Target capacity	Countermeasure
Three-phase 200V Three-phase 400V	All capacities	Confirm compliance with "the Harmonic Suppression Guidelines for Consumers Who Receive High Voltage or Special High Voltage" published in September 1994 by the Ministry of International Trade and Industry (present Ministry of Economy, Trade and Industry). Take countermeasures if required. Use the following materials as reference to calculate the power supply harmonics. Reference materials • Harmonic suppression guidelines for transistorized inverters by the Japan Electrical Manufacturers' Association (JEMA) (January 2004) • The technical data JEM-TR201 (calculating transistorized inverter harmonics for specific consumers) by JEMA (revised in December 2003)

Compliance with the "Harmonic Suppression Guidelines for Consumers Who Use General-purpose Inverters (with 20A Input Current or Less)" published by JEMA.

Input power	Target capacity	Countermeasure
Three-phase 200V	3.7kW or lower	Connect the AC reactor or DC reactor recommended in the Catalogs and Instruction Manuals. Reference materials • The technical data JEM-TR226 (harmonic suppression guidelines for transistorized inverters with 20A or lower input current) by JEMA (enacted December 2003)

Follow the procedure below to determine whether a harmonic measure is required to comply with "the Harmonic Suppression Guidelines for Consumers Who Receive High Voltage or Special High Voltage".

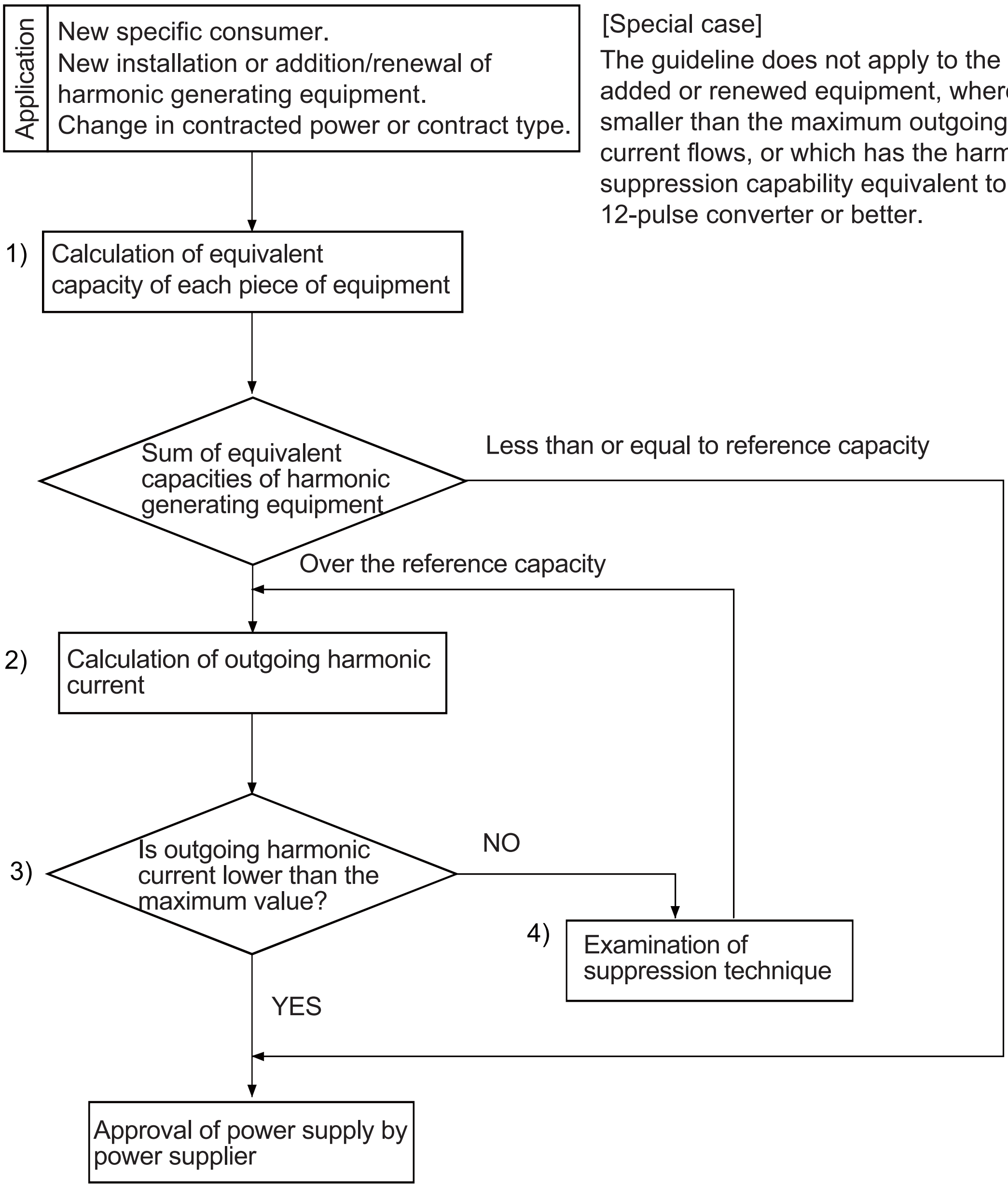


Fig.4.5 Harmonic Examination Flowchart

Appendix 4.5 Overview of Harmonic Suppression Techniques

The following table lists an overview of principles, features, etc. of harmonic suppression and absorption techniques.

No.	Item	Description	Effects, etc.
1)	Reactors for inverter (FR-HAL, FR-HEL)	Connect an AC reactor on the power supply side of the inverter or a DC reactor on its DC side or both to increase the circuit impedance, suppressing harmonic currents.	Harmonic currents are suppressed to about 1/2.
2)	High power factor converter (FR-HC2)	This converter trims the current waveform to be a sine waveform by switching in the converter part. Doing so suppresses the generated harmonic amount significantly. Connect it to the DC area of an inverter.	Harmonic current is suppressed to almost zero.
3)	Power factor improving capacitor	A power factor improving capacitor is small in impedance to high frequency components. When used with a series reactor, it has an effect of absorbing harmonic currents. This capacitor may be installed in either a high or low voltage side.	The absorbing effect is greater in the low voltage side.
4)	Transformer multi-phase operation	When two or more transformers are used, connecting them with a phase angle difference of 30° as in Y -Δ, Δ-Δ combination will cause a timing shift to suppress peak currents, providing an effect, equivalent to that of a 12-pulse bridge.	If the capacity of the Y -Δ, Δ-Δ combination differs, an effect equivalent to that of a 12-pulse bridge can be expected for the smaller capacity, and harmonic currents can be suppressed to about 1/2.
5)	AC filter	Similar to a power factor improving capacitor, a capacitor and series reactor are used together to reduce impedance to a specific frequency (degree), absorbing harmonic currents greatly.	Produces a great suppression effect. (Can satisfy the requirements of the guideline.)
6)	Active filter	This filter detects the current of a circuit generating a harmonic current and generates a harmonic current equivalent to a difference between that current and a fundamental wave current to suppress a harmonic current at a detection point.	Provides a great suppression effect. (Can satisfy the requirements of the guideline.) As this filter corrects the whole waveform, a power factor improving effect is also expected.

The techniques above are advantageous in the following order (highest to lowest):
- For suppression effect: 6) or 2), 5), 4), 3) and 1).
- For cost: 1), 2), 3), 4), 5) and 6).

Appendix 4.6 Influence of an Instantaneous Power Failure to the Inverter

When a power failure occurs, the power supply voltage for the control circuit used to control an inverter stops. To prevent a control malfunction, the instantaneous power failure protection is activated to stop the inverter output and maintain the output stop status. This protective operation differs according to the length of the instantaneous power failure. The explanation is given below using FR-A800 series as an example.

Appendix 4.6.1 Inverter operations according to the instantaneous power failure

(1) When an instantaneous power failure is within 15ms
The protective function is not activated, and the operation continues normally.

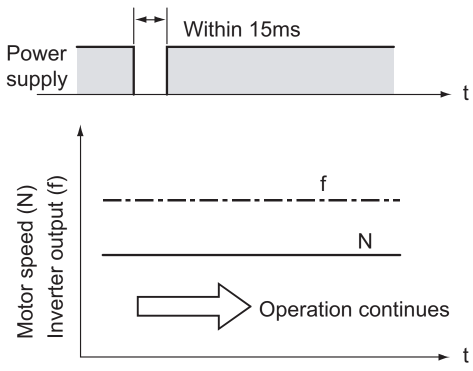


Fig.4.6 Instantaneous power failure within 15ms

(2) When an instantaneous power failure is longer than 15ms and shorter than 100ms
The protective function is activated, and the inverter output stops. (The motor coasts to stop.)

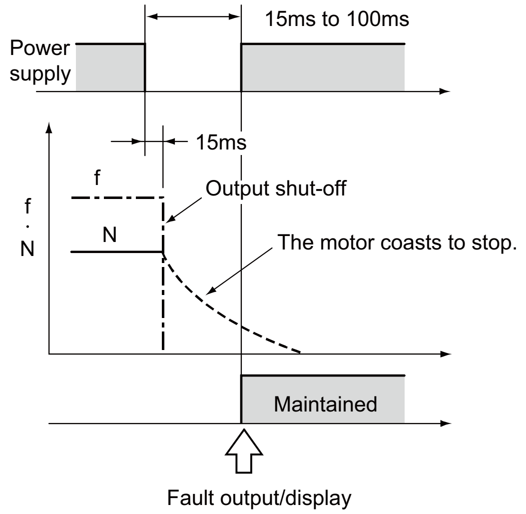


Fig.4.7 Instantaneous power failure longer than 15ms and shorter than 100ms

(3) Instantaneous power failure for 100ms or longer
The inverter is automatically reset upon power restoration and becomes ready for resuming an operation.

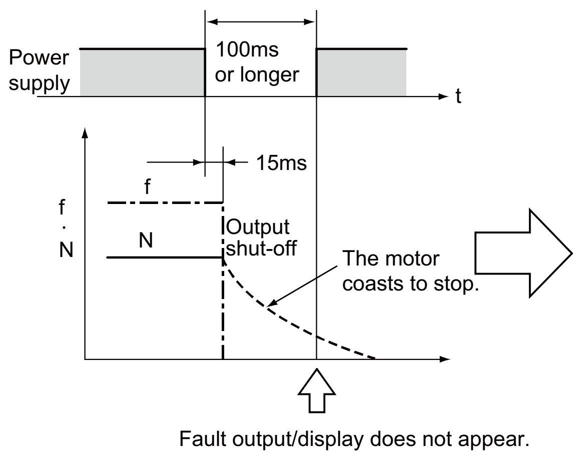
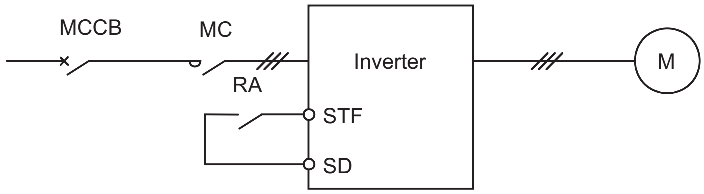


Fig.4.8 Instantaneous power failure for 100ms or longer

[Point to note]
When the start signal (STF, STR) is on, the inverter restarts upon power restoration. If a motor is coasting at this time, the overvoltage or overcurrent protection is activated and a trip may occur. To restart the inverter upon power restoration, use the instantaneous power failure restart function. (This function is available for FR-A800 series as standard. However, the restart function is not activated in the initial setting. Set "0" in Pr. 57.)
See Appendix 4.6.3 for details on the automatic restart after instantaneous power failure function.

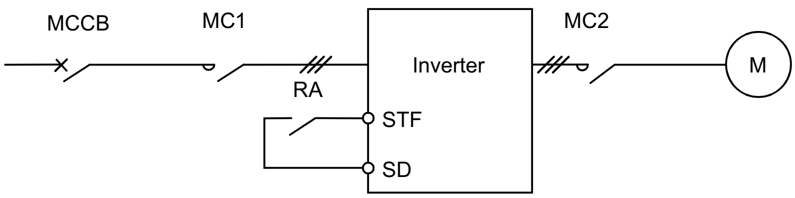
Appendix 4.6.2 Inverter peripheral circuit and inverter operation at instantaneous power failure

(1) When a magnetic contactor (MC) is installed in the primary side of the inverter



The operation shown in Appendix 4.6.1 will be performed if the instantaneous-power-failure time is too short to short circuit the magnetic contactor (MC) or the relay (RA). (The start signal STF continues to be ON.)
When only the magnetic contactor MC is opened, the motor coasts to a stop. To restart the operation upon power restoration, wait until the motor coasts to a stop, then turn ON the MC again or use the automatic restart after instantaneous power failure function. (Coasting interlock timer is required.)

(2) When magnetic contactors (MC) are installed in both primary and secondary sides of the inverter



The operation shown in Appendix 4.6.1 will be performed if the instantaneous-power-failure time is too short to open the magnetic contactor (MC1) or the relay (RA). (The start signal STF continues to be ON.)
When only the magnetic contactor MC1 is short circuited, the motor coasts to a stop. To restart the operation upon power restoration, wait until the motor coasts to a stop, then turn ON the MC1 again or use the automatic restart after instantaneous power failure function. (Coasting interlock timer is required.)

When only the magnetic contactor MC2 is short circuited, the motor coasts to a stop. Depending on the period of the power failure time, the inverter continues outputting or is reset upon power restoration and restarts by itself. Thus, inputting MC2 again would cause the motor to be suddenly started at the inverter's output frequency and may cause an inverter trip due to an excessive current.

Useful information

(a) Even if an instantaneous power failure occurs at the receiving end, a (perfect) instantaneous power failure does not always occur at the low voltage side, i.e., the inverter input terminals (R, S and T). Most cases are instantaneous voltage drops (as the undervoltage protection operation).

(b) The inverter has the instantaneous power failure protection function and the undervoltage protection function. The undervoltage protection function is activated when the voltage in the inverter DC circuit below a certain level continues for a certain period. When an instantaneous power failure occurs at the power supply, the protective function is activated for some inverters depending on the load output (kW). If the load output is small, inverters may continue the operation.

(c) Once a magnetic contactor or relay is switched on, it may not open with an instantaneous voltage drop. Generally, it opens at the voltage of 30 to 50% or less of the coil rating.

Appendix 4.6.3 Automatic restart after instantaneous power failure control

(1) Commercial power supply switchover, automatic restart after instantaneous power failure function

NOTE These functions are effective when a single motor is connected to an inverter.
They do not work when multiple motors are used.

- Commercial power supply switchover
  To switch from the commercial power supply operation to the inverter operation, the inverter can be started without a motor stopped but while it is coasting.
- Automatic restart after instantaneous power failure
  When an instantaneous power failure occurs, a motor does not need to be stopped to continue the operation after the power restoration.

(2) Automatic restart operation after instantaneous power failure

(a) When an instantaneous power failure occurs during operation, the motor coasts to a stop.
(b) After the power is restored, DC voltage is applied from the inverter to the coasting motor. Then, the DC current flows through the motor. (Refer to Fig.4.9 A) in the figure)
This DC current includes the ripple at the frequency proportional to the motor speed.
(c) The CPU takes in the signal from a current detector to count the frequency for the ripple and determines the motor speed.
(d) The inverter outputs the signal with the frequency according to the motor speed. (Refer to Fig.4.9 B) in the figure) Then, the inverter operation is restarted, controlling the start current of the motor by gradually increasing the output voltage.

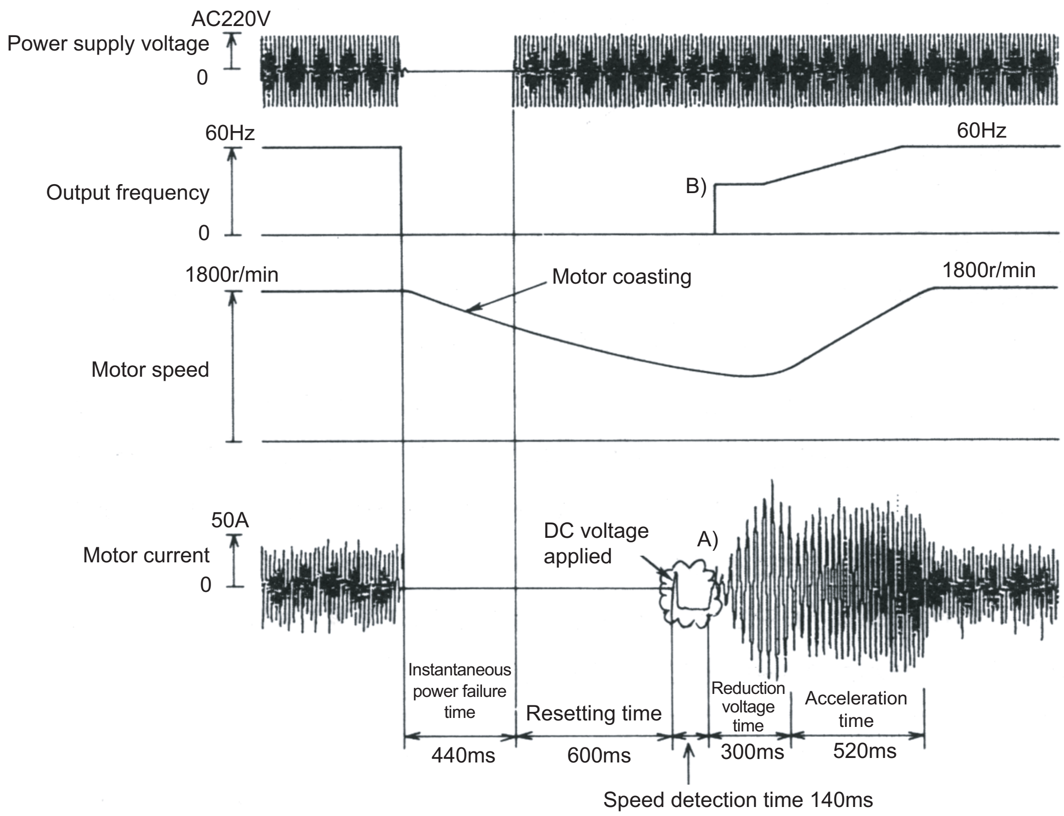


Fig.4.9 Example of automatic restart after instantaneous power failure operation

When the automatic restart after instantaneous power failure function is equipped (Example: FR-A800 series)
Short circuit across CS and SD to use the automatic restart after instantaneous power failure function.

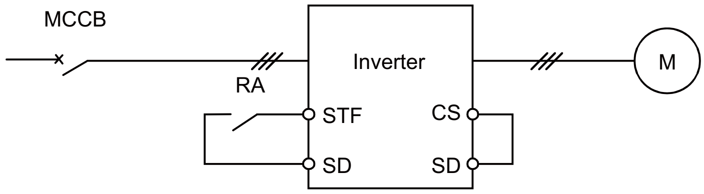
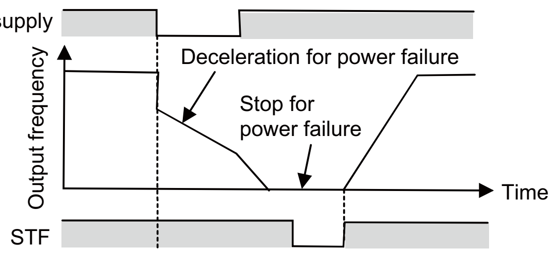


Fig.4.10 Wiring of automatic restart after instantaneous power failure function

☒ Useful information

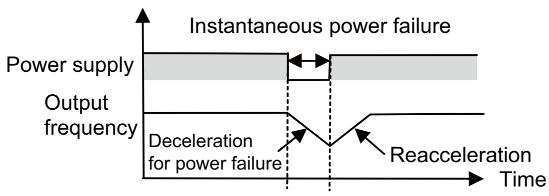
Power-failure deceleration stop function

The motor coasts to a stop at an instantaneous power failure in the normal setting, but with the power failure deceleration brake function, the motor can stop faster by utilizing the regenerative power. When this function is used, the motor does not restart upon power restoration even if a start signal has been input. Also, the reacceleration mode can be selected for the power restoration during power failure deceleration.



Instantaneous power-failure operation continuation function

This function makes the operation continue using the regenerative energy generated by deceleration after detecting an instantaneous power failure. After the power is restored, it accelerates the motor to the command frequency and continues the operation.
The inverter will trip if enough regenerative energy is not obtained from the motor due to the small load inertia.
In this case, use the automatic restart after instantaneous power failure function.



Remark

We recommend taking the Inverter Maintenance Course for the details of Appendix 4 to Appendix 6.

APPENDIX 5 Noise

With the widespread usage of electrical devices, the troubles caused by noise tend to increase. Since the inverter generates noise from the operation principle, it may affect the adjacent devices. The degree of the effect varies according to the inverter control system, noise capacity of external devices, laying condition of wiring, installation distance, grounding method, etc. When installing the devices described below near the inverter, it is recommended to take the following measures according to the conditions.

[Devices that need to have measures taken against noise]
Sensors (proximity switch, etc.), video cameras (ITV, image scanner, etc.), radios (including an AM radio), acoustic devices (microphone, video, audio, etc.), CRT display and medical equipments

[Devices that are recommended to have measures taken against noise]
Measuring equipments and internal telephones

Appendix 5.1 Principle of Noise Generation

As described in Chapter 3, the output voltage waveform is controlled by switching the DC voltage at high speed in the inverter.
The magnified output waveform is as shown in Fig.3.23 of Chapter 3.
Since the steep rise and drop include many high frequency components, these components are the noise source.
The noise generated here and the harmonics mentioned in APPENDIX 4 are sometimes confused since both of them affect other electrical equipment. Generally, however, the harmonics commonly refer to waves with a frequency between 40th and 50th (2.4 to 3kHz) whereas noise commonly refers to waves with a frequency of tens of kilohertz or higher.

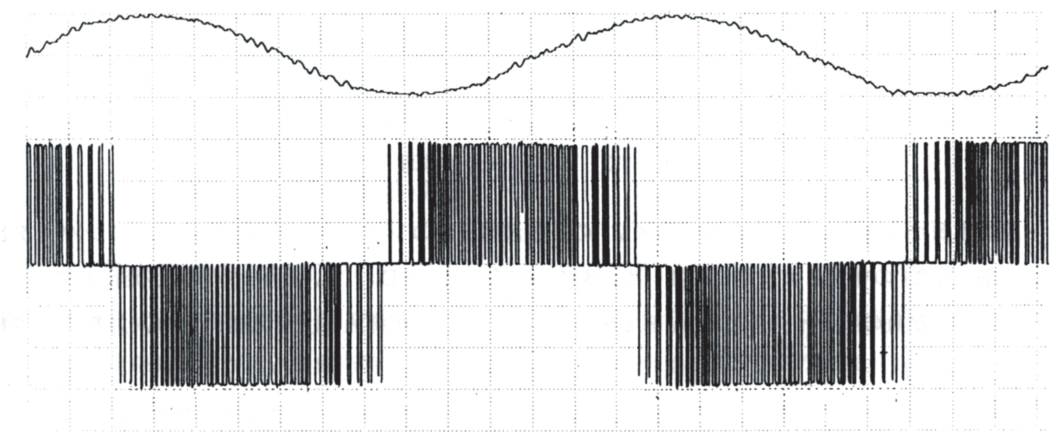


Fig.5.1 Waveforms of the measured output current and voltage of an FR-A800 series inverter (at 2kHz carrier frequency)

Appendix 5.2 Noise Types and Propagation Paths

Inverter-generated noises are largely classified into those radiated by the cables connected to the inverter and inverter main circuits (I/O), those electromagnetically and electrostatically induced to the signal cables of the peripheral devices close to the main circuit power supply, and those transmitted through the power supply cables.
The types of noise are shown in Fig.5.2 of this section and the paths of noise in Fig.5.3 of this section.

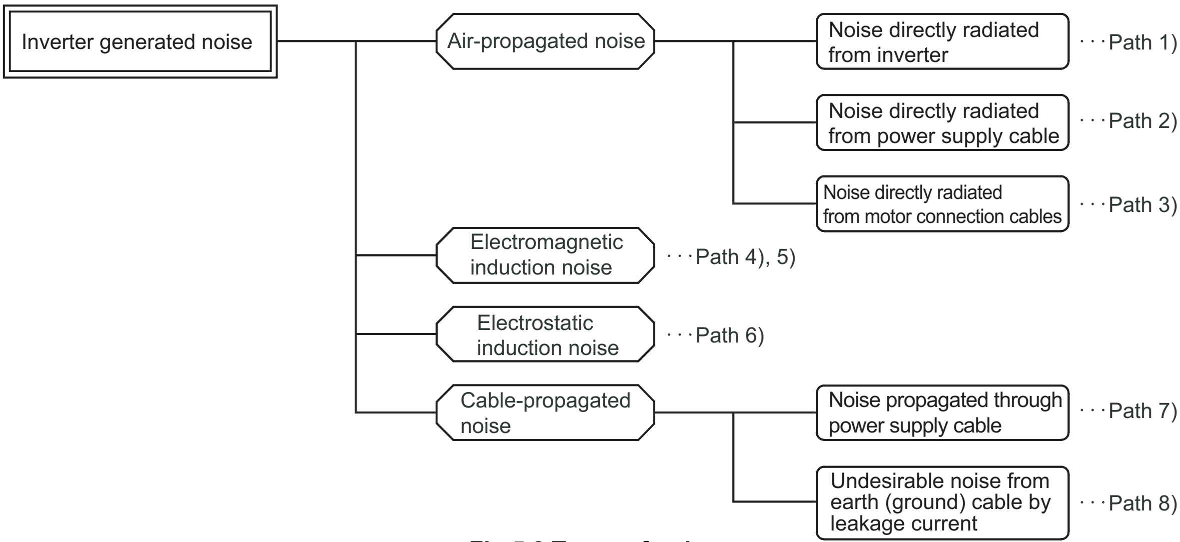


Fig.5.2 Types of noise

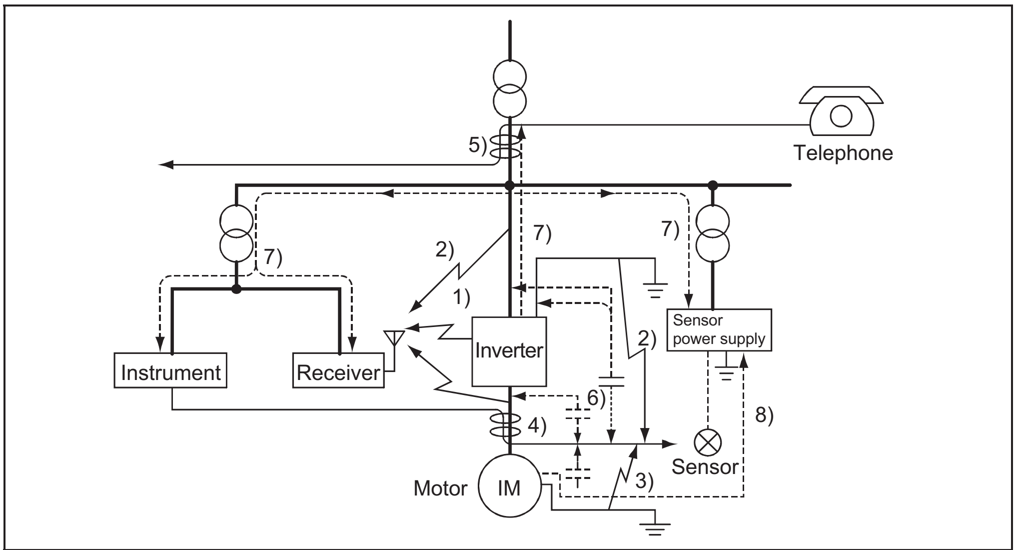


Fig.5.3 Paths of noise

The noise levels tend to become lower as the noise frequency band gets higher. Generally, the noise level is low enough not to be problematic in frequencies of 30MHz or higher.
With some exceptions, though the noise does not affect a TV or FM radio used in the frequency of 30MHz or higher, it affects the radios of the low frequency band (0.5 to 10MHz) such as an AM radio. Therefore it is logical to examine measures against noise with consideration to the frequency band.

(1) Air-propagated noise (Paths 1) to 3))

This noise is generated in an inverter and radiated to the air. The paths of this noise can be classified into the three types shown in Fig.5.4 of this section.

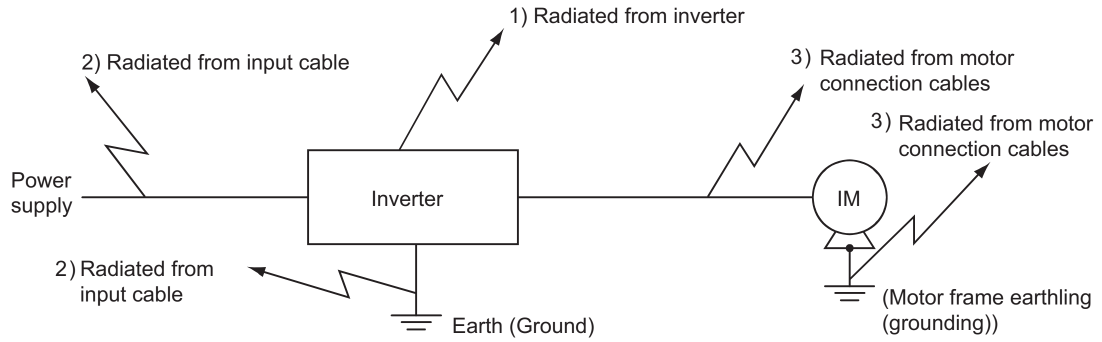


Fig.5.4 Air-propagated noise

(2) Electromagnetic induction noise (Paths 4) and 5))

This noise is generated and transmitted when power cables or signal cables of peripheral devices cross a magnetic field generated by the current that is input to or output from an inverter. (Refer to Fig.5.5 in this section.) When both cables are adjacent and parallel or the size of the loop created by each cable is large, the noise to be induced is also larger.

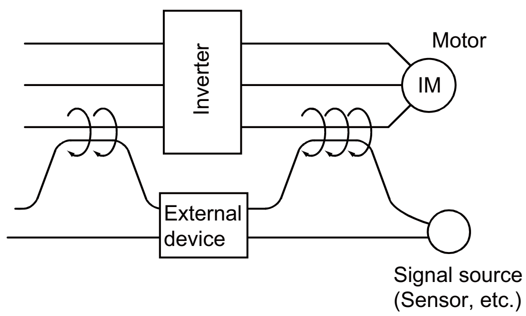


Fig.5.5 Electromagnetic induction noise

(3) Electrostatic induction noise (Path 6))

This noise is generated and transmitted when an electric field generated by the inverter I/O cable is combined with signal cables through the electrostatic capacitances.
(Refer to Fig.5.6 in this section.)

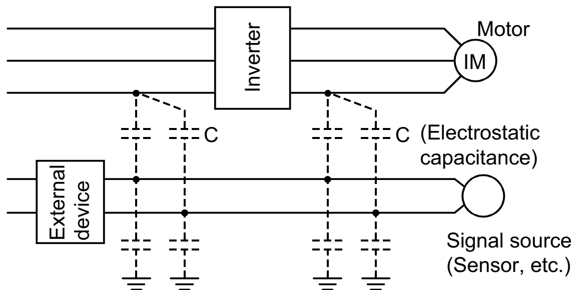


Fig.5.6 Electrostatic induction noise

(4) Cable-propagated noise (Path 7))

This noise is a high-frequency noise that is generated inside the inverter and transmitted to peripheral devices through cables on the power supply side.
(Refer to Fig.5.7 in this section.)

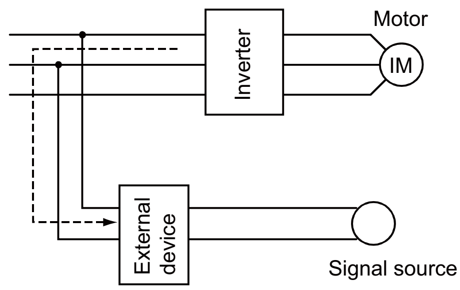


Fig.5.7 Cable-propagated noise

Appendix 5.3 Measures against Noise

Appendix 5.3.1 Concept of the measures against noise

Although there are many noise propagation paths as described in Appendix 5.2, noise sources can broadly be classified into the following three types as shown in Fig.5.2 and Fig.5.3.

1) Propagation, induction or radiation from an input power supply cable
2) Induction or radiation from motor connection cables
3) Radiation from an inverter

These noises tend to reduce as the noise frequency band is higher. Generally, the noise level is not to be problematic in frequencies of 10MHz or higher.
Consequently, though the noise does not affect a TV or FM radio used in the frequency of 70MHz or higher, it affects the radios of the low frequency band such as an AM radio. Therefore it is logical to examine measures against noise with consideration to the frequency band.

(1) Reducing noises transmitted to the power supply cable

Installing a filter between the inverter and the power supply cable is an effective measure in reducing noise.
Available filters are described below.
The following describes how to use each filter and their effect on noise reduction.

1) Radio noise filters FR-BIF (200V class) and FR-BIF-H (400V class)

This filter is classified into 2 classes: The 200V class and the 400V class. They can be used for all capacities.
As shown in Fig.5.8 in this section, it is connected to the power input terminals of the inverter. If the connection cables between the filter and the inverter are long, this part becomes a noise radiation antenna and becomes ineffective. Therefore, connect the filter connection cables including the ground cable directly to the terminals of the inverter and make the cables as short as possible.
Also, if the distance from the earth (ground) terminal of the inverter to the earth is too long, the earthing (grounding) cable becomes an antenna and the intended reduction of noise may not be obtained. Therefore, the earthing (grounding) cable must be also made as short as possible.
This filter has a large effect at several MHz or lower and is effective to reduce the noise to an AM radio.
In addition, this filter has a built-in capacitor. Connecting it to the inverter output side causes damage, and therefore care must be taken to avoid an incorrect connection.

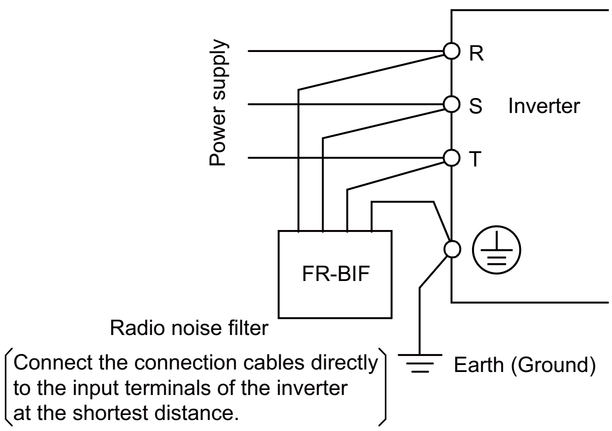


Fig.5.8 Installation of radio noise filter FR-BIF

2) Line noise filter FR-BSF01, FR-BLF

Since this filter consists of only a core, it can be used for all models regardless of the power supply voltage or capacity.
As shown in Fig.5.9 of this section, wind 3-phase wires in the same direction and insert them to the power input side of the inverter. The effect is higher when the number of turns is higher. Make as many turns as possible (at least three turns (4T)).
If the cable is too thick to make three turns (4T) or more, use two filters to make the number of turns three turns (4T) or more (for the input side of the inverter).
There are two types used depending on the cable size to be used.
This filter has a larger effect at several 100 kHz or more. Also, this filter can be used on the inverter output side. When installing the filter to the output side of the inverter, make three turns (4T) or less.

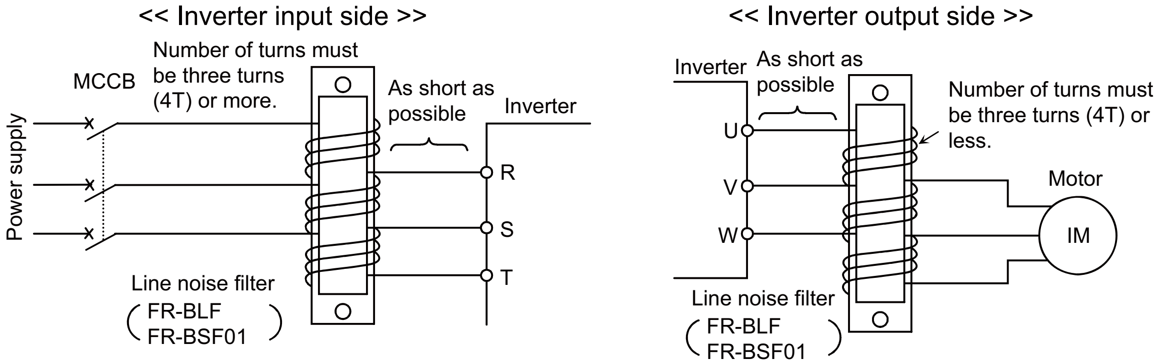


Fig.5.9 Installation of line noise filters FR-BSF01 and FR-BLF

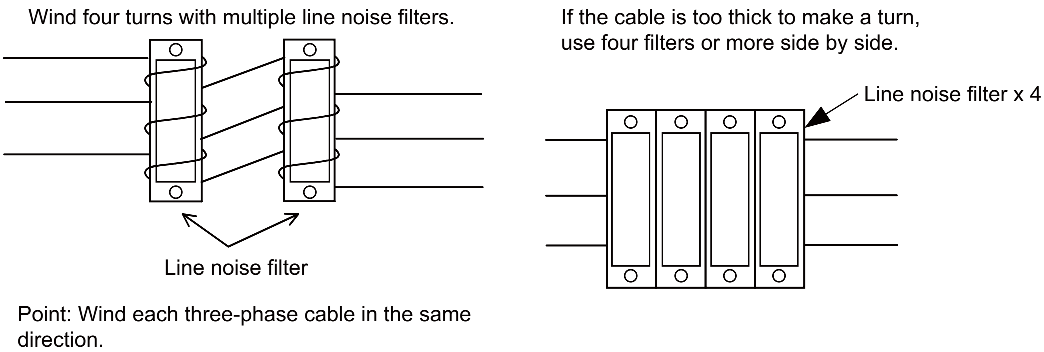


Fig.5.10 Usage of multiple line noise filters

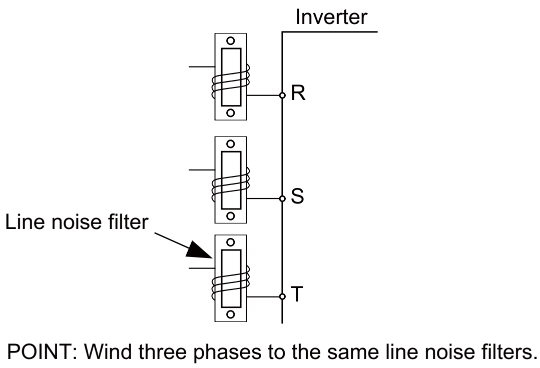


Fig.5.11 Incorrect usage of line noise filters

Table5.1 Applicable cables and pass-through time

● FR-BSF01

Cable (mm)^2	Number of cable turns (T)
2	4
3.5	4
5.5	3
8	2
14	2
22	1
38 to 150	× Cannot be used.

With a thick cable (5.5mm^2 or thicker)

The cable cannot make four turns with one filter. Using two or more filters is recommended to make the total of 4 pass-through times.

Use the cables listed above or use an FR-BLF line noise filter.

● FR-BLF

Cable (mm)^2	Number of cable turns (T)
2 to 22	4
30 to 60	3
80	2
100 to 150	1

With a thick cable (30mm^2 or thicker)

The cable cannot make four turns with one filter. Using two or more filters is recommended to make the total of 4 pass-through times.

3) Combination of FR-BIF(-H) and FR-BLF/FR-BSF01

As described above, FR-BIF is relatively effective to the noise of the low frequency, and FR-BLF to that of the high frequency. Therefore, combining the both filters brings a better result.

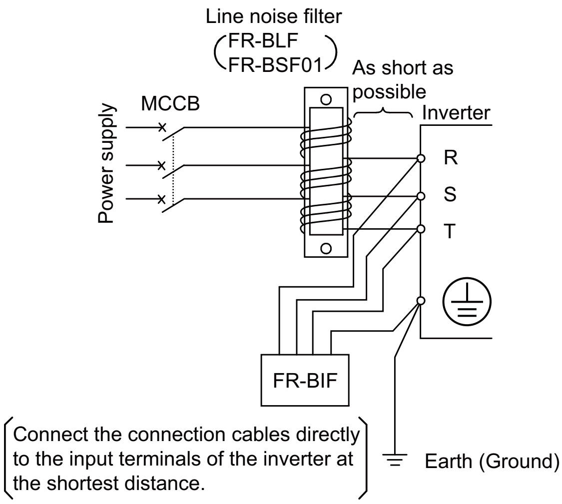


Fig.5.12 Combination of FR-BIF and FR-BLF/FR-BSF01

Useful information

FR-A800 and F700P series 55kW or lower-capacity inverters come with a built-in filter that is equivalent to the line noise filter at the input side and a radio noise filter.
The 75kW or higher-capacity inverters come with a filter equivalent to the line noise filter only.

4) Noise suppression transformer

A noise suppression transformer has primary and secondary coils with minimum magnetic and static bindings. It provides a noise suppression effect.

(2) Reducing noises radiated from cables between an inverter and a motor

Installing the previously described FR-BLF or FR-BSF01 line noise filter to the output side of the inverter is a method to reduce the radiated noises. Generally, a metal pipe or shielded cable is used as shown in Fig.5.13 of this section. Here, grounding the motor must be performed on the inverter side with one wire of the four-core cables, and using a pipe with wall thickness of 2mm or more produces a better effect.

Also, running the cable through a pit of concrete instead of a metal pipe or placing the cable in a room surrounded by the concrete can produce a similar effect.

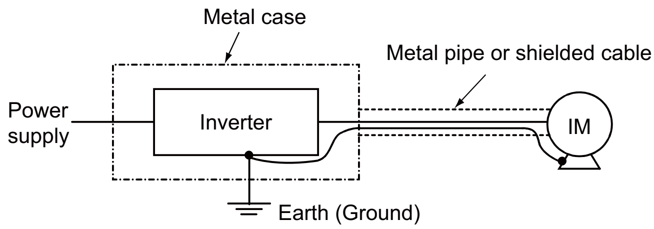


Fig.5.13 Piping process of motor connection cables

(3) Reducing noises radiated from an inverter

Generally, noises radiated from an inverter are relatively small and less problematic. However, when an inverter is installed close to the previously described devices easily affected by noises, placing the inverter in a metal case and installing a noise filter on the power supply side is required.

Also, for the output side, connect a metal pipe to the case.

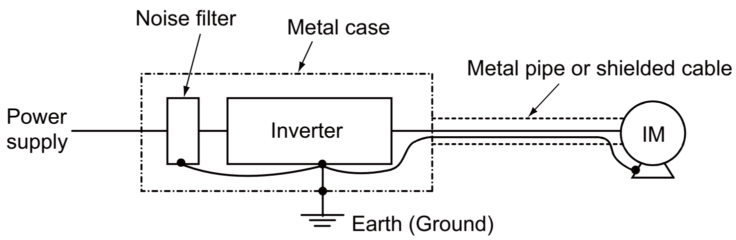


Fig.5.14 Reducing noises radiated from an inverter

Remark

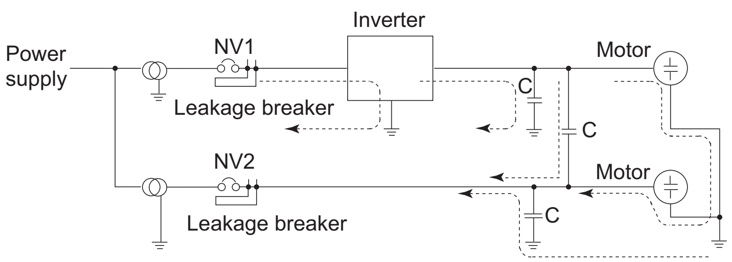
Refer to page 139 for the countermeasures for noise and their effect.

Appendix 5.4 Leakage Current

Capacitances exist between the inverter I/O cables, other cables and earth and in the motor, through which a leakage current flows. Since its value depends on the static capacitances, carrier frequency, etc., low acoustic noise operation at the increased carrier frequency of the inverter will increase the leakage current. Therefore, take the measures described below. Select the earth leakage circuit breaker according to its rated sensitivity current, regardless of the carrier frequency setting.

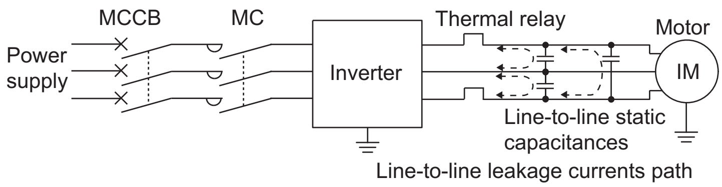
Appendix 5.4.1 Leakage current between the ground

Table5.2 Influence and countermeasure for leakage current between the ground

Type	Influence and countermeasure
Influence and countermeasure	•Leakage currents may flow not only into the inverter's own line but also into the other lines through the earth (ground) cable, etc. These leakage currents may operate earth (ground) leakage circuit breakers and earth leakage relays unnecessarily. ●Suppression technique •If the carrier frequency setting is high, decrease the E600(Pr.72) PWM frequency selection setting. Note that motor noise increases. Selecting E601(Pr.240) Soft-PWM operation selection makes the sound inoffensive. •By using earth leakage circuit breakers designed for harmonic and surge suppression in the inverter's own line and other lines, operation can be performed with the carrier frequency kept high (with low noise).
Transmission path	

Appendix 5.4.2 Line-to-line leakage current

Table5.3 Influence and countermeasure for line-to-line leakage current

Type	Influence and countermeasure
Influence and countermeasure	•Line-to-line leakage current flows through the capacitance between the inverter output lines. •Harmonic component of the leaked current may cause unnecessary operation of a thermal relay. When the wiring length is long (50m or more) for the 400V class small-capacity model (7.5K or lower), the external thermal relay is likely to operate unnecessarily because the ratio of the leakage current to the rated motor current increases. ●Measures •Use H000(Pr.9) Electronic thermal O/L relay. •If the carrier frequency setting is high, decrease the E600(Pr.72) PWM frequency selection setting. Note that motor noise increases. Selecting E601(Pr.240) Soft-PWM operation selection makes the sound inoffensive. To ensure that the motor is protected against line-to-line leakage currents, it is recommended to use a temperature sensor to directly detect motor temperature.
Transmission path	

Appendix 5.5 Earth (Ground)

Generally, an electrical apparatus has an earth (ground) terminal, which must be connected to the ground before use.
An electrical circuit is usually insulated by an insulating material and encased. However, it is impossible to manufacture an insulating material that can shut off a leakage current completely, and therefore, a small current leaks into the case.
The purpose of earthing (grounding) the case of an electrical apparatus is to prevent operator from getting an electric shock from this leakage current when touching it.
To avoid the influence of external noises, this earthing (grounding) is important to audio equipment, sensors, computers and other machines that handle low-level signals or operate very fast.
As above, there are two types of the earthing (grounding), which have completely different characteristics. Applying them together for earthing (grounding) causes troubles as a matter of course. Therefore, it is necessary to differentiate between a dirty earthing (grounding) for electric shock prevention and a clean earthing (grounding) for noise prevention.
In addition, when an inverter is used, the output voltage becomes not a sine wave but a steep waveform as shown in Fig.3.23 of Chapter 3, and therefore the charging/discharging current to the electrostatic capacitances existing in the insulation part flows as leakage current.
Moreover, the same charging/discharging leakage current flows to the motor to which the output voltage of this inverter is applied, and it becomes a larger current value with more high frequency components compared to that in the operation with the commercial power supply as shown in Fig.5.15 in this section. The higher the inverter carrier frequency is, the stronger this tendency develops.

Appendix 5.5.1 Earthing (grounding) methods and earthing (grounding) work

As described previously, earthing (grounding) is roughly classified into an electrical shock prevention type and a noise-affected malfunction prevention type.
Therefore, these two types should be discriminated clearly, and the following work must be done to prevent the leakage current containing high frequency components from entering the malfunction prevention type earthing (grounding):

(a) If possible, use independent earthing (grounding) for the inverter. (Refer to Fig.5.15 in this section)
If independent earthing (grounding) (Fig.5.15 (I)) is impossible, use common earthing (grounding) (Fig.5.15 (II)) where the inverter is connected with the other equipment at an earthing (grounding) point.
Common earthing (grounding) as in (III) of Fig.5.15 must be avoided as the inverter is connected with the other equipment by a common earthing (grounding) cable.
Especially, common earthing (grounding) with a high-power equipment such as a motor and transformer must be avoided.
Also a leakage current including many high frequency components flows in the earthing (grounding) cables of the inverter and inverter-driven motor. Therefore, they must use the independent earthing (grounding) method and be separated from the earthing (grounding) of equipment sensitive to the aforementioned noises.
In a tall building, it is a good policy to use the noise malfunction prevention type earthing (grounding) with steel frames and carry out electric shock prevention type earthing (grounding) in the independent earthing (grounding) method.

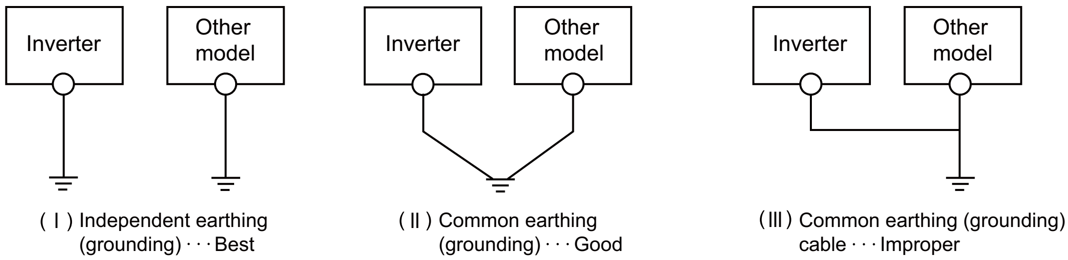


Fig.5.15 Earthing (grounding) methods

(b) Use Class D grounding (grounding resistance 100Ω or less) for the 200V class inverter and Class C grounding (grounding resistance 10Ω or less) for the 400V class on the earthing (grounding) work.

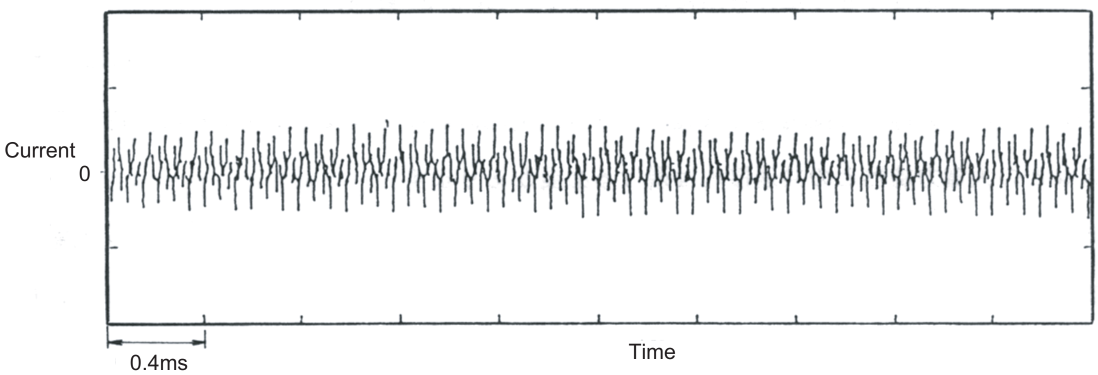
(c) Use the thickest possible earth (ground) cable. The earth (ground) cable should be no less than the size indicated in the instruction manual.

(d) An earthing (grounding) point should be as close to the inverter as possible, and make an earthing (grounding) cable as short as possible.

(e) Run the earthing (grounding) cable as far away as possible from the I/O wiring of equipment sensitive to noises and run them in parallel in the minimum distance.

(f) Use one wire in a 4-core cable with the earth (ground) terminal of the motor and earth (ground) it on the inverter side.

If the earthing (grounding) of the inverter and the motor driven with the inverter is connected together with the earthing (grounding) of an audio, sensor, computer, etc., the generated leakage current becomes a noise source and creates a negative effect.
To solve this problem, earthing (grounding) work must be performed using separately a dirty earthing (grounding) of an inverter, etc. and a clean earthing (grounding) of an audio, sensor computer, etc.



Example of motor earth cable current when driven with the inverter
(Inverter: 200V system 0.75K, Motor: SF-JR 0.75kW 4P)

Remark

We recommend taking the Inverter Maintenance Course for the details of Appendix 4 to Appendix 6.

APPENDIX 6 IPM Energy Savings Simulation File

The IPM energy savings simulation file provides energy saving effect and CO_2 reduction rate achieved by replacing commercial power supply operation (damper/valve control) with IPM motor operation or general-purpose or high-efficiency motor operation by inverter. The file is an EXCEL® file and requires inputs of motor capacity, number of motors used, air volume, operating time, operating days per year, power cost, and CO_2 factor. Also the payback period can be calculated by inputting the initial cost and bearing exchange cost.

[Copyright]
Mitsubishi Electric Corporation

[Operating environment]
The IPM energy saving simulation file is operatable in EXCEL® 2003/2002/2000.
*EXCEL® is a registered trademark of Microsoft Corporation in the United States and other countries.

This file can be downloaded via internet.
MITSUBISHI ELECTRIC FA Site
http://www.MitsubishiElectric.co.jp/fa/

APPENDIX 7 Maintenance/Inspection

A general-purpose inverter is a static unit mainly consisting of semiconductor devices. Daily inspection must be performed to prevent any fault from occurring due to adverse effects of the operating environment, such as temperature, humidity, dust, dirt and vibration, changes in the parts with time, service life, and other factors.

Appendix 7.1 Precautions for Maintenance and Inspection

For some time after the power is switched off, a high voltage remains in the smoothing capacitor. When accessing the inverter for inspection, wait for at least 10 minutes after the power supply has been switched OFF, and then make sure that the voltage across the main circuit terminals P/+ and N/- of the inverter is not more than 30 VDC using a tester, etc.

Appendix 7.2 Inspection Items

(1) Daily inspection

- Basically, check for the following faults during operation.
  1) Whether the motor operates properly as set
  2) Improper installation environment
  3) Cooling system fault
  4) Unusual vibration and noise
  5) Unusual overheat and discoloration

(2) Periodic inspection

- Check the areas inaccessible during operation and requiring periodic inspection.
  1) Cooling system fault .... Clean the air filter, etc.
  2) Tightening check and retightening .... The screws and bolts may become loose due to vibration, temperature changes, etc.
  3) Check the conductors and insulating materials for corrosion and damage.
  4) Measure the insulation resistance.
  5) Check and change the cooling fan and relay.

(Note) A general-purpose inverter has a power supply indication, which indicates that the inverter is in operation, and error (alarm) indications at trouble occurrences. Understand the contents of these indications. Also, check the data of the electronic thermal relays, acceleration/deceleration time, etc. using the parameter unit, and record their setting values for normal operation.

For the inspection items and criteria of the daily and periodic inspections, refer to the table provided on the next page.

Daily and periodic inspection

Area of Inspection	Inspection Item	Description	Interval: Daily	Interval: Periodic *3	Corrective Action at Alarm Occurrence	Customer's Check
General	Surrounding environment	Check the surrounding air temperature, humidity, dirt, corrosive gas, oil mist , etc.	○		Improve environment	
	Overall unit	Check for unusual vibration and noise.	○		Check alarm location and retighten	
		Check for dirt, oil, and other foreign material. *1	○		Clean.	
	Power supply voltage	Check that the main circuit voltages and control voltages are normal.*2	○		Inspect the power supply	
Main circuit	General	(1) Check with megger (across main circuit terminals and earth (ground) terminal). (2) Check for loose screws and bolts. (3) Check for overheat traces on parts. (4) Check for stains.		○ ○ ○ ○	Contact the manufacturer Retighten Contact the manufacturer Clean	
	Conductors, cables	(1) Check conductors for distortion. (2) Check cable sheaths for breakage and deterioration (crack, discoloration, etc.).		○ ○	Contact the manufacturer Contact the manufacturer	
	Transformer/reactor	Check for unusual odors and abnormal increase in whining sound.	○		Stop the device and contact the manufacturer.	
	Terminal block	Check for damage.		○	Stop the device and contact the manufacturer.	
	Smoothing aluminum electrolytic capacitor	(1) Check for liquid leakage. (2) Check for safety valve projection and bulge. (3) Visual check and judge by the life check of the main circuit capacitor.		○ ○ ○	Contact the manufacturer Contact the manufacturer	
	Relay/contactor	Check that the operation is normal and no chatter is heard.		○	Contact the manufacturer	
	Resistor	(1) Check for crack in resistor insulation. (2) Check for a break in the cable.		○ ○	Contact the manufacturer Contact the manufacturer	
Control circuit protective circuit	Operation check	(1) Check that the output voltages across phases with the inverter operated alone is balanced. (2) Check that no fault is found in protective and display circuits in a sequence protective operation test.		○ ○	Contact the manufacturer Contact the manufacturer	
	Parts check: Overall	(1) Check for unusual odors and discoloration. (2) Check for serious rust development.		○ ○	Stop the device and contact the manufacturer. Contact the manufacturer	
	Parts check: Aluminum electrolytic capacitor	(1) Check for liquid leakage in a capacitor and deformation trace. (2) Visual check and judge by the life check of the control circuit capacitor.		○ ○	Contact the manufacturer	
Cooling system	Cooling fan	(1) Check for unusual vibration and noise. (2) Check for loose screws and bolts. (3) Check for stains.	○	 ○ ○	Replace the fan Fix with the fan cover fixing screws Clean	
	Heatsink	(1) Check for clogging. (2) Check for stains.		○ ○	Clean Clean	
Display	Indication	(1) Check that display is normal. (2) Check for stains.	○	 ○	Contact the manufacturer Clean	
	Meter	Check that reading is normal.	○		Stop the device and contact the manufacturer.	
Load motor	Operation check	Check for vibration and abnormal increase in operation noise.	○		Stop the device and contact the manufacturer.	

*1 Oil component of the heat dissipation grease used inside the inverter may leak out. The oil component, however, is not flammable, corrosive, nor conductive and is not harmful to humans. Wipe off such oil component with a cloth.
*2 It is recommended to install a device to monitor voltage for checking the power supply voltage to the inverter.

*3 One to two years of periodic inspection cycle is recommended. However, it differs according to the installation environment. Consult us for periodic inspection.

Remark

Continuous use of a leaked, deformed, or degraded smoothing aluminum electrolytic capacitor (as shown in the table above) may lead to a burst, breakage or fire. Replace such a capacitor immediately.

Appendix 7.3 Replacement of Parts

An inverter consists of many electronic parts such as semiconductor devices.
The following parts may deteriorate with age because of their structures or physical characteristics, leading to reduced performance or fault of the inverter. For preventive maintenance, the parts must be replaced periodically.
For 800 series, use the life check function as a guidance of parts replacement.

(1) Cooling fan

The cooling fan, which is used on heat-generating parts such as the main circuit semiconductor devices, has a bearing. This bearing is estimated to serve for approximately 87600 hours (for the 800 series). This is equivalent to approximately 10 years if the unit with the cooling fan is continuously operated without any stop. Replace the entire cooling fan when replacing.
However, when unusual noise and/or vibration is noticed during inspection, the cooling fan must be replaced immediately.
The 800 series provides a function to set the ON/OFF control of the cooling fan.
With the ON/OFF control, the service life of the cooling fan can be extended. Replacement is also made easily with a cassette.

(2) Smoothing capacitor

A large-capacity aluminum electrolytic capacitor is used for smoothing in the main circuit DC section, and an aluminum electrolytic capacitor is used for stabilizing the control power in the control circuit. Their characteristics are deteriorated by the adverse effects of ripple currents, etc.
The replacement intervals greatly vary with the ambient temperature and operating conditions.
When the inverter is operated in air-conditioned, normal environment conditions, replace the capacitors about every 10 years (for the 800 series).
When a certain period of time has elapsed, the capacitors will deteriorate more rapidly. Check the capacitors at least every year (less than six months if the life will be expired soon).
The appearance criteria for inspection are as follows:

1) Case: Check the side and bottom faces for expansion.
2) Sealing plate: Check for remarkable warp and extreme crack.
3) Explosion-proof valve: Check valves for significant extension, and check valves that have operated
4) Check for external crack, discoloration, fluid leakage, etc. It is determined that that the capacitor has reached its life when the measured capacitance of the capacitor reduced to 85% or below of the rating.

(3) Relays

To prevent a contact fault, etc., relays must be replaced according to the cumulative number of switching times (switching life). The following table shows replacement criteria for the inverter parts.

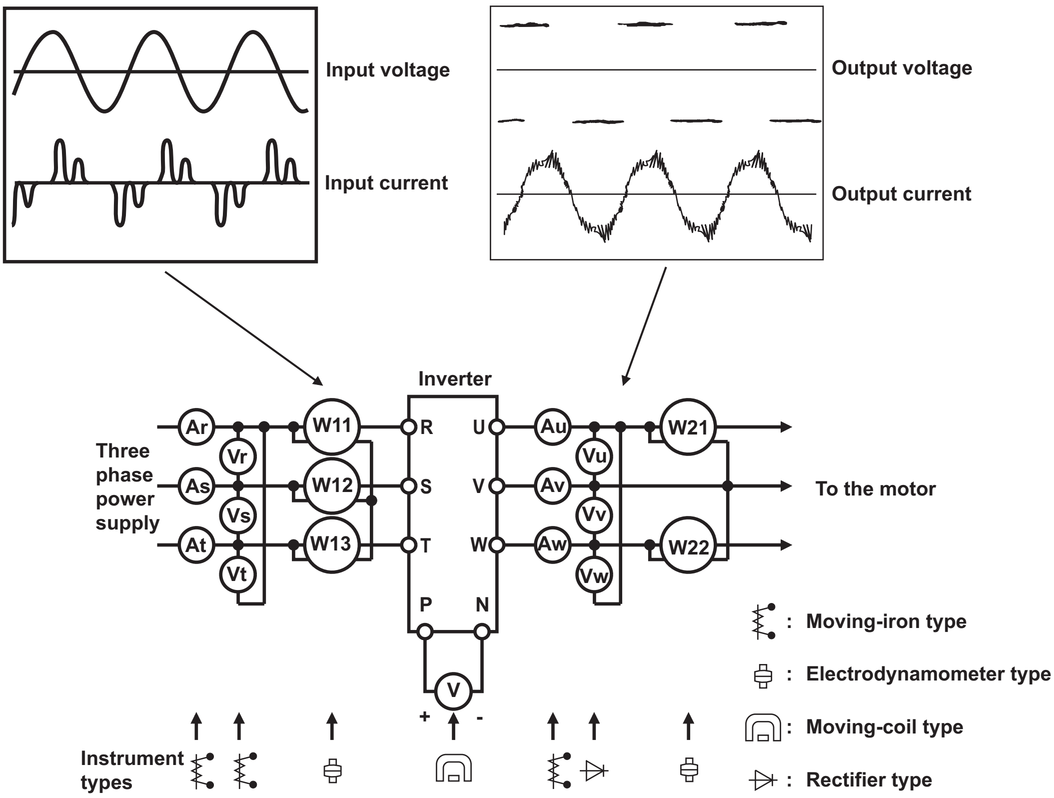
Inverter parts to be replaced (800 series inverter)

Part Name	Estimated lifespan *1	Replacement method and remarks
Cooling fan	10 years	Replace (as required)
Main circuit smoothing capacitor	10 years *2	Replace (as required)
On-board smoothing capacitor	10 years *2	Replace the board (as required)
Relays	——	as required

*1 Estimated lifespan for when the yearly average surrounding air temperature is 40°C (without corrosive gas, flammable gas, oil mist, dust and dirt etc).
*2 Output current: 80% of the inverter rating

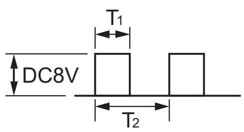
Appendix 7.4 Measurement of Main Circuit Voltages, Currents and Powers

- Measurement of voltages and currents
  Since the voltages and currents on the inverter power supply and output sides include harmonics, measurement data depends on the circuits measured.
  When instruments for commercial power supply frequency are used for measurement, measure the following circuits with the instruments given on the next page.
- When installing meters etc. on the inverter output side
  When the inverter-to-motor wiring length is long, especially in the 400V class, small-capacity models, the meters and CTs may generate heat due to line-to-line leakage current. Therefore, choose equipment which has enough allowance for the current rating.
  When measuring and indicating the output voltage and output current of the inverter, it is recommended to utilize the terminals AM and FM output function of the inverter.



Examples of Measuring Points and Instruments

Measuring points and instruments

<table>
<tr><th>Item</th><th>Measuring Point</th><th>Measuring Instrument</th><th colspan="2">Remarks (Reference Measured Value)</th></tr>
<tr><td>Power supply voltage V_1</td><td>Across R and S
Across S and T
Across T and R</td><td>Moving-iron type AC voltmeter (Note 4)</td><td colspan="2">Commercial power supply
Within permissible AC voltage fluctuation (Refer to the Instruction Manual of the inverter)</td></tr>
<tr><td>Power supply side current I_1</td><td>R, S, T line current</td><td>Moving-iron type AC ammeter (Note 4)</td><td colspan="2"></td></tr>
<tr><td>Power supply side power P_1</td><td>R, S, T and
Across R and S
Across S and T
Across T and R</td><td>Digital power meter (designed for inverter) or electrodynamic type single-phase wattmeter</td><td colspan="2">$P_1 = W_{11} + W_{12} + W_{13}$
(3-wattmeter method)</td></tr>
<tr><td>Power supply side power factor Pf_1</td><td colspan="4">Calculate after measuring power supply voltage, power supply side current and power supply side power.
$Pf_1 = \frac{P_1}{\sqrt{3}V_1 \cdot I_1} \times 100\ \%$</td></tr>
<tr><td>Output side voltage V_2</td><td>Across U and V,
V and W,
W and U</td><td>Rectifier type AC voltage meter (Note 1, 4)
(Moving-iron type cannot measure)</td><td colspan="2">Difference between the phases is within ±1% of the maximum output voltage.</td></tr>
<tr><td>Output side current I_2</td><td>U, V and W line currents</td><td>Moving-iron type AC ammeter (Note 2, 4)</td><td colspan="2">Rated inverter current or lower.
Difference between the phases is 10% or lower.</td></tr>
<tr><td>Output side power P_2</td><td>U, V, W and
U and V,
V and W</td><td>Digital power meter (designed for inverter) or electrodynamic type single-phase wattmeter</td><td colspan="2">$P_2 = W_{21} + W_{22}$
2-wattmeter method (or 3-wattmeter method)</td></tr>
<tr><td>Output side power factor Pf_2</td><td colspan="4">Calculate in similar manner to power supply side power factor.
$Pf_2 = \frac{P_2}{\sqrt{3}V_2 \cdot I_2} \times 100\ \%$</td></tr>
<tr><td>Converter output</td><td>Across P and N.</td><td>Moving-coil type (such as tester)</td><td colspan="2">Inverter LED is lit. 1.35 × V1</td></tr>
<tr><td rowspan="3">Frequency setting signal</td><td>Across 2(+) and 5</td><td rowspan="10">Moving-coil type
(Tester and such may be used)
(Internal resistance: 50kΩ or larger)</td><td>0 to 5VDC/0 to 10VDC</td><td rowspan="6">"5" is common</td></tr>
<tr><td>Across 1(+) and 5</td><td>0 to ±5VDC/0 to ±10VDC</td></tr>
<tr><td>Across 4 (+) and 5</td><td>DC4 to 20mA</td></tr>
<tr><td rowspan="2">Frequency setting power supply</td><td>Across 10 (+) and 5</td><td>5VDC</td></tr>
<tr><td>Across 10E(+) and 5</td><td>10VDC</td></tr>
<tr><td rowspan="2">Frequency meter signal</td><td>Across AM(+) and 5</td><td>Approximately 10VDC at maximum frequency (without frequency meter)</td></tr>
<tr><td>Across FM(+) and SD</td><td>Approximately 5VDC at maximum frequency
(without frequency meter)

Pulse width T1: Adjusted by M310(Pr.900)
Pulse cycle T2: Set by M040(Pr.55)
(Valid for frequency monitoring only)</td><td rowspan="4">"SD" is common</td></tr>
<tr><td>Start signal
Select signal</td><td>Across SD and the following:
STF, STR, RH, RM, RL, JOG, RT, AU, STOP, CS (+)</td><td rowspan="3">When open
20 to 30VDC
ON voltage: 1V or less</td></tr>
<tr><td>Reset</td><td>Across RES (+) and SD</td></tr>
<tr><td>Output stop</td><td>Across MRS (+) and SD</td></tr>
</table>

Measuring points and instruments

Item	Measuring Point	Measuring Instrument	Remarks (Reference Measured Value)
Fault signal	Across A and C Across B and C	Moving-coil type (such as tester)	Conduction check (Note 3) <Abnormal> <Normal> Across A and C Discontinuity Continuity Across B and C Continuity Discontinuity

(Note 1) Use an FFT to measure the output voltage accurately. A tester or general measuring instrument cannot measure accurately.

(Note 2) When the carrier frequency exceeds 5kHz, do not use this instrument since using it may increase eddy-current losses produced in metal parts inside the instrument, leading to burnout. If the wiring length between the inverter and motor is long, the instrument and CT may generate heat due to line-to-line leakage current.

(Note 3) When the setting of M405(Pr.195) ABC1 terminal function selection is the positive logic

(Note 4) A digital power meter (designed for inverter) can also be used to measure.

Appendix 7.5 List of Fault or Alarm Display

The following table shows the displays on the operation panel that indicate the source of an erroneous operation.

(Display on the FR-A800 series inverter)

(1) Error message

A message regarding operational fault and setting fault by the operation panel (FR-DU08) is displayed.
The inverter does not trip.

Operation panel indication		Name
E----	E---	Faults history
HOLd	HOLD	Operation panel lock
LOCd	LOCD	Password locked
Er1 to Er4 Er8	Er1 to 4 Er8	Parameter write error
rE1 to rE4 rE6 to rE8	rE1 to 4 rE6 to 8	Copy operation error
Err.	Err.	Error

(2) Warning

The inverter does not trip even when a warning is displayed. However, failure to take appropriate measures can lead to a serious fault.

Operation panel indication		Name
OL	OL	Stall prevention (overcurrent)
oL	oL	Stall prevention (overvoltage)
Rb	RB	Regenerative brake pre-alarm
TH	TH	Electronic thermal relay function pre-alarm
PS	PS	PU stop
SL	SL	Speed limit indication
CP	CP	Parameter copy
SA	SA	Safety stop
MT1 to MT3	MT1 to MT3	Maintenance signal output
UF	UF	USB host error
HP1	HP1	Home position return setting error
HP2	HP2	Home position return uncompleted
HP3	HP3	Home position return parameter setting error
EV	EV	24 V external power supply operation

(3) Alarm

The inverter does not trip. An Alarm (LF) signal can also be output with a parameter setting.

Operation panel indication		Name
FN	FN	Fan alarm

(4) **Fault**

A protective function trips the inverter and outputs a Fault (ALM) signal.
The data code is used for checking the fault detail via communication or with H103(Pr.997) Fault initiation.

Operation panel indication		Name
E. OC1	E.OC1	Overcurrent trip during acceleration
E. OC2	E.OC2	Overcurrent trip during constant speed
E. OC3	E.OC3	Overcurrent trip during deceleration or stop
E. OV1	E.OV1	Regenerative overvoltage trip during acceleration
E. OV2	E.OV2	Regenerative overvoltage trip during constant speed
E. OV3	E.OV3	Regenerative overvoltage trip during deceleration or stop
E. THT	E.THT	Inverter overload trip (electronic thermal relay function)
E. THM	E.THM	Motor overload trip (electronic thermal relay function)
E. FIN	E.FIN	Heatsink overheat
E. IPF	E.IPF	Instantaneous power failure
E. UVT	E.UVT	Undervoltage
E. ILF	E.ILF	Input phase loss
E. OLT	E.OLT	Stall prevention stop
E. SOT	E.SOT	Loss of synchronism detection
E. bE	E.BE	Brake transistor alarm detection
E. GF	E.GF	Output side earth (ground) fault overcurrent
E. LF	E.LF	Output phase loss
E. OHT	E.OHT	External thermal relay operation
E. PTC	E.PTC	PTC thermistor operation
E. OPT	E.OPT	Option fault
E. OP1	E.OP1	Communication option fault
E. 16	E.16	User definition error by the PLC function
E. 17	E.17	
E. 18	E.18	
E. 19	E.19	
E. 20	E.20	
E. PE	E.PE	Parameter storage device fault

Operation panel indication		Name
E. PUE	E.PUE	PU disconnection
E. RET	E.RET	Retry count excess
E. PE2	E.PE2	Parameter storage device fault
E. CPU	E. 5 to E. 7 E. CPU	CPU fault
E. 5		
E. 6		
E. 7		
E. CTE	E.CTE	RS-485 terminals power supply short circuit
E. P24	E.P24	24 VDC power fault
E. CdO	E.CDO	Abnormal output current detection
E. IOH	E.IOH	Inrush current limit circuit fault
E. SER	E.SER	Communication fault (inverter)
E. AIE	E.AIE	Analog input fault
E. USb	E. USB	USB communication fault
E. SAF	E. SAF	Safety circuit fault
E. PbT	E.PBT	Internal circuit fault
E. 13	E.13	
E. OS	E.OS	Overspeed occurrence
E. OSd	E.OSD	Speed deviation excess detection
E. ECT	E.ECT	Signal loss detection
E. Od	E.OD	Excessive position fault
E. Mb1	E.MB1 to E.MB7	Brake sequence fault
E. Mb2		
E. Mb3		
E. Mb4		
E. Mb5		
E. Mb6		
E. Mb7		
E. EP	E.EP	Encoder phase fault
E. LCI	E.LCI	4 mA input fault
E. PCH	E.PCH	Pre-charge fault
E. PId	E.PId	PID signal fault
E. 1	E.1	Option fault
E. 2	E.2	
E. 3	E.3	
E. 11	E.11	Internal circuit fault

Appendix 7.6 Checkpoints for faulty operations (examples for FR-A800 series inverters)

POINT

If the cause is still unknown after every check, it is recommended to initialize the parameters (initial value), set the necessary parameters again and perform the checks again.

Appendix 7.6.1 Motor does not start

Check Points	Possible Cause	Countermeasures
Main Circuit	Appropriate power supply voltage is not applied. (Operation panel display is not provided.)	Power ON a moulded case circuit breaker (MCCB), an earth leakage circuit breaker (ELB), or a magnetic contactor (MC).
		Check for the decreased input voltage, input phase loss, and wiring.
		If only the control power is ON when using a separate power source for the control circuit, turn ON the main circuit power.
	Motor is not connected properly.	Check the wiring between the inverter and the motor. If commercial power supply-inverter switchover function is active, check the wiring of the magnetic contactor connected between the inverter and the motor.
	The jumper across P/+ and P1 is disconnected. A DC reactor (FR-HEL) is not connected.	Securely fit a jumper across P/+ and P1. When using a DC reactor (FR-HEL), remove the jumper across P/+ and P1, and then connect the DC reactor. Connect the DC reactor securely for a capacity where a DC reactor is required.
Input Signal	Start signal is not input.	Check the start command source, and input a start signal. PU operation mode: FWD / REV External operation mode: STF/STR signal
	Both the forward and reverse rotation start signals (STF, STR) are input simultaneously.	Turn ON either forward or reverse rotation start signal (STF or STR). If STF and STR signals are turned ON simultaneously in the initial setting, a stop command is given.
	Frequency command is zero. (FWD or REV LED on the operation panel is flickering.)	Check the frequency command source and enter a frequency command.
	Terminal 4 input selection (AU) is not ON when terminal 4 is used for frequency setting. (FWD or REV LED on the operation panel is flickering.)	Turn ON the AU signal. Turning ON the AU signal activates terminal 4 input.
	Output stop signal (MRS) or reset signal (RES) is ON. (FWD or REV LED on the operation panel is flickering.)	Turn MRS or RES signal OFF. Inverter starts the operation with a given start command and a frequency command after turning OFF MRS or RES signal. Ensure that it is safe before turning OFF.
	CS signal is OFF when automatic restart after instantaneous power failure function is selected (A702(PR.57) Restart coasting time ≠ "9999"). (FWD or REV LED on the operation panel is flickering.)	Turn ON the automatic restart after instantaneous power failure/flying start (CS) signal. When the CS signal is assigned to an input terminal, automatic restart operation is enabled when the CS signal is turned ON.
	Jumper connector of sink - source is wrongly selected. (FWD or REV LED on the operation panel is flickering.)	Check that the control logic switchover jumper connector is correctly installed. If it is not installed correctly, input signal is not recognized.
	Wiring of encoder is incorrect. (Under encoder feedback control or vector control)	Check the wiring of encoder.
	Voltage/current input switch is not correctly set for analog input signal (0 to 5V/0 to 10V, 4 to 20mA). (FWD or REV LED on the operation panel is flickering.)	Set T0000(Pr.73) Analog input selection, T001(Pr.267) Terminal 4 input selection, and a voltage/current input switch correctly, then input an analog signal in accordance with the setting.
	STOP RESET was pressed. (Operation panel indication is PS (PS).)	During the External operation mode, check the method of restarting from a STOP RESET input stop from PU.
	Two-wire or three-wire type connection is wrong.	Check the connection. Connect STOP signal when three-wire type is used.

Check Points	Possible Cause	Countermeasures
Parameter Setting	G000(Pr.0) Torque boost setting is improper when V/F control is used.	Increase G000(Pr.0) setting by 0.5% increments while observing the rotation of a motor. If that makes no difference, decrease the setting.
	D020(Pr.78) Reverse rotation prevention selection is set.	Check the D020(Pr.78) setting. Set D020(Pr.78) when you want to limit the motor rotation to only one direction.
	D000(Pr.79) Operation mode selection setting is wrong.	Select the operation mode which corresponds with the input methods of start command and frequency command.
	Bias and gain (calibration parameter T200, T201, T203, T400, T401 and T403 (C2 to C7)) settings are improper.	Check the bias and gain (calibration parameter T200, T201, T203, T400, T401 and T403 (C2 to C7)) settings.
	F102(Pr.13) Starting frequency setting is greater than the running frequency.	Set running frequency higher than F102(Pr.13). The inverter does not start if the frequency setting signal is less than the value set in F102(Pr.13).
	Frequency settings are zero for various running frequencies (such as multi-speed operation). Especially, H400(Pr.1) Maximum frequency is zero.	Set the frequency command according to the application. Set H400(Pr.1) to the actual frequency used or higher.
	D200(Pr.15) Jog frequency setting is lower than D200(Pr.13) Starting frequency during JOG operation.	Set D200(Pr.15) Jog frequency to D200(Pr.13) or higher.
	The C141(Pr.359) Encoder rotation direction setting is incorrect under encoder feedback control or under vector control.	If the "REV" on the operation panel is lit even though the forward-rotation command is given, set C141(Pr.359) = "1."
	Operation mode and writing device do not match.	Check D000(Pr.79) Operation mode selection, D010(Pr.338) Communication operation command source, D011(Pr.339) Communication speed command source, D012(Pr.550) NET mode operation command source selection and D013(Pr.551) PU mode operation command source selection, and select an operation mode suitable for the purpose.
	Start signal operation selection is set by the G106(Pr.250) Stop selection	Check G106(Pr.250) setting and connection of STF and STR signals.
	Inverter decelerated to a stop when power failure deceleration stop function is selected.	When power is restored, ensure safety before turning OFF the start signal once, then turn ON again to restart. Inverter restarts when A730(Pr.261) = "2, 12".
	Auto tuning is being performed.	For PU operation, press STOP RESET on the operation panel after the ofline auto tuning completes. For External operation, turn OFF the start signal (STF, STR). By this operation, offline auto tuning is cancelled, and the monitor display on the PU goes back to normal. (If this operation is not performed, you cannot proceed to the next operation.)
	Automatic restart after instantaneous power failure function or power failure stop function is activated. (Performing overload operation during input phase loss may cause voltage insufficiency, and that may result in detection of power failure.)	Set H201(Pr.872) Input phase loss protection selection = "1" (input phase failure protection active). Disable the automatic restart after instantaneous power failure function and power failure stop function. Reduce the load. Increase the acceleration time if the automatic restart after instantaneous power failure function or power failure stop function occurred during acceleration.
	The motor test operation is selected under vector control or PM sensorless vector control.	Check the G200(Pr.800) Control method selection setting.
Load	Load is too heavy.	Reduce the load.
	Shaft is locked.	Inspect the machine (motor).

Appendix 7.6.2 Motor or machine is making abnormal acoustic noise

Check Points	Possible Cause	Countermeasures
Input Signal	Disturbance due to EMI when frequency command is given from analog input (terminal 1, 2, 4).	Take countermeasures against EMI.
Parameter Setting		Increase the T002(Pr.74) Input filter time constant if steady operation cannot be performed due to EMI.
Parameter Setting	No carrier frequency noises (metallic noises) are generated.	In the initial setting, E601(Pr.240) Soft-PWM operation selection is enabled to change motor noise to an unoffending complex tone. Therefore, no carrier frequency noises (metallic noises) are generated. Set E601(Pr.240) = "0" to disable this function.
	Resonance occurs. (output frequency)	Set H420 to H425(Pr.31 to Pr.36) and H429(Pr.552) (Frequency jump). When it is desired to avoid resonance attributable to the natural frequency of a mechanical system, these parameters allow resonant frequencies to be jumped.
	Resonance occurs. (carrier frequency)	Change E600(Pr.72) PWM frequency selection setting. Changing the PWM carrier frequency produces an effect on avoiding the resonance frequency of a mechanical system or a motor.
		Set a notch filter.
	Auto tuning is not performed under Advanced magnetic flux vector control, Real sensorless vector control, or vector control.	Perform offline auto tuning.
	Gain adjustment during PID control is insufficient.	To stabilize the measured value, change the proportional band A613(Pr. 129) to a larger value, the integral time A614(Pr. 130) to a slightly longer time, and the differential time A615(Pr. 134) to a slightly shorter time. Check the calibration of set point and measured value.
	The gain is too high under Real sensorless vector control, vector control, or PM sensorless vector control	During speed control, check the setting of G211(Pr.820) speed control P gain.
		During torque control, check the setting of Pr. G213(Pr.824) torque control P gain.
Others	Mechanical , ooseness	Adjust machine/equipment so that there is no mechanical looseness.
	Contact the motor manufacturer.	
Motor	Operating with output phase loss	Check the motor wiring.

Appendix 7.6.3 Inverter generates abnormal noise

Check Points	Possible Cause	Countermeasures
Fan	Fan cover was not correctly installed when a cooling fan was replaced.	Install the fan cover correctly.

Appendix 7.6.4 Motor generates heat abnormally

Check Points	Possible Cause	Countermeasures
Motor	Motor fan is not working (Dust is accumulated.)	Clean the motor fan. Improve the environment.
	Phase to phase insulation of the motor is insufficient.	Check the insulation of the motor.
Main Circuit	The inverter output voltage (U, V, W) are unbalanced.	Check the output voltage of the inverter. Check the insulation of the motor.
Parameter Setting	The C100(Pr.71) Applied motor setting is wrong.	Check the C100(Pr.71) Applied motor setting.
—	Motor current is large.	Refer to "Appendix 7.6.11 Motor current is too large"

Appendix 7.6.5 Motor rotates in the opposite direction

Check Points	Possible Cause	Countermeasures
Main Circuit	Phase sequence of output terminals U, V and W is incorrect.	Connect phase sequence of the output cables (terminal U, V, W) to the motor correctly.
Input Signal	The start signals (forward rotation, reverse rotation) are connected improperly.	Check the wiring. (STF: forward rotation , STR: reverse rotation)
	The polarity of the frequency command is negative during the polarity reversible operation set by T000(Pr.73) Analog input selection.	Check the polarity of the frequency command.
Input Signal, Parameter Setting	Torque command is negative during torque control under vector control.	Check the torque command value.

Appendix 7.6.6 Speed greatly differs from the setting

Check Points	Possible Cause	Countermeasures
Input Signal	Frequency setting signal is incorrectly input.	Measure the input signal level.
	The input signal lines are affected by external EMI.	Take countermeasures against EMI such as using shielded wires for input signal lines.
Parameter Setting	H400(Pr.1) Maximum frequency, H401(Pr.2) Minimum frequency, H402(Pr.18) High speed maximum frequency and the calibration parameter T200, T201, T203, T400, T401, and T403(C2 to C7) settings are improper.	Check the settings of H400(Pr.1), H401(Pr.2), and H402(Pr.18).
		Check the calibration parameter T200, T201, T203, T400, T401, and T403(C2 to C7) settings.
	H420 to H425(Pr.31 to Pr.36), H429(Pr.552) (frequency jump) settings are improper.	Narrow down the range of frequency jump.
Load	Stall prevention (torque limit) function is activated due to a heavy load.	Reduce the load.
Parameter Setting		Set H500(Pr.22) Stall prevention operation level (torque limit level) higher according to the load. (Setting H500(Pr.22) too large may result in frequent overcurrent trip (E.OC□).)
Motor		Check the capacities of the inverter and the motor.

Appendix 7.6.7 Acceleration/deceleration is not smooth

Check Points	Possible Cause	Countermeasures
Parameter Setting	Acceleration/deceleration time is too short.	Increase acceleration/deceleration time.
	Torque boost (G000(Pr.0), G010(Pr.46) and G020(Pr.112)) setting is improper under V/F control, so the stall prevention function is activated.	Increase/decrease G000(Pr.0) Torque boost setting value by 0.5% increments to the setting. Deactivate stall prevention.
	The base frequency setting and the motor characteristic does not match.	For V/F control, set G001(Pr.3) Base frequency, G011(Pr.47) Second V/F (base frequency), and G021(Pr.113) Third V/F (base frequency).
		For vector control, set C105(Pr.84) Rated motor frequency.
	Regeneration avoidance operation is performed	If the frequency becomes unstable during regeneration avoidance operation, decrease the setting of G124(Pr.886) Regeneration avoidance voltage gain.
Load	Stall prevention (torque limit) function is activated due to a heavy load.	Reduce the load.
Parameter Setting		Set H500(Pr.22) Stall prevention operation level (torque limit level) higher according to the load. (Setting H500(Pr.22) too large may result in frequent overcurrent trip (E.OC□).)
Motor		Check the capacities of the inverter and the motor.

Appendix 7.6.8 Speed varies during operation

When Advanced magnetic flux vector control, Real sensorless vector control, vector control or encoder feedback control is exercised, the output frequency varies with load fluctuation between 0 and 2Hz. This is a normal operation and is not a fault.

Check Points	Possible Cause	Countermeasures
Load	Load varies during an operation.	Select Advanced magnetic flux vector control, Real sensorless vector control, vector control, or encoder feedback control.
Input Signal	Frequency setting signal is varying.	Check the frequency setting signal.
	The frequency setting signal is affected by EMI.	Set filter to the analog input terminal using T002(Pr.74) Input filter time constant, T003(Pr.822) Speed setting filter 1.
		Take countermeasures against EMI, such as using shielded wires for input signal lines.
	Malfunction is occurring due to the undesirable current generated when the transistor output unit is connected.	Use terminal PC (terminal SD when source logic) as a common terminal to prevent a malfunction caused by undesirable current.
	Multi-speed command signal is chattering.	Take countermeasures to suppress chattering.
	Feedback signal from the encoder is affected by EMI.	Place the encoder cable far from the EMI source such as main circuit and power supply voltage. Earth (ground) the shield of the encoder cable to the enclosure using a metal P-clip or U-clip.
Parameter Setting	Fluctuation of power supply voltage is too large.	Change the G002(Pr.19) Base frequency voltage setting (about 3%) under V/F control.
	C101(Pr.80) Motor capacity and C102(Pr.81) Number of motor poles are not appropriate for the motor capacity under Advanced magnetic flux vector control, Real sensorless vector control, vector control, or PM sensorless vector control.	Check the settings of C101(Pr.80) and C102(Pr.81).
	Wiring length exceeds 30m when Advanced magnetic flux vector control, Real sensorless vector control, vector control, or PM sensorless vector control is selected.	Perform offline auto tuning.
	Wiring is too long for V/F control, and the a voltage drop occurs.	Adjust the G000(Pr.0) Torque boost setting by increasing with 0.5% increments for the low-speed operation.
		Change the control method to Advanced magnetic flux vector control or Real sensorless vector control.
	Hunting occurs by the generated vibration, for example, when structural rigidity at load side is insufficient.	Disable automatic control functions, such as the energy saving operation, the fast-response current limit function, the torque limit, the regeneration avoidance function, Advanced magnetic flux vector control, Real sensorless vector control, vector control, encoder feedback control, droop control, the stall prevention, online auto tuning, the notch filter, and orientation control. During the PID control, set smaller values to A613(Pr.129) PID proportional band and A614(Pr.130) PID integral time. Lower the control gain, and adjust to increase the stability.
		Change E600(Pr.72) PWM frequency selection setting.

Appendix 7.6.9 Operation mode is not changed properly

Check Points	Possible Cause	Countermeasures
Input Signal	Start signal (STF or STR) is ON.	Check that the STF and STR signals are OFF. When either is ON, the operation mode cannot be changed.
Parameter Setting	D000(Pr.79) setting is improper.	When D000(Pr.79) setting is "0" (initial value), the inverter is placed in the External operation mode at input power ON. To switch to the PU operation mode, press PU EXT on the operation panel (press PU when the parameter unit (FR-PU04) is used) . At other settings (1 to 4, 6, 7), the operation mode is limited accordingly.
	Operation mode and writing device do not correspond.	Check D000(Pr.79) Operation mode selection, D010(Pr.338) Communication operation command source, D011(Pr.339) Communication speed command source, D012(Pr.550) NET mode operation command source selection and D013(Pr.551) PU mode operation command source selection, and select an operation mode suitable for the purpose.

Appendix 7.6.10 Operation panel (FR-DU08) display is not operating

Check Points	Possible Cause	Countermeasures
Main Circuit, Control Circuit	Power is not input.	Input the power.
Front Cover	Operation panel is not properly connected to the inverter.	Check if the inverter front cover is installed securely.

Appendix 7.6.11 Motor current is too large

Check Points	Possible Cause	Countermeasures
Parameter Setting	Torque boost (G000(Pr.0), G010(Pr.46), and G020(Pr.112)) setting is improper under V/F control, so the stall prevention function is activated.	Increase/decrease G000(Pr.0) Torque boost setting value by 0.5% increments to the setting.
	V/F pattern is improper when V/F control is performed. (G001(Pr.3), G003(Pr.14), and G002(Pr.19))	Set rated frequency of the motor to G001(Pr.3) Base frequency. Use G002(Pr.19) Base frequency voltage to set the base voltage (e.g. rated motor voltage).
		Change G003(Pr.14) Load pattern selection according to the load characteristic.
	Stall prevention (torque limit) function is activated due to a heavy load.	Reduce the load.
		Set H500(Pr.22) Stall prevention operation level (Torque limit level) higher according to the load. (Setting H500(Pr.22) too large may result in frequent overcurrent trip (E.OC□).)
		Check the capacities of the inverter and the motor.
	Auto tuning is not performed under Advanced magnetic flux vector control, Real sensorless vector control, or vector control.	Perform offline auto tuning.

Appendix 7.6.12 Speed does not accelerate

Check Points	Possible Cause	Countermeasures
Input Signal	Start command and frequency command are chattering.	Check if the start command and the frequency command are correct.
	The wiring length used for analog frequency command is too long, and it is causing a voltage (current) drop.	Perform analog input bias/gain calibration.
	Input signal lines are affected by external EMI.	Take countermeasures against EMI, such as using shielded wires for input signal lines.
Parameter Setting	H400(Pr.1) Maximum frequency, H401(Pr.2) Minimum frequency, H402(Pr.18) High speed maximum frequency, and the calibration parameter T200, T201, T203, T400, T401, and T403(C2 to C7) settings are improper.	Check the settings of H400(Pr.1) and H401(Pr.2). To run the motor at 120Hz or higher, set H402(Pr.18).
		Check the calibration parameter T200, T201, T203, T400, T401, and T403(C2 to C7) settings.
	Torque boost (G000(Pr.0), G010(Pr.46), and G020(Pr.112)) setting is improper under V/F control, so the stall prevention function is activated.	Increase/decrease G000(Pr.0) Torque boost setting value by 0.5% increments so that stall prevention does not occur.
	V/F pattern is improper when V/F control is performed. (G001(Pr.3), G003(Pr.14), and G002(Pr.19))	Set rated frequency of the motor to G001(Pr.3) Base frequency. Use G002(Pr.19) Base frequency voltage to set the base voltage (e.g. rated motor voltage).
		Change G003(Pr.14) Load pattern selection according to the load characteristic.
	Stall prevention (torque limit) function is activated due to a heavy load.	Reduce the load weight.
		Set H500(Pr.22) Stall prevention operation level (torque limit level) higher according to the load. (Setting H500(Pr.22) too large may result in frequent overcurrent trip (E.OC□).)
		Check the capacities of the inverter and the motor.
	Auto tuning is not performed under Advanced magnetic flux vector control, Real sensorless vector control, or vector control.	Perform offline auto tuning.
	The setting of pulse train input is improper.	Check the specification of the pulse generator (open collector output or complementary output) and check the adjustment of the pulse train and frequency (D110(Pr.385) Frequency for zero input pulse and D111(Pr.386) Frequency for maximum input pulse).
	During PID control, output frequency is automatically controlled to make measured value = set point.	
Main Circuit	Brake resistor is connected across terminals P/+ and P1 or across P1 and PR by mistake. (22K or lower)	Connect an option brake resistor (FR-ABR) across terminals P/+ and PR.

Appendix 7.6.13 Unable to write parameter setting

Check Points	Possible Cause	Countermeasures
Input Signal	Operation is not stopped. (signal STF or STR is ON).	Stop the operation. When E400(Pr.77) Parameter write selection = "0" (initial value), write is enabled only during a stop.
Parameter Setting	Setting the parameter in the External operation mode.	Choose the PU operation mode. Or, set E400(Pr.77) Parameter write selection = "2" to enable parameter write regardless of the operation mode.
	Parameter writing is disabled by the E400(Pr.77) Parameter write selection setting.	Check E400(Pr.77) Parameter write selection setting.
	Key lock is activated by the E200(Pr.161) Frequency setting/key lock operation selection setting.	Check E200(Pr.161) Frequency setting/key lock operation selection setting.
	Operation mode and writing device do not correspond.	Check D000(Pr.79), D010(Pr.338), D011(Pr.339), D012(Pr.550) and D013(Pr.551), and select an operation mode suitable for the purpose.
	An attempt to set E600(Pr.72) PWM frequency selection to "25" was made during PM sensorless vector control. Alternatively, an attempt to set PM sensorless vector control was made while E600(Pr.72) = "25".	E600(Pr.72) = "25" cannot be set under PM sensorless vector control. (A sine wave filter (MT-BSL/BSC) cannot be used under PM sensorless vector control.)

Appendix 7.6.14 Power lamp is not lit

Check Points	Possible Cause	Countermeasures
Main Circuit, Control Circuit	Wiring or installation is improper.	Check for the wiring and the installation. Power lamp is lit when power is input to the control circuit (R1/L11, S1/L21).

Appendix 7.7 Protective Function

When a protective function (fault) is activated, power the inverter off and power it on again, or reset the inverter using the reset terminal (RES). (Alternatively, reset the inverter using the Help menu of the PU.)

(1) Error message
A message regarding operational troubles is displayed. Output is not shut off.

Function name	Description	Display	Check point	Corrective action
Operation panel lock	Appears when operation was attempted during operation panel lock.	HOLD		Press MODE for 2s to release lock.
Password locked	Appears if reading/writing of a password-protected parameter is attempted.	LOCD		Enter the password in E411(Pr.297) Password lock/ unlock to release the password lock.
Parameter write error	Appears when an error occurred during parameter writing	Er1	Check the settings of E400(Pr.77), H420 to H425(Pr.31 to Pr.36), G040 to G049(Pr.100 to Pr.109). Check the connection of the PU and inverter.	
		Er2	Check the E400(Pr.77) setting. Check that the inverter is not operating.	
		Er3	Check the settings of the calibration parameters T201(C3), T203(C4), T401(C6), T403(C7).	
		Er4	Check if the operation mode is "PU operation mode". Check the D013(Pr.551) setting.	
USB memory device operation error	An operation command was given during the USB memory device operation. A copy operation (writing) was performed while the PLC function was in the RUN state. A copy operation was attempted for a password locked project.	Er8	Check if the USB memory device is operating. Check if the PLC function is in the RUN state. Check if the project data is locked with a password.	Perform the operation after the USB memory device operation is completed. Stop the PLC function. (Refer to FR-A800 PLC function programming manual.) Unlock the password of the project data using FR Configurator2. (Refer to the Instruction Manuals of FR Configurator2 and GX Works2.)

Function name	Description	Display	Check point	Corrective action
Copy operation error	A failure has occurred at the operation panel side EEPROM while reading the copied parameters. A failure has occurred in the USB memory device while copying the parameters or reading the PLC function project data.	rE1		Perform parameter copy again.
	Parameter copy from the operation panel to the inverter was attempted during operation.	rE2	Check if the inverter is stopped.	Perform again after stopping operation.
	The data in the inverter are different from the data in the operation panel.	rE3	Check for the parameter setting of the source inverter and inverter to be verified.	Press SET to continue the verification.
	A different model was used when parameter copy from the operation panel or parameter verification was performed.	rE4	Check that the verified inverter is the same model. Check that operation is not stopped by switching off the power supply while reading parameter copy or by disconnecting the operation panel.	Use the same model for parameter copy and verification.
	The parameter copy file in the USB memory device cannot be recognized.	rE6		Perform parameter copy again.
	A parameter copy was attempted to the USB memory device in which 99 copy files had already been saved.	rE7	Check if the number of copy files in the USB memory device has reached 99.	Delete the copy files in the USB memory device and perform parameter copy again.
	The specified PLC function project file does not exist in the USB memory device.	rE8	Check that the file exists in the USB memory device. Check that the folder name and the file name in the USB memory device are correct.	
Error	Appears when the RES signal is on or the PU and inverter cannot make normal communication.	Err		Turn off the RES signal. Check the connection of the PU and inverter.

(2) Warning

When the protective function is activated, the output is not shut off.

Function name	Description	Display	Check point	Corrective action
Stall prevention (overcurrent)	Appears during overcurrent stall prevention.	OL	Check that the load is not too heavy. Check that the setting values of G000(Pr.0) and F102(Pr.13) are not too large. Check that the setting values of F010(Pr.7) and F011(Pr.8) are not too short.	Reduce the load weight. Change the settings of G000(Pr.0), F010(Pr.7), F011(Pr.8), F102(Pr.13) and G003(Pr.14). Increase capacities of the motor and inverter.
Stall prevention (overvoltage)	Appears during overvoltage stall prevention. Appears while the regeneration avoidance function is activated.	oL	Check for sudden speed reduction. Check if the regeneration avoidance function is used.	Increase the deceleration time using F011(Pr.8).
Regenerative brake pre-alarm	Appears when the regenerative brake duty reaches or exceeds 85% of the setting of G107(Pr.70). If the regenerative brake duty reaches 100%, a regenerative overvoltage (E. OV_) occurs.	RB	Check that the brake resistor duty is not high. Check that the settings of E300(Pr.30) and G107(Pr.70) are correct.	Increase the deceleration time. Correct E300(Pr.30) and G107(Pr.70).
Electronic thermal relay function pre-alarm	Appears when the integrating value of the electronic thermal relay function reaches or exceeds 85% of the H000 and C103(Pr.9) setting. If it reaches 100% of the H000 and C103(Pr.9) setting, a motor overload shut-off (E. THM) occurs.	TH	Check for large load or sudden acceleration. Check that the H000 and C103(Pr.9) setting is appropriate.	Reduce the load weight or the frequency of operations. Set an appropriate value in H000 and C103(Pr.9).
PU stop	Appears when STOP/RESET on the operation panel was pressed during external operation.	PS	Check for a stop made by pressing STOP/RESET of the operation panel.	Turn the start signal off and release with PU/EXT.
Speed limit indication	Displays when the speed restriction level is exceeded during torque control.	SL	Check that the torque command is not larger than required. Check that the speed restriction level is not low.	Decrease the torque command value. Increase the speed restriction level.
Parameter copy	Appears when parameters are copied between models with capacities of 55K or lower and 75K or higher.	CP		Set the initial value in E490(Pr.989).
Safety stop	Appears when safety stop function is activated (during output shutoff).	SA	Check if an emergency stop device is activated. If the safety stop function is not used, check that the shorting wires between S1 and SIC and between S2 and SIC are connected.	When safety stop function is active, identify the cause of emergency stop, ensure the safety and restart the system. When not using the safety stop function, short across terminals S1 and SIC and across S2 and SIC with shorting wires for the inverter to run.
Maintenance signal output	Appears when the cumulative energization time has exceeded the maintenance output timer set value.	MT to MT3	Check that the E710(Pr.503)(E712(Pr.686), E714(Pr.688)). setting is not larger than the E711(Pr.504)(E713(Pr.687),E715(Pr.689)) setting.	Write "0" to E710(Pr.503)(E712(Pr.686), E714(Pr.688)).

Function name	Description	Display	Check point	Corrective action
USB host error	Appears when an excessive current flows into the USB A connector.	UF	Check if a USB device other than a USB memory device is connected to the USB A connector.	If a device other than a USB memory device is connected to the USB A connector, remove the device.
Home position return error	Appears when an error occurs during the home position return operation under position control.	HP1 to HP3	Identify the cause of the error occurrence.	Check the parameter setting, and check that the input signal is correct.
24 V external power supply operation	Flickers when the main circuit power supply is off and the 24 V external power supply is being input.	EV	Power is supplied from a 24 V external power supply.	Turning ON the power supply (main circuit) of the inverter clears the indication.

(3) Alarm

When the protective function is activated, the output is not shut off. The alarm signal can also be output by setting the parameters.
(Set "98" in any of M400 to M406(Pr.190 to Pr.196) (output terminal function selection).)

Function name	Description	Display	Check point	Corrective action
Fan alarm	Appears when the cooling fan stops due to a fault or when operation different from the setting of H100(Pr.244) is performed during speed reduction. This indication applies only in the inverter that contains a cooling fan.	FN	Check the cooling fan for a fault.	Replace the fan.

(4) Fault

When the protective function is activated, the inverter output is shut-off and an alarm output is provided.

Function name	Description	Display	Check point	Corrective action
Overcurrent trip during acceleration	Appears when the inverter output current rose to or above about 235%* of the rated current during acceleration.	E.OC1	Check for sudden acceleration. Check for output short circuit.	Increase the acceleration time. (Shorten the downward acceleration time in vertical lift application.) Check the wiring for output short circuit.
Overcurrent trip during constant speed	Appears when the inverter output current rose to or above about 235%* of the rated current during constant-speed operation.	E.OC2	Check for sudden load change. Check for output short circuit.	Keep load stable. Check the wiring for output short circuit.
Overcurrent trip during deceleration or stop	Appears when the inverter output current rose to or above about 235%* of the rated current during deceleration or a stop.	E.OC3	Check for sudden speed reduction. Check for output short circuit. Check for too fast operation of the motor's mechanical brake.	Increase the deceleration time. Check the wiring for output short circuit. Check the mechanical brake operation.
Regenerative overvoltage trip during acceleration	Appears when regenerative energy causes the inverter's internal main circuit DC voltage to reach or exceed the specified value during acceleration, or when a surge voltage occurs in the power supply system causing the shut-off to operate.	E.OV1	Check for too slow acceleration. (e.g. during downward acceleration in vertical lift load)	Decrease the acceleration time. Utilize the regeneration avoidance function.
Regenerative overvoltage trip during constant speed	Appears when regenerative energy causes the inverter's internal main circuit DC voltage to reach or exceed the specified value during constant-speed operation, or when a surge voltage occurs in the power supply system causing the shut-off to operate.	E.OV2	Check for sudden load change.	Keep load stable. Utilize the regeneration avoidance function. Use the brake unit or power regeneration common converter as required.
Regenerative overvoltage trip during deceleration or stop	Appears when regenerative energy causes the inverter's internal main circuit DC voltage to reach or exceed the specified value during deceleration or stop, or when a surge voltage occurs in the power supply system causing the shut-off to operate.	E.OV3	Check for sudden speed reduction.	Increase the deceleration time. Reduce the frequency of operations. Utilize the regeneration avoidance function. Use the brake unit or power regeneration common converter as required.
Inverter overload trip (electronic thermal relay function)	Appears when inverse-time characteristics cause the electronic thermal relay to be activated to protect the output transistors due to that a current not less than 150% of the rated output current flows and overcurrent shut-off does not occur (220% or less).	E.THT	Check the motor for use under overload.	Reduce the load weight. Increase capacities of the motor and inverter.

* Varies according to ratings. The rating can be changed using E301(Pr.570) Multiple rating setting.
148% for SLD rating,170% for LD rating, 235% for ND rating (initial setting), and 280% for HD rating

Function name	Description	Display	Check point	Corrective action
Motor overload trip (electronic thermal relay function)	Appears when the electronic thermal relay function built in the inverter detects motor overheat exceeding the specification value due to overload or reduced cooling capability during constant-speed operation.	E.THM	Check the motor for use under overload. Check that the C103(Pr.9) and C100(Pr.71) setting is correct.	Reduce the load weight. For a constant-torque motor, set the constant-torque motor in C100(Pr.71). Increase capacities of the motor and inverter.
Motor overload trip (electronic thermal relay function)	Appears when the electronic thermal relay function built in the inverter detects motor overheat exceeding the specification value due to overload or reduced cooling capability during constant-speed operation.	E.THM	Check the motor for use under overload. Check that the Pr. 9, Pr. 71 setting is correct.	Reduce the load weight. For a constant-torque motor, set the constant-torque motor in Pr. 71. Increase capacities of the motor and inverter.
Fin overheat	Appears when the heatsink overheated causing the temperature sensor to be activated.	E.FIN	Check for too high surrounding air temperature. Check for heatsink clogging. Check if the cooling fan has stopped.	Set the ambient temperature to within the specifications. Clean the heatsink. Replace the cooling fan.
Instantaneous power failure	Appears when a power failure occurs for longer than 15ms (this also applies to inverter input shut-off), causing the instantaneous power failure protective function to be activated to prevent the control circuit from malfunctioning. If a power failure persists for 100ms or longer, the alarm warning output is not provided, and the inverter restarts if the start signal is on upon power restoration. (The inverter continues operating if an instantaneous power failure is within 15ms.)	E.IPF	Find the cause of instantaneous power failure occurrence.	Restore the instantaneous power failure. Prepare a backup power supply for instantaneous power failure. Set the automatic restart after instantaneous power failure function.
Brake transistor alarm detection	Appears when an error occurred in the brake circuit, e.g. damaged brake transistors.	E.BE	Reduce the load inertia. Check that the frequency of using the brake is proper.	Replace the inverter.
Undervoltage	If the power supply voltage of the inverter decreases, the control circuit will not perform normal functions. In addition, the motor torque will be insufficient and/or heat generation will increase. To prevent such trouble, this indication appears when the power supply voltage decreases to approx. 150VAC (300VAC in the 400V class) or lower.	E.UVT	Check for start of large-capacity motor. Check that a jumper or DC reactor is connected across terminals P/+ and P1.	Check the power supply system equipment such as power supply. Connect a jumper or DC reactor across terminals P/+ and P1.
Input phase failure	Appears when one of the three phase power input opened with the function enabled in H201(Pr.872).	E.ILF	Check for a break in the cable for the three-phase power supply input.	Repair the broken portion of the cable.

Function name	Description	Display	Check point	Corrective action
Stall prevention	Appears 3s after the output frequency decreased to 0.5Hz due to the stall prevention being activated. (Under V/F control and Advanced magnetic flux vector control) When speed control is performed, a fault (E.OLT) appears and the inverter trips if frequency drops to the M446(Pr.865) Low speed detection (initial value is 1.5 Hz) setting by torque limit operation and if the output torque exceeds the H730(Pr.874) OLT level setting (initial value is 150%) for 3 s.	E.OLT	Check that the H500(Pr.22), M446(Pr.865) and H730(Pr874) values are correct. Check the motor for use under overload.	Reduce the load weight. Increase capacities of the motor and inverter. Set the H500(Pr.22), M446(Pr.865) and H730(Pr.874) values correctly.
Loss of synchronism detection	The inverter trips when the motor operation is not synchronized. (This function is available only under PM sensorless vector control.)	E.SOT	Check that the PM motor is not driven overloaded. Check if a PM motor other than the MM-CF series is driven.	Set the acceleration time longer. Reduce the load.
Output side earth (ground) fault overcurrent	Appears when an earth (ground) fault occurred on the inverter’s output side (load side).	E.GF	Check for an earth (ground) fault in the motor and connection cable.	Remedy the faulty portion of the earth (ground).
Output phase loss	Appears when one of the three phases (U, V, W) on the inverter's output side (load side) opens.	E.LF	Check the wiring. Check that the motor is normal. Check that the capacity of the motor used is not smaller than that of the inverter.	Check the wiring. Change the setting of H200(Pr.251).
External thermal relay operation	Appears when the external thermal relay provided for motor overheat protection or the internally mounted temperature relay in the motor, etc. switches on.	E.OHT	Check for motor overheating. Check that the value of 7 is set correctly in any of T700 to T711(Pr.178 to Pr.189).	Reduce the load or the frequency of operations.
PTC thermistor operation	Appears when the motor overheat status is detected for 10s or more by the external PTC thermistor input connected to the terminal AU.	E.PTC	Check the connection between the PTC thermistor switch and thermal protector. Check the motor for operation under overload. Check that T706(Pr.184) is enabled.	Reduce the load.
Option fault	Appears when the AC power supply is accidentally connected to R/L1, S/L2, and T/L3 with the high power factor converter connected, or when torque command by the plug-in option is selected using D400(Pr.804) "Torque command source selection" and no plug-in option is mounted. Also appears if the plug-in optional switch for manufacturer use is switched.	E.OPT	Check that the AC power supply is not connected to the terminals R/L1, S/L2, T/L3 when a high power factor converter or power regeneration common converter is connected. Check that the plug-in option for torque command setting is connected.	Check the E300(Pr.30) setting and wiring. Check for connection of the plug-in option. Check the D400(Pr.804) setting. Switch back the plug-in optional switch for manufacturer use.
Communication option fault	Appears when a communication line error occurred in the communication option.	E.OP1	Check for a wrong option function setting and operation. Check that the plug-in option unit is plugged into the connector securely. Check for a break in the communication cable. Check that the terminal resistor is installed.	Check the option function setting, etc. Connect the plug-in option securely. Check that the communication cables are connected properly.

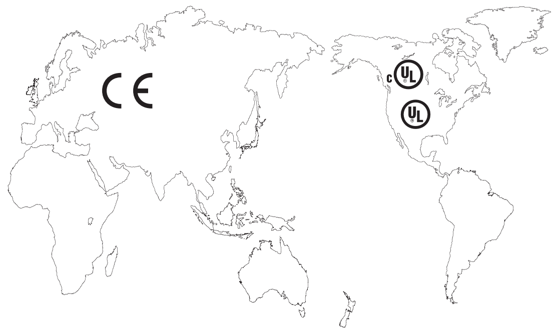
Function name	Description	Display	Check point	Corrective action
User definition error by the PLC function	The protective function is activated when "16 to 20" is set to the special register SD1214 for the PLC function. The inverter trips when the protective function is activated. This function is activated when the PLC function is enabled.	E.16 to E.20	Check if "16 to 20" is set in the special register SD1214.	Set a value other than "16 to 20" in the special register SD1214.
Parameter storage device fault (control circuit board)	Appears when an error occurred in stored parameters. (EEPROM failure)	E.PE	Check for excessive number of parameter write times.	Replace the inverter.
Parameter storage device fault (main circuit board)	Appears when an error occurred in stored parameters. (EEPROM failure)	E.PE2		Replace the inverter.
PU disconnection	Appears when a communication error between the PU and inverter occurred, the communication interval exceeded the permissible time during the RS-485 communication with the PU connector, or communication errors exceeded the number of retries during the RS-485 communication.	E.PUE	Check that the FR-DU07 or parameter unit fitting is not loose. Check the E101(Pr.75) setting.	Fit the FR-DU07 or parameter unit securely.
Retry count excess	Appears when the operation was not restarted normally within the set number of retries.	E.RET	Find the cause of the error occurrence.	Identify the cause of the error preceding this error indication.
CPU fault	Appears when a communication error occurred in the built-in CPU.	E. 5 to E. 7 E.CPU	Check for devices producing excess electrical noises around the inverter.	Take measures against noises if there are devices producing excess electrical noises around the inverter.

Function name	Description	Display	Check point	Corrective action
RS-485 terminal power supply short circuit	Appears when the RS-485 terminal power supply is shorted.	E.CTE	Check that the RS-485 terminals are connected correctly.	Check the connection of the RS-485 terminals.
Brake sequence fault	Appears when a sequence error occurs during use of the brake sequence function.	E.MB1 to 7	Find the cause of the error occurrence.	Check the set parameters and wiring.
Overspeed occurrence	Appears when the motor speed exceeds the set over speed level during the encoder feedback control or vector control.	E.OS	Check that the H800(Pr.374) setting is correct. Check if the number of encoder pulses differ from the actual number of encoder pulses.	Set H800(Pr.374) and C140(Pr.369) correctly.
Speed deviation excess detection	Appears when the motor speed is increased or decreased under the influence of the load, etc. during the vector control and cannot be controlled in accordance with the speed command value.	E.OSD	Check that the H416(Pr.285) and H417(Pr.853) settings are correct. Check for sudden load change. Check if the number of encoder pulses differ from the actual number of encoder pulses.	Set H416(Pr.285), H417(Pr.853) and C140(Pr.369) correctly. Keep load stable.
Signal loss detection	Appears when the encoder signal is shut off during the orientation control, encoder feedback control or vector control.	E.ECT	Check for a break in the cable of the encoder signal. Check that the encoder specifications are correct. Check for a loose connector. Check that the switch setting of the FR-A8AP is correct. Check that power is applied to the encoder.	Remedy the break. Use an encoder which meets the specifications. Check the connection. Correct the switch setting of the FR-A8AP. Supply power to the encoder.
Excessive position falult	Appears when the difference between the position command and position feedback exceeded the reference during the position control.	E.OD	Check that the position detecting encoder mounting orientation matches the parameter. Check that the load is not large. Check that the B008(Pr.427) and C140(Pr.369) settings are correct.	Check the parameters. Reduce the load weight. Set B008(Pr.427) and C140(Pr.369) correctly.
Encoder phase fault	Appears when the rotation command of the inverter differs from the actual motor rotation direction detected from the encoder during offline auto tuning.	E.EP	Check for mis-wiring of the encoder cable. Check the C141(Pr.359) setting.	Perform connection and wiring securely. Set C141(Pr.359) correctly.
24VDC power supply output short circuit	Appears when the 24VDC power supply output from the PC terminal is shorted.	E.P24	Check for a short circuit in the PC terminal output.	Remedy the short circuit portion.
Output current detection value exceeded	Appears when the output current has exceeded the setting of M460(Pr.150).	E.CDO	Check the settings of M460(Pr.150), M461(Pr.151), M433(Pr.166) and M464(Pr.167).	
Inrush current limit circuit fault	Appears when the resistor of the inrush current limit circuit overheats.	E.IOH	Check that frequent ON/OFF of power supply is not repeated.	Change the system to the one where frequent ON/OFF is not repeated. Replace the inverter.

Function name	Description	Display	Check point	Corrective action
Communication fault (inverter)	Appears when a communication error occurred during the RS-485 communication with the RS-485 terminals.	E.SER	Check the RS-485 terminal wiring.	Perform wiring of the RS-485 terminals properly.
Analog input fault	Appears when 30mA or more is input or a voltage (7.5V or more) is input with the terminal 2/4 set to current input.	E.AIE	Check the settings of T000(Pr.73) and T101(Pr.267).	Either give a frequency command by current input or set T000(Pr.73) and T101(Pr.267) to voltage input.
USB communication fault	Appears when communication has broken for the period of time set in N041(Pr.548).	E.USB	Check the USB communication cable.	Change the setting of N041(Pr.548). Check the USB communication cable.
Safety circuit fault	The inverter trips when a safety circuit fault occurs.	E.SAF	Check that the safety relay module or the connection has no fault.	Check that wiring of terminal S1, S2 and SIC is correct and the safety stop input signal source such as a safety relay module is operating properly.
4mA input fault	The inverter trips when the analog input current becomes 2mA or less and continues for the time set in T054(Pr.778).	E.LCI	Check for a break in the wiring for the analog current input. Check that the T054(Pr.778) setting is not too short.	Check the wiring for the analog current input. Set a larger value to T054(Pr.778).
PID pre-charge fault	The inverter trips when the pre-charge time exceeds A620(Pr.764) or when the measured value exceeds A619(Pr.763).	E.PCH	Check that the A620(Pr.764) setting is not too short. Check that the A619(Pr.763) setting is not too small. Check that the A612(Pr.127) PID control automatic switchover frequency setting is not too low.	Set a larger value to A620(Pr.764). Set a larger value to A619(Pr.763). Set a larger value to A612(Pr.127).
PID signal fault	The inverter trips if the measured value exceeds the upper/lower limit set in the parameter, or the absolute deviation value exceeds the detection value set in the parameter during PID control.	E.PID	Check the meter for a failure or disconnection. Check that the parameter settings are correct.	Check that the meter has no failure or disconnection. Set the parameters correctly.
Option fault	Appears when a contact fault is found between the inverter and the plug-in option, or when the communication option is not connected to the connector 3.	E. 1 to E. 3	Check that option is securely connected to the connector. Check for excessive noise around the inverter. Check if the communication option is connected to the connector 1 or 2.	Connect the option securely. Take measures against noises if there are devices producing excess electrical noises around the inverter. Connect the communication option to the connector 3.
Opposite rotation deceleration fault	When the forward/reverse rotation has been switched during torque control of the Real sensorless vector control, the rotation direction of the speed command may not match with the rotation direction of the estimated speed. This mismatch will interfere with the lowering of the speed. Overload due to the un-switched rotation direction may trip the inverter.	E.11	Check if the forward/reverse rotation has been changed during torque control of the Real sensorless vector control.	Take measures to avoid switching of the forward/ reverse rotation during torque control of the Real sensorless vector control.
Internal circuit fault	Appears when an internal circuit error occurred.	E.PBT E.13		Replace the inverter.

Appendix 7.8 Compliance to Standards

Mitsubishi Electric offers inverters that conform with oversea standards, such as the UL and CSA standards and the European Norm.

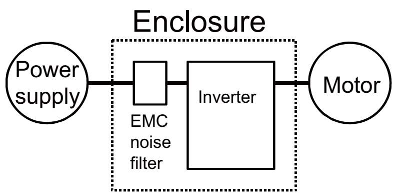


- **UL (Underwriters Laboratories Inc.): An American standard**
  UL is a nonprofit product testing organization founded by the National Board of Fire Underwriters, providing conformity assessment for industrial products. Safety standards defined by UL are exceptionally strict and cover virtually all possible cases that may occur while products are in use. This has brought the UL mark up to a position with extremely high authority and reliability. In many of provinces or cities of the United States, conforming to UL standards is required by state laws or ordinances.
- **CSA standard**
  This is a standard of Canada. By the state law of all ten states and two territories of Canada, the product is required to be compliant with safety standard of CSA standard. CSA standard is a necessary standard for the electronic product used in Canada. For products that are acquiring the safety standard of Canada bu UL, the MRA mutual acquisition for UL and CSA is considered equivalent to CSA acquisition, and the cUL mark must be displayed.

- **EN (European Norm)**

  EN (European Norm) refers to a European safety standard. In the process of uniting Europe, EC (the European Commission) has been making an effort to establish balanced rules that are adopted beyond countries. The intention of these rules is to realize borderless and free exchange of people, goods and services as well as free sales of goods and services. As one of these rules, EC proposed the integrated standard for technologies involving human health and safety as a form of 13 directives. The nations are currently seeking legislation based on these directives. The rules state that the-directive-targeted products must have the CE mark, which is the indication that approves exportation, free exchange and sales of the product across the Europe area. The directives involving driving products are the following three:

(1)	**Directive of Machinery**	This directive defines safety requirements for machinery. This directive basically requires that the health and safety of both man and animals and the safety of any objects should not be endangered under the condition that proper installation, maintenance and operation are conducted.
(2)	**EMC Directive**	This directive defines electromagnetic compatibility. This directive basically requires that an inverter should not adversely affect other equipment by electromagnetic interferences and that an inverter should have sufficient noise resistance. (EMC Directive compliant filters are prepared for the requirement.)
(3)	**Low Voltage Directive**	This directive defines safety requirements for electrical equipment. This directive basically requires that the health and safety of both man and animals and the safety of any objects should not be endangered under the condition that proper installation, maintenance and operation are conducted.



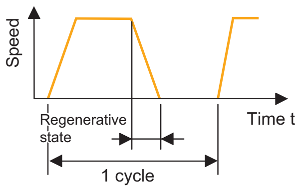
Remark

We recommend taking the Inverter Maintenance Course for the details of Appendix 4 to Appendix 6.

APPENDIX 8 Glossary

· %ED

%ED shows the regenerative status time as a percentage of the operation time per cycle in repeated operation. With the regenerative state = 10s and 1 cycle = 100s, for example, the 10%ED is obtained.



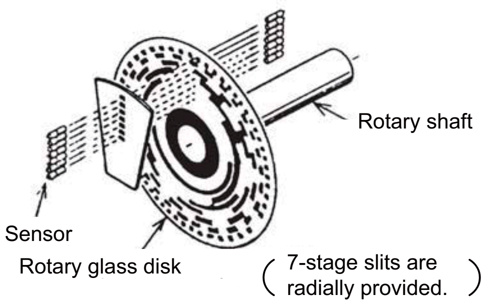
[Operation pattern example]

· Absolute (absolute position) encoder <Antonym; Incremental encoder>

This is an encoder which can output the angle data within one rotation of the encoder to the outside, and the one which can take out 360° in 8 to 12-bit data is generally used.

If using the encoder as a servo motor encoder, the position within one revolution of the motor is identified. Therefore, this is used when the absolute positioning system is configured with a rotation amount counter. The encoder that is used for vector control with inverter is an incremental encoder.

The following figure shows the common structure of the absolute position encoder. In this case, the absolute position signal of 7 bits is output.



Structure example of absolute position encoder

· Acceleration

This is a change of the motor speed, which is expressed with ratio to the acceleration time, and is a slope to the time of motor speed change.

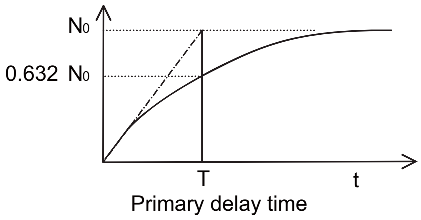
· Acceleration time

This is a time which is taken to reach from the current motor speed to the next motor speed when the motor speed is changed.

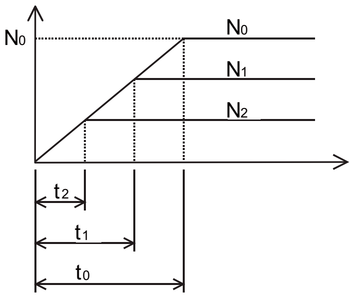
· Acceleration time constant

This is a time which is taken from start to end of the acceleration when the motor is accelerated from the stop status to the certain motor speed (rated motor speed, parameter limit speed, etc.).

For the acceleration pattern of the primary delay function, it indicates the time taken when the actual speed reaches to 63.2% of the target speed.



Acceleration pattern with primary delay constant
Acceleration time and acceleration time constant



t_0 : Acceleration time up to the reference speed = Acceleration time constant
t_1 : Acceleration time up to the motor speed N_1
t_2 : Acceleration time up to the motor speed N_2

· All digital control (Digital control)

This is a system which is controlled by a micro computer or a circuit configured with the peripheral LSI and logic IC.

· Analog control <Antonym: Digital control>

A control method that is performed by a circuit configured with analog devices, such as an operational amplifier.

· Angular frequency (ω)

The number of cycles per second is expressed in Hz (hertz) as a unit to express the continuous sine wave, and it is called angular frequency when expressed in angle (radian). It is converted to $2\pi f$ [rad/s] at frequency f [Hz].

· Auto tuning (Offline auto tuning/Online auto tuning)

The offline auto tuning is a function with which an inverter itself measures and stores a necessary motor constant.

The online auto tuning is a function with which the status of the motor is quickly tuned at a start. Therefore, the high accuracy operation unaffected by the motor temperature and stable operation with high torque down to ultra low speed can be performed.

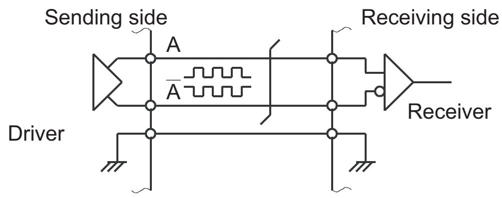
· Capacitor regeneration

This is a method to perform a regenerative operation by charging the regenerative energy in the capacitor of the main circuit.

Since heat is not generated, the capacitor can be repeatedly used when the regenerative energy is smaller than the energy charged in the capacitor. However, the method is only applied to small capacity models since the energy, which can be charged in the capacitor, is small.

· Differential transmission system

This is a system in which one signal is simultaneously transmitted in pair with a signal of reversed polarity. Since the logic of the signals can be evaluated at the same time on the receiving side, this system has superior noise resistance and is used for a signal transmission at high speed such as the input and output of pulse trains. Generally, the sending side is called driver and the receiving side receiver, and a dedicated IC is used.



· Digital control <Antonym; Analog control>

This is a control system which is realized with a control circuit comprised of digital devices. In recent times, a system, in which an operation is processed with software using a micro computer or micro processor for the increase of the calculation amount, has become common.

The advantages of the digital control system are that there is no temperature drift and the performance is stable and has a high-repeatability.

· Earthing (Grounding) fault

Earthing (grounding) fault is a state where a motor power line (one of U, V, and W) is short circuited with the earth (ground)

· Electronic gear

This indicates that the feedback pulse ratio to a command pulse is changed. However, the position resolution is not changed since it is determined with an encoder. The ratio change can be made using fractions with parameters.

Unlike a mechanical gear, the motor torque is not increased even if the ratio magnification is increased.

· Feedback control

This is a control which detects a gap between a command and an actual speed with a closed loop and compensates the command value to reduce this gap.

· Frequency response (characteristic)

This expresses the speed response quantitatively. The frequency to which the actual motor can respond is indicated in ωc [rad/s] or fc [Hz] when the speed command is changed into a sine wave pattern as a extremely low-speed command of approximately 10r/min. This frequency response can be enhanced by increasing the speed loop gain. However, if it is increased too much, a vibration or stability easily occurs due to the rigidity of a mechanical system.

· IGBT(Insulated Gate Bipolar Transistor)

Compared to the existing transistor, IGBT is available for high-speed switching and is better for current, pressure resistance, etc.

· Impact drop

This expresses the temporal response characteristic as a value indicating the fluctuation range of the output to the input command in the feedback control. The value is indicated with the size and duration time of the temporary movement amount for when the load is changed in a staircase pattern.

Especially, it will be effective when including an integral operation.

· Incremental encoder [Antonym: absolute encoder]

Pulses are output in accordance with the rotation number of the encoder. The accumulated output pulses can be used as a position data.

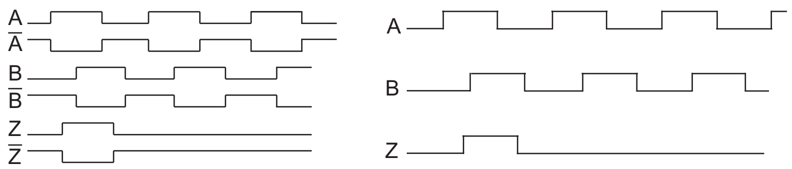
The encoder used for vector control with inverter is an incremental encoder. The difference between A-phase and B-phase is used to determine the rotation direction, and the Z-phase indicates one rotation.

● **Differential line driver**

A/$\overline{A}$ phase signal 1000P/R to 4096P/R
B/$\overline{B}$ phase signal 1000P/R to 4096P/R
Z/$\overline{Z}$ phase signal 1P/R

● **Complementary, open collector**

A-phase signal 1000P/R to 4096P/R
B-phase signal 1000P/R to 4096P/R
Z-phase signal 1P/R



Output pulse specification example

· Inertia moment (Inertia)

This is the amount which indicates the rotation gravity of a rotator and is equivalent to the mass of the linear operation.

Definitional equation $J = m \cdot r^2$

Here, J: Inertia moment [$kg \cdot cm^2$]

M: Mass [kg]

r: Rotation radius [cm]

In addition, GD^2 is usually used as the amount to indicate the inertia moment. The r (radius) of the equation above is expressed in 2r (diameter), and there is a relationship as shown below.

$GD^2 = m \cdot (2r)^2 = 4J$

· Instantaneous power failure

The inverter continues the operation when the power failure is very short (normally, 15ms or less). However, if the power failure is longer than 15ms, it stops the control with outputting an instantaneous power failure error.

If the power failure continues (normally, several 100ms or more), as in the case of power off, it is recovered to the same condition as at power on by power restoration.

The power failure, which is 15ms or more and several 100ms or less as described above, is normally called instantaneous power failure, and the instantaneous power failure error is hold.

· Machine analyzer

Automatically vibrates a vector motor to analyze the frequency characteristic of the machine. This analysis is influenced by the personal computer's computing power.

· Model adaptive speed control

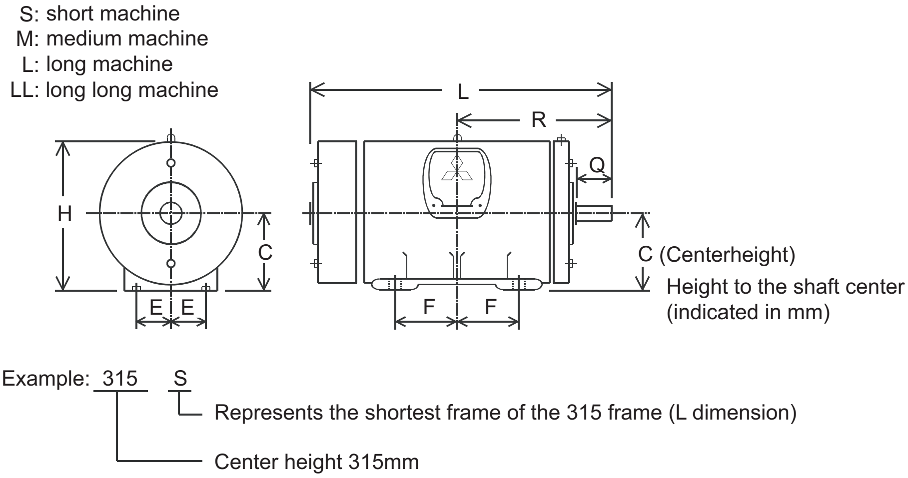
Individually sets the motor's trackability to speed commands and the responsivity to the disturbance torque.

· Motor electromagnetic brake

The electromagnetic brake, which is installed on the motor with the electromagnetic brake, is a no-excitation operation brake to be used in a up-and-down drive, etc. for preventing a drop at power failure or inverter error occurrence or for keeping during a stop.

· Motor frame number

The installation dimension, shaft diameter and shaft length, etc. of standard motor are standardized by JIS standards as shown below.
The size of the electric motor can be checked with the frame number.
For the display method of the frame number, the C dimension is indicated in mm, and the size of the frame length is shown after that.
The additional letter such as S, M, L, and LL is applied.



· Open loop

Since this system does not use an encoder, the control system is simple and economical. Therefore, it is often used for a relatively rough positioning or small-capacity applications which do not really need a torque at high speed. Most inverters use this method.

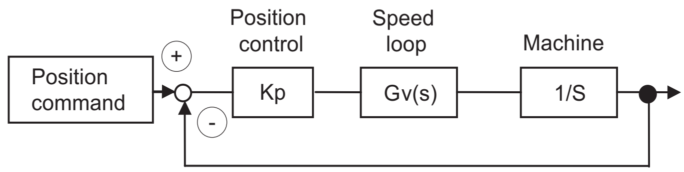
· Position loop gain

This indicates the response to a command in the position control. The following shows the block diagram of the position control indicating the speed control system as Gv(s).

Here, the position loop gain is expressed as follows

Position loop gain = $K_P \cdot G_V(s)$

$= K_P$



The speed control is assumed as $Gv(s) \approx 1$ since the response to the position control is sufficiently high.
The position loop gain will be $K_P = \omega_P$[rad/s] expressed as a position response.

· Power regeneration

This is a system to return the regenerative energy to the power supply side via the bus of the inverter. A dedicated unit for returning the regenerative energy to the power supply side is required. There are advantages, such as the heat generation is less than that in the resistance regenerative system, and the installation dimension becomes smaller with the large regenerative energy. This system is mainly used for the operation to be a continuous regeneration such as large-capacity models and an up-and-down shaft.

· Primary delay time constant

This is a time constant of exponential function, which is a time taken to reach 63% of the final value.
Refer to "Acceleration time constant" on page APP- 56.

· Regeneration

This is a condition that the power flows from the motor side to the power supply (inverter) side. For instance, when the motor speed is faster than the speed command, the difference of the rotation energy flows to the power supply side. The inverter stores this energy in a capacitor or consumes it in a resistor if it is large.

· Regenerative brake

Normally the power is supplied from an inverter to a motor when a load is driven with the motor. This condition is called driving. On the contrary, the rotation energy of the motor and load flows to the inverter when the load speed is decelerated at motor deceleration or descent load drive. This status is called regeneration.

The inverter obtains the regenerative brake torque with consuming the regenerative energy in a capacitor and resistor.

The regenerative brake torque is automatically adjusted depending on the deceleration pattern. However, the regenerative brake option is used when the regenerative frequency is high.

· Regenerative overvoltage

This is a condition that the converter bus voltage exceeds the permissible value due to the regenerative energy which flows to the inverter during regenerative operation. In this case, since the breakdown of the capacitor, etc. may occur, the control function is stopped with the regenerative overvoltage error.

This condition may occur when the regenerative energy is extremely large or the capability of regenerative brake resistor is low.

· Resistance regeneration

This is a system in which a braking torque is obtained by applying the regenerative energy to the resistor connected to the bus of the inverter and consuming it as heat.

· Response

This indicates the trackability in response to each command and generally the speed response.

· Speed feed forward control

Improves the motor trackability to the speed command changes.

· Speed fluctuation percentage

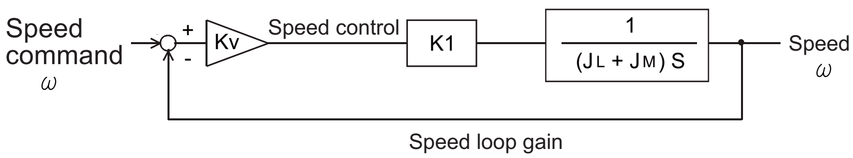
Fluctuation ratio of the motor speed. How much the speed deviates from the rated speed is displayed in percentage.

The speed fluctuation percentage by load fluctuation is shown in the following formula.

$$\text{Speed fluctuation ratio} = \frac{\text{Speed under rated load - Speed under no load}}{\text{Rated speed}} \times 100\ [\%]$$

· Speed loop gain

This indicates the response to a command on the speed control. When the constant to be determined by a motor is assumed as K1.



The speed loop gain is expressed with the following formula.

$$\text{Speed loop gain} = \frac{K1 \times Kv}{J_M + J_L}$$

Kv: Speed amplifier gain

J_L: Load inertia

J_M: Motor inertia

· Undervoltage

If the power supply voltage to the inverter drops to the specified value or lower, the operation is stopped and an fault is externally output to protect the equipment. This specified value is usually 150VAC for the 200VAC inverters, and this value or lower is called undervoltage level.

· Uneven rotation

This is an instant fluctuation of motor speed to a command. The unevenness generally increases at low speed and decreases at high speed.

· V/F control

This is a control system in which the ratio of frequency to the output voltage is constant when the frequency is changed.

In this system, if the voltage to be actually valid decreases due to a voltage drop in a wiring or the primary coil of a motor, enough amount of torque cannot be output (the slower the speed is, the more this phenomenon affects). Therefore, the amount of voltage drop estimated in advance is set higher (torque boost) to cover the shortage of the torque at low speed.

· Vector control

Motor speed is detected with an encoder and a motor slip is calculated to identify the load magnitude.

This system divides the inverter output current into an excitation current (a current necessary to generate a magnetic flux) and a torque current (a current proportional to the load torque) by vector calculation and controls a frequency and voltage optimally to flow a necessary current according to this load magnitude.

Memo

INVERTER SCHOOL TEXT
INVERTER PRACTICAL COURSE

MITSUBISHI ELECTRIC CORPORATION
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When exported from Japan, this manual does not require application to the Ministry of Economy, Trade and Industry for service transaction permission.

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MODEL CODE	

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Specifications subject to change without notice.