

FATEC

**INVERTER SCHOOL TEXT
INVERTER BASIC COURSE (FR-E800)**

● SAFETY PRECAUTIONS ●

(Read these precautions before using this product.)

When designing a system, always read the relevant manuals and give due consideration to safety.
In addition, pay careful attention to the following points for proper handling during training.

[Precautions during training]



WARNING

- To prevent electric shock, do not touch the terminal block while the power is supplied.
- Before opening the safety cover, turn OFF the power, or check that it is sufficiently safe.
- Do not touch moving parts.



CAUTION

- Follow the instructor's directions during training.
- Do not remove the units of a demonstration machine or change the wiring without permission.
Doing so may cause a failure, malfunction, injury and/or fire.
- Do not touch moving parts.
- If the demonstration machine emits an abnormal odor or sound, stop it by operating the Power switch or Emergency stop button.
- If any trouble occurs, notify the instructor immediately.

CONTENTS

Chapter 1	BASICS OF INVERTERS	1-1
1.1	Roles of inverters	1-1
1.2	What is an inverter?	1-2
1.3	Advantages of using inverters	1-3
1.4	Inverter application examples	1-4
1.5	Specifications of Mitsubishi Electric inverters	1-6
1.5.1	Comparison table.....	1-6
1.5.2	Inverter line-up	1-7
1.5.3	Applicable series for each industry	1-9
1.5.4	Introduction of the inverter series	1-10
1.5.5	Mitsubishi Electric inverter component names	1-13
Chapter 2	MOTOR CHARACTERISTICS AT INVERTER DRIVE	2-1
2.1	Motor classifications	2-1
2.2	Structure of motor	2-3
2.2.1	Outer sheath form of motor.....	2-4
2.2.2	Torque and current curves.....	2-5
2.2.3	Motor speed	2-6
2.2.4	Slip.....	2-6
2.2.5	Motor speed fluctuation and motor load current	2-7
2.2.6	Rated motor torque	2-8
2.2.7	Characteristics comparison with the inverter operation	2-9
2.2.8	Features of the inverter operation.....	2-10
2.3	Relationship between the motor applied voltage (V), frequency (f), and torque	2-11
2.3.1	Operation at frequencies exceeding 50 Hz or 60 Hz	2-11
2.4	Standard motor output characteristics in inverter operation	2-12
2.5	Power driving and regenerative driving	2-14
2.6	Load torque types and V/F patterns	2-15
2.7	Demonstration machine configuration	2-16
2.8	Appearance of demonstration machine	2-17
2.9	Basic parameter settings	2-18
2.9.1	Parameters	2-18
2.9.2	Typical parameters	2-19
2.10	Operation panel	2-21
2.11	Operation mode	2-24
2.12	Types of operation methods	2-25
2.12.1	External operation mode (D000 (Pr.79) = "0 (initial value) or 2")	2-25
2.12.2	PU operation mode (D000 (Pr.79) = "0 (initial value) or 1").....	2-25
2.12.3	PU/External combined operation mode 1 (D000 (Pr.79) = "3")	2-26
2.12.4	PU/External combined operation mode 2 (D000 (Pr.79) = "4")	2-26
2.13	Parameter clear / All parameter clear	2-27
2.14	Parameter setting procedure (parameter display in numerical order).....	2-28
2.15	Parameter display by function group	2-29
2.16	Operation using the operation panel.....	2-30

2.17	Operation using external switches (External operation)	2-31
2.18	Monitoring the status of the inverter	2-32
2.19	Giving a start command from the operation panel for JOG operation	2-33
2.20	Operation mode selection	2-34
2.21	Operation of the inverter (principles)	2-36
2.22	Frequently-used parameters (simple mode parameters).....	2-37
2.23	Torque boost.....	2-39
2.24	Torque boost setting	2-41
2.25	Operation check under V/F control (torque boost function).....	2-43

Chapter 3 PRINCIPLE AND FUNCTIONS OF INVERTER 3-1

3.1	Configuration of inverter	3-1
3.2	Configuration of converter section	3-2
3.3	Configuration of inverter section	3-4
3.4	Inverter control methods and auto tuning function.....	3-7
3.4.1	V/F control	3-7
3.4.2	Real sensorless vector control	3-8
3.4.3	Offline auto tuning function	3-8
3.5	Parameter settings using FR Configurator2 [Training]	3-9
3.6	Auto tuning under Real sensorless vector control [Training]	3-11
3.7	Operation under Real sensorless vector control [Training].....	3-11
3.7.1	Inverter check point	3-15
3.8	Protective functions	3-17
3.8.1	Purposes and types of protective functions.....	3-17
3.8.2	Reset method for the protective functions	3-17
3.8.3	Retry function	3-18
3.8.4	Emergency drive.....	3-18
3.9	Protecting the inverter (V/F control) [Training].....	3-19
3.10	Acceleration/operating characteristics of inverter	3-22
3.10.1	Start	3-22
3.10.2	Acceleration	3-22
3.10.3	Overcurrent stall prevention	3-23
3.10.4	Constant-speed operation	3-23
3.10.5	Deceleration	3-23
3.10.6	Stop	3-24
3.10.7	Stall prevention operation [Training].....	3-24
3.11	Batch monitor, test operation, and diagnosis using FR Configurator2 [Training]	3-25
3.12	USB bus power connection [Training]	3-30

Chapter 4 ENERGY SAVING WITH INVERTERS 4-1

4.1	Efficiency	4-1
4.2	Power factor.....	4-2
4.2.1	Power factor	4-2
4.2.2	Inverter input current and power factor improvement.....	4-3

4.3	Energy saving with inverters	4-7
4.3.1	Energy saving with speed control	4-7
4.3.2	Energy saving with Optimum excitation control	4-9
4.3.3	Energy saving monitoring	4-10
4.4	Energy saving with motors	4-11
4.4.1	General-purpose motor (SF-PR)	4-11
4.4.2	PM motor (MM-GKR, EM-A)	4-11
4.4.3	Energy-saving high-accuracy PM motor EM-A series	4-12
4.4.4	Premium high-efficiency IPM motor MM-EFS series	4-13
4.5	Energy saving with the regenerative option	4-15

Chapter 5 CAPACITY SELECTION FOR MOTOR AND INVERTER 5-1

5.1	Selection	5-1
5.2	How to use Drive System Sizing Software	5-2
5.3	Selection example	5-4

Appendix APP-1

Appendix 1	Power supply of inverter (harmonics and instantaneous power failure)	APP-1
Appendix 1.1	Harmonics	APP-1
Appendix 1.2	Characteristics of rectifier circuit and generated harmonics	APP-3
Appendix 1.3	Split-flow path of harmonic current	APP-4
Appendix 1.4	Harmonic suppression guidelines	APP-5
Appendix 1.5	Overview of harmonic suppression measures	APP-7
Appendix 1.6	Influence to inverter at instantaneous power failure	APP-8
Appendix 1.7	Inverter peripheral circuit and inverter operation at instantaneous power failure	APP-10
Appendix 2	Noise	APP-13
Appendix 2.1	Processing speed improvement for main circuit elements	APP-13
Appendix 2.2	Inverter operating principle	APP-13
Appendix 2.3	Noise and harmonics	APP-14
Appendix 2.4	Mechanism of noise generation	APP-15
Appendix 2.5	Influence of noise	APP-16
Appendix 2.6	Noise propagation path	APP-17
Appendix 2.7	Measures against noise	APP-18
Appendix 2.8	Specific examples of countermeasures	APP-28
Appendix 2.9	Regulations regarding the inverter noise and supplemental information	APP-33
Appendix 3	Leakage current	APP-36
Appendix 3.1	Mechanism of leakage current generation	APP-36
Appendix 3.2	Effect of the leakage current	APP-37
Appendix 3.3	Leakage current data and measurement method	APP-39
Appendix 3.4	Countermeasures against unnecessary operations due to leakage current	APP-40
Appendix 3.5	Specific examples of countermeasures	APP-44
Appendix 3.6	Impacts of the leakage current on human bodies and related laws and regulations	APP-45
Appendix 4	Earth (ground)	APP-48
Appendix 4.1	Earth (ground) and leakage current	APP-48
Appendix 4.2	Earthing (grounding) system to be established	APP-49
Appendix 5	Voltage-doubler circuit	APP-50
Appendix 6	Glossary	APP-51

CHAPTER 1 BASICS OF INVERTERS

An inverter is equipment that controls the rotation speed of a motor. It can change the rotation speed of a standard motor freely. Inverters are widely used in various applications in our daily lives.

POINT

Inverter as an FA (factory automation) device

Motors are used for operating various products around us. Inverters are used to help control motor speeds to prevent sudden starts when the switch is turned on.

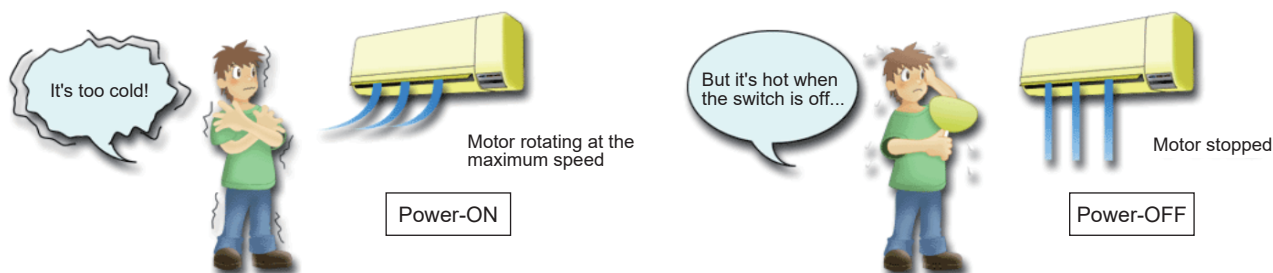
1.1 Roles of inverters

Recently, the term "inverter" has become familiar in various household appliances.

For example, "inverter air conditioners" are commonly used.

In these air conditioners, motors circulate coolant to control the temperature.

It would be inconvenient if the motor operation were limited to either maximum speed or complete stop.



By allowing flexible control of motor rotations per minute, inverters enable the setting of the desired temperature.



Equipment and products with built-in inverters can adjust the motor rotation speed freely, smoothly, and efficiently.

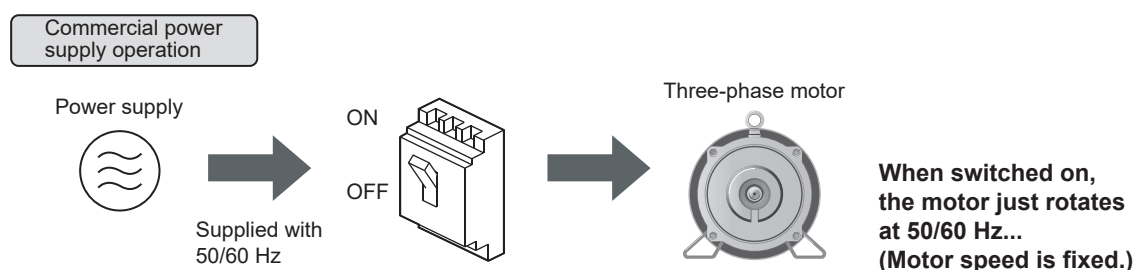
1 BASICS OF INVERTERS

1.2 What is an inverter?

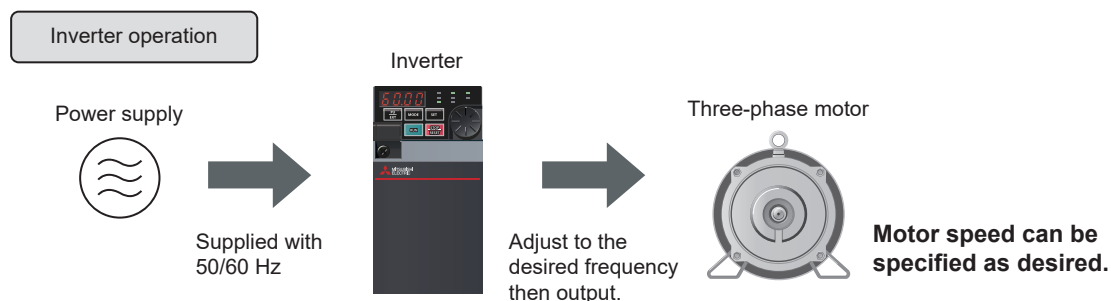
The applicable motors for the industrial inverters are generally three-phase squirrel cage motors (induction motors). (For clarity, they are referred to as three-phase motors or simply motors in this document.)

The power supply (AC) at factories and houses is fixed according to the country and area, such as 200 V/60 Hz, 200 V/50 Hz, 100 V/60 Hz, and 100 V/50 Hz. With the fixed voltage and frequency obtained from the power supply, the motor can be rotated only at a single speed. However, with an inverter which freely changes the voltage and frequency, the motor can be rotated at different speeds.

Thus, inverters are used in various applications, for example to control fan's air volume and conveyor speed, exhibiting their ability to freely change standard motor's speed.



When the power supply frequency supplied from the power supplier is fed to the motor without using the inverter, the motor rotation speed is fixed according to the frequency. This is the commercial power supply operation.



The motor rotation speed is determined by the power supply frequency fed to the motor.

Although the power supply frequency supplied from the power supplier is fixed to 50/60 Hz, the motor can be rotated at different speeds when the frequency can be changed flexibly.

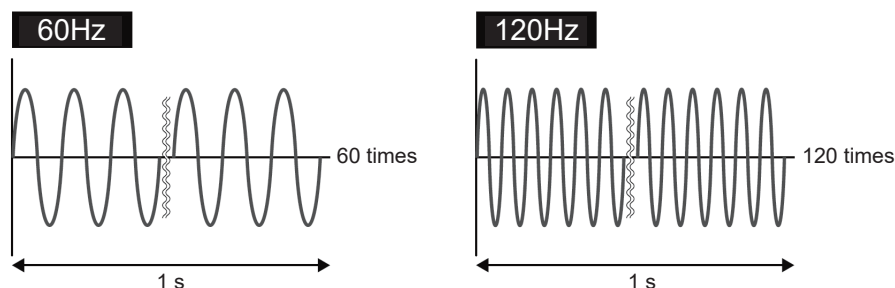
Focusing on this theory, inverters are configured to change the frequency flexibly.

1 BASICS OF INVERTERS

Remark

Frequency

The frequency can be expressed as a wave-like graph. A frequency of 60 Hz indicates that a cycle from positive to negative is repeated 60 times per second.



1.3 Advantages of using inverters

Using inverters provides the following advantages.

- The standard motor speed can be changed freely. Existing standard motors are also applicable.
- A standard motor can rotate at constant speed without being affected by the power supply frequency.
- Energy (electricity) can be saved.
- Productivity can be improved by changing the standard motor rotation speed according to the application.
- The starting current of the standard motor can be reduced, allowing the motor to start and stop smoothly.
- Factory automation system, such as automatic operation and synchronized operation with multiple machines, can be introduced easily.

1.4 Inverter application examples

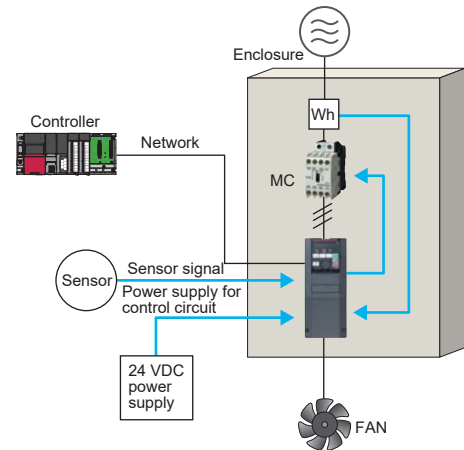
Inverters are used in various fields.

(1) Fans and ventilation fans used in buildings

- Fan, blower
- Ventilation fan
- Pump
- Cooling tower
- Drying machine (Furnace fan)

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.

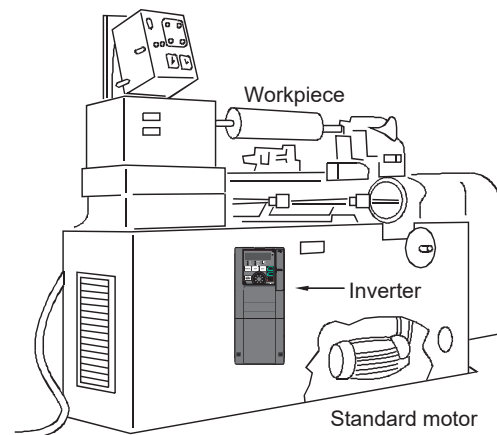


(2) Drive for a main spindle of a machine tool

- Drive for a main spindle of a machine tool
- Table of a machine tool
- Drive for a cutter
- Rice mill

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.

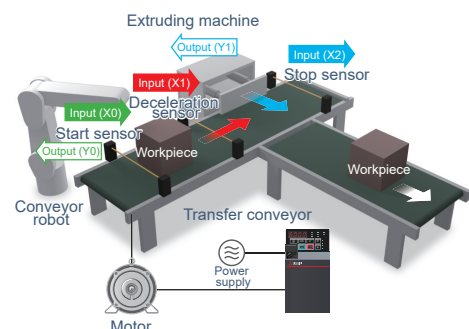


(3) Belt conveyors used in factories, etc.

- Belt conveyor
- Cart
- Wood working machine
- Weighing machine
- Packaging machine

Higher machine efficiency, specified position stop, automatic operation

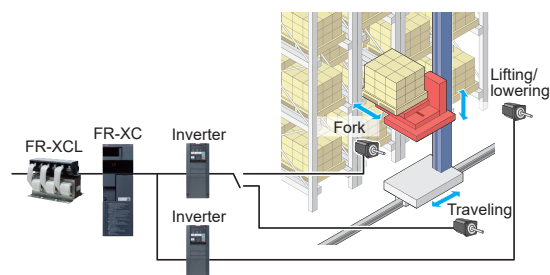
- The operation efficiency can be improved and carts can be stopped at the specified position.
- The conveyor speed can be changed to the most suitable value for every workpiece.
- The soft start and stop prevents products from falling down and wobbling.
- Shocks to machines are absorbed and acceleration and deceleration without shocks are realized.



1 BASICS OF INVERTERS

(4) Specified position stop, automatic operation in automated warehouse

- Automated warehouse
- Multi-story parking lot
- Cargo elevator
- Conveyor



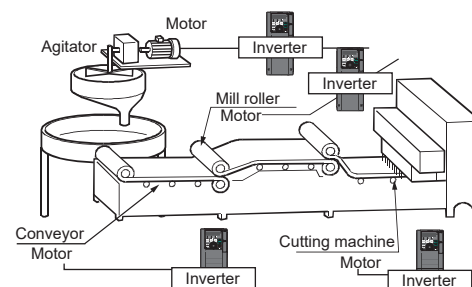
Specified position stop, automatic operation

- Carts can be stopped at the specified position.
- Multi-story car parking lots 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 multifunction regeneration converter FR-XC (optional) to construct an efficient driving system, by which further energy saving effect is expected.

(5) Agitators and rollers driven by Vector control

- Agitator
- Roller driving
- Extruder
- Molding machine
- Wire drawing machine
- Testing machine



Vector control or sensorless vector control enables generation of high starting torque and minimum speed fluctuation.

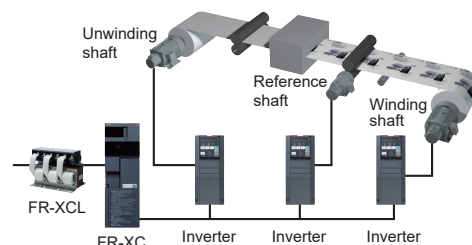
- Accurate control over extrusion pressure according to the material extruded.
- Even for loads that change (increase) their viscosity as speed decreases, operations continue without torque shortages occurring.

(6) Winding/unwinding line

- Various winding
- Unwinding line

Controlling torque with vector control

- Winding/unwinding torque can be controlled with vector control.



1 BASICS OF INVERTERS

1.5 Specifications of Mitsubishi Electric inverters

1.5.1 Comparison table

Notation

[A800]: RS-485 model, [A800-E]: Ethernet model, [A800-GF]: CC-Link IE Field Network communication function type, [A800-GN]: CC-Link IE TSN communication function type

[F800]: RS-485 model, [F800-E]: Ethernet model

[E800]: Standard model, [E800-E]: Ethernet model, [E800-EPA]: Ethernet model (Protocol group A only), [E800-EPB]: Ethernet model (Protocol group B only).

[E800-SCE]: Safety communication model, [E800-SCEPA]: Safety communication model (Protocol group A only), [E800-SCEPB]: Safety communication model (Protocol group B only)

"✓" mark or description: Available
Blank: Not available

Blank. Not available							
Control method	Item	FR-A800	FR-F800	FR-E800	FR-D800	FR-D700	FR-F700PJ
	V/F control	✓	✓	✓	✓	✓	✓
	General-purpose magnetic flux vector control					✓	✓
	Advanced magnetic flux vector control	✓	✓	✓	✓		
	Real sensorless vector control	✓		✓			
	Vector control ¹⁾	✓		✓			
	PM sensorless vector control	✓		✓	✓		
Starting torque	PM motor control		✓				✓
	Induction motor	<div>AD MFVC</div> 200% 0.5 Hz (3.7K or lower) 150% 0.5 Hz (5.5K or higher) <div>Sensorless</div> <div>Vector</div> 200% ²⁾ at 0.3 Hz	<div>AD MFVC</div> 120% 0.5 Hz	<div>AD MFVC</div> 150% 0.5 Hz <div>Sensorless</div> <div>Vector</div> 200% 0.3 Hz (3.7K or lower) 150% 0.3 Hz (5.5K or higher)	<div>AD MFVC</div> 200% 0.5 Hz (3.7K or lower) 150% 0.5 Hz (5.5K or higher)	<div>General-purpose MFVC</div> 150% 1 Hz 200% 3 Hz (3.7K or lower) with slip compensation enabled	<div>General-purpose MFVC</div> 120% 1 Hz with slip compensation enabled
	PM motor	High frequency superposition control: 200% ³⁾ Current synchronization operation: 50%	50%	EM-A, MM-GKR: 200% Motor other than the above: 50%	50%		50%
Output frequency range		0.2 to 590 Hz ⁴⁾				0.2 to 400 Hz	
Regenerative braking	Built-in brake transistor	200 V class: Built-in for 0.4K to 22K 400 V class: Built-in for 0.4K to 55K		Built-in for 0.4K to 22K	Built-in for 0.4K to 15K	Built-in for 0.4K to 15K	Built-in for 0.4K to 15K
Acceleration/deceleration time setting		0 to 3600 s					
Multi-speed	Individual acceleration/deceleration setting	Up to 3 types		Up to 2 types			
	Speed command	Speed 15					
Speed command	Analog	0 to 5 VDC, 0 to 10 VDC, 0 to ±5 VDC, 0 to ±10 VDC, 4 to 20 mA		0 to 5 VDC, 0 to 10 VDC, 4 to 20 mA			
	Digital	Set with pulse train input, operation panel, or parameter unit. 4-digit BCD or 16-bit binary (when using the FR-A8AX plug-in option).		Set with the operation panel or parameter unit. 4-digit BCD or 16-bit binary (when using the FR-A8AX plug-in option).	Set with the setting dial or parameter unit.	Set with the setting dial, operation panel, or parameter unit.	
Restart after instantaneous power failure		Available (reduced voltage method [frequency search method selectable])					
Input signal	Contact input	12		[E800] : 7 [E800-E] : 2 [E800-SCE] : 0	5		
	Pulse train input	100k pulses/s			100k pulses/s		
Output signal	Open collector output	5		[E800] : 2 [E800-E] [E800-SCE] : 0	2		
	Contact output (1 changeover contact)	2			1		
Fault output		1 changeover contact (230 VAC 0.3 A, 30 VDC 0.3 A), open collector output		1 changeover contact (250 VAC 2 A, 30 VDC 1 A), open collector output	1 changeover contact (240 VAC 2 A, 30 VDC 1 A), open collector output	1 changeover contact (230 VAC 0.3 A, 30 VDC 0.3 A), open collector output	
Monitor function	Fault code (4 bits) output	✓	✓				
	Pulse train output	1440 pulses/s, 2 mA (FM type)		1440 pulses/s, 1 mA (FM type)	1440 pulses/s, 1 mA		
Removable terminal block	Analog output	0 to ±10 VDC		0 to ±10 VDC (AM type)	0 to +10 VDC / 12 bits		
	Used for control circuit terminals						
Built-in communication function ⁵⁾	RS-485 (Mitsubishi inverter protocol)	✓	✓	[E800]	✓	✓	✓
	RS-485 (MODBUS®RTU)	[A800] [A800-GF] [A800-GN]	[F800]	[E800]	✓	✓	✓
	CC-Link IE TSN	1Gbps/100Mbps [A800-GN]	1Gbps/100Mbps Supported by options	100Mbps [E800-EPA] [E800-EPB] [E800-SCEPA] [E800-SCEPB]			
	CC-Link IE Field Network	[A800-GF]	Supported by options				
	CC-Link IE Field Network Basic	[A800-E]	[F800-E]	[E800-EPA] [E800-EPB] [E800-SCEPA] [E800-SCEPB]			
	MODBUS/TCP	[A800-E]	[F800-E]	[E800-EPA] [E800-EPB] [E800-SCEPA] [E800-SCEPB]			
	PROFINET	✓ (HMS network option)	✓ (HMS network option)	[E800-EPB] [E800-SCEPB]			
	EtherNet/IP	✓ (HMS network option)	✓ (HMS network option)	[E800-EPA] [E800-SCEPA]			
	BACnet/IP		[F800-E]	[E800-EPA] [E800-SCEPA]			
	CC-Link IE TSN safety communication function			[E800-SCEPA] [E800-SCEPB]			
	PROFIsafe			[E800-SCEPB]			
	CIP Safety			[E800-SCEPA]			
Safety stop function		✓	✓	✓	✓		

*1: Vector control is available when a Vector control compatible option is installed.

*2: In the initial setting for the FR-A820-00340(5.5K) or higher and the FR-A840-00170(5.5K) or higher, the starting torque is limited to 150% by the torque limit level.

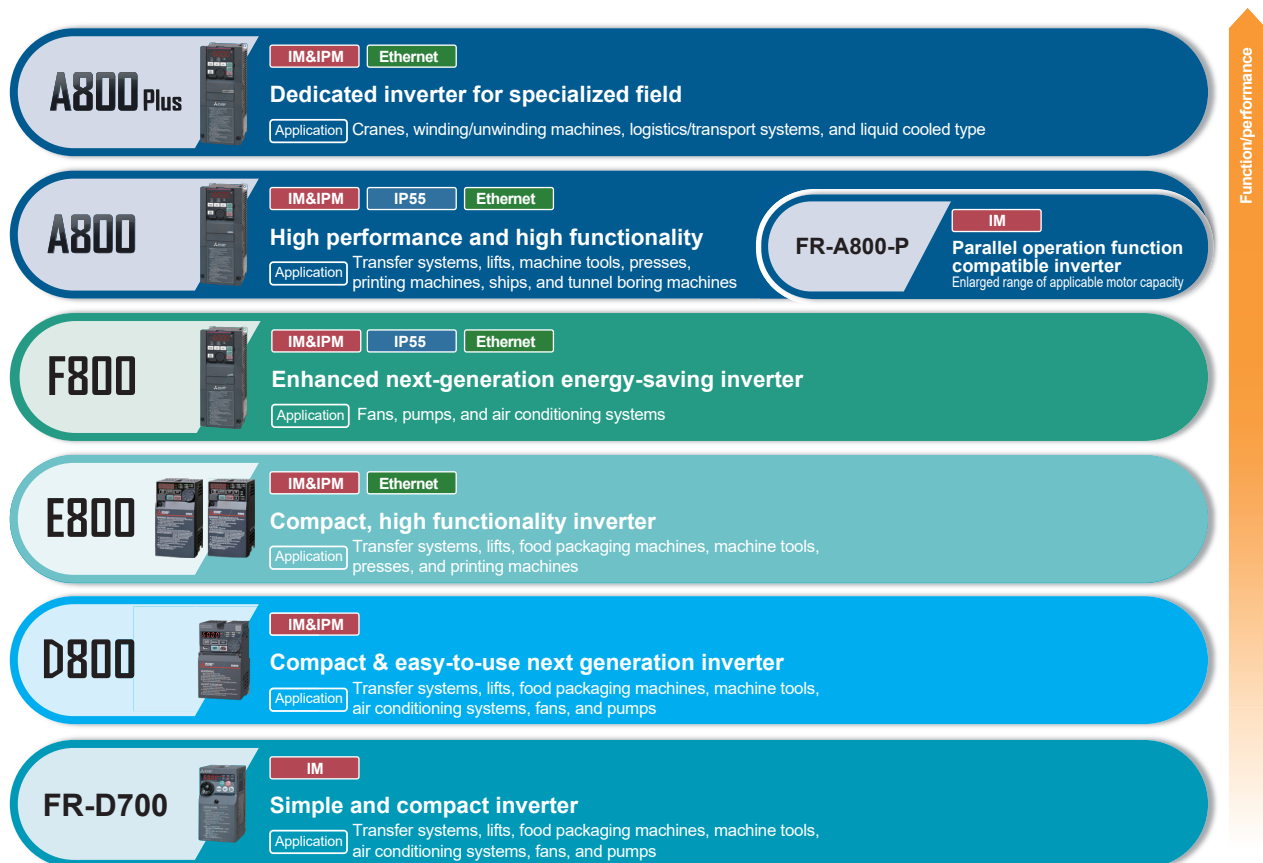
*3: The starting torque for use with MM-CF is 200% for the 1.5 kW or lower, and 150% for the 2.0 kW or higher.

*4: The upper frequency limit is 400 Hz under Advanced magnetic flux vector control, Real sensorless vector control, Vector control, PM sensorless vector control, and PM motor control.

*5: Refer to the relevant inverter catalog for other available communication functions or communication functions supported by options.

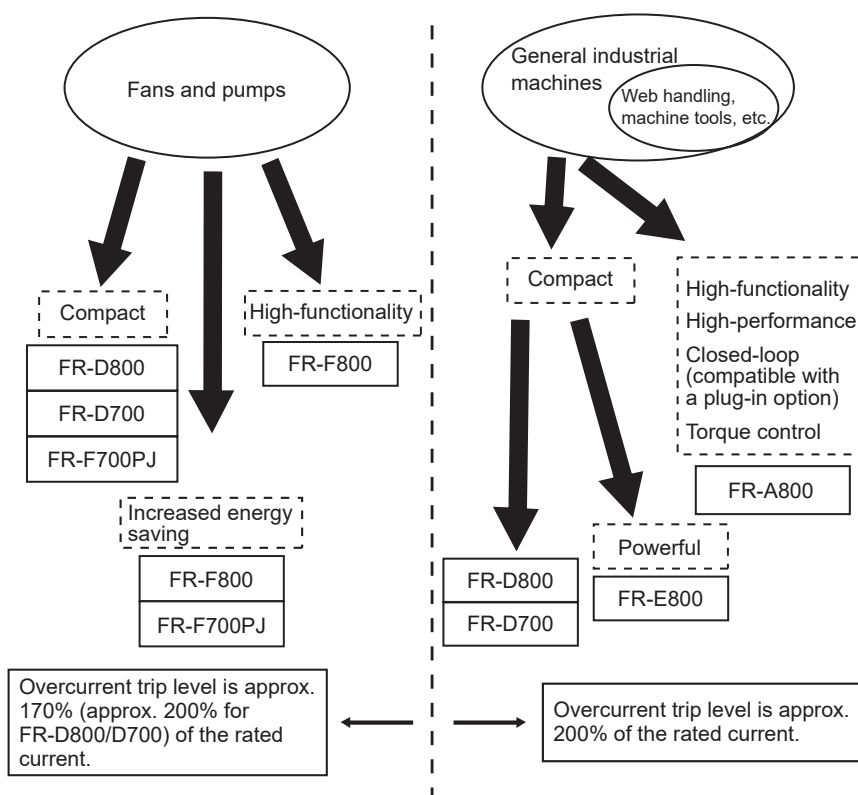
1 BASICS OF INVERTERS

1.5.2 Inverter line-up



1 BASICS OF INVERTERS

1.5.3 Applicable series for each industry



1 BASICS OF INVERTERS

1.5.4 Introduction of the inverter series

For fans and pumps

FR-F800



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.
- This inverter has long life parts and the life check function as standard.
- Compatible with various plug-in options.
Also 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).

1 BASICS OF INVERTERS

General industrial applications

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

FR-E800



Single-phase 100V class	0.1K to 0.75K
Single-phase 200V class	0.1K to 2.2K
Three-phase 200V class	0.1K to 22K
Three-phase 400V class	0.4K to 22K
Three-phase 575V class	0.75K to 7.5K

- Real-time connection with the host IT system enables centralized or remote monitoring of operation.
- AI technology and smartphone connectivity support initial startup or troubleshooting.
- Various safety sub-functions and wireless inverter connection enable stable and safe operation of the system.
- Expanding a range of applications with multi-protocols
Protocols of major global industrial Ethernet networks are supported by the inverter without using a plug-in option. (Ethernet model / Safety communication model)

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
Single-phase 200V class	0.1K to 2.2K
Three-phase 200V class	0.1K to 15K
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

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

FR-D800



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

- Quest for ease of use
Wiring work efficiency is improved with the flip-type front cover and the wiring cover integrated into the inverter.
- Revolution in ease of selection
The functions of the FR-D700 and FR-F700PJ series are inherited and enhanced.
- Advanced environmental performance
 - Using high-efficiency motors and reducing the standby power help reduce the running cost and CO₂ emission.
 - The CO₂ emission reduction amount can be monitored.

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.

1 BASICS OF INVERTERS

Dedicated inverter for specialized field

FR-A800 Plus Series



Features

■ Pursuing optimum functions to meet our customers' needs

A lineup of dedicated inverters for specialized fields are offered.

Plus! The optimum functions for each dedicated field are added to the already high performance and high functionality FR-A800 series inverter.



FR-A800 Plus

■ Optimum functions for cranes FR-A800-CRN



■ Optimum functions for roll to roll applications FR-A800-R2R



■ Liquid Cooled Type Inverter FR-A800-LC



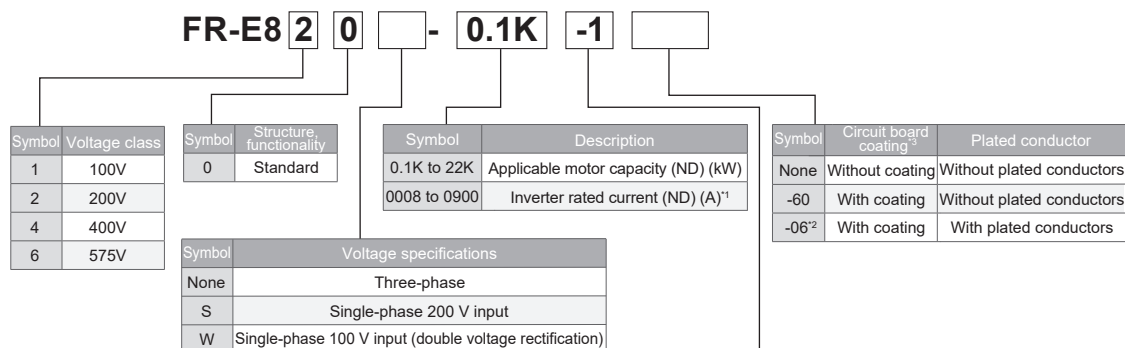
■ Logistics/Transport Dedicated Inverter FR-A800-AWH



1 BASICS OF INVERTERS

1.5.5 Mitsubishi Electric inverter component names

- Inverter model (Example: FR-E800)



Symbol	Communication /functional safety specifications	Monitoring/protocol specifications	Rated frequency (initial setting)	Control logic (initial status)
-1	RS-485 + SIL2/PLd	Pulse (terminal FM)	60Hz	Sink logic
-4 ^{*1*4}		Voltage (terminal AM)	50Hz	Source logic
-5		Voltage (terminal AM)	60Hz	Sink logic
EPA	Ethernet + SIL2/PLd	Protocol group A ^{*5}	60Hz	Sink logic
EPB		Protocol group B ^{*5}	50Hz	Sink logic/Source logic ^{*6}
EPC		Protocol group C ^{*5}	60Hz	Sink logic/Source logic ^{*6}
SCEPA	Ethernet + SIL3/PLe	Protocol group A ^{*5}	60Hz	Source logic ^{*7}
SCEPB		Protocol group B ^{*5}	50Hz	Source logic ^{*7}
SCEPC		Protocol group C ^{*5}	50Hz	Source logic ^{*7}

*1 : Models with circuit board coating (-60/-06) only.

*2 : Applicable for the FR-E820-0470(11K) or higher, and the FR-E840-0380(18.5K) or higher.

*3 : Compatible with IEC 60721-3-3:1994 3C2.

*4 : The kW indication is not available for models with a suffix "-4". When the kW indication is required, purchase the applicable model with a suffix "-5" and change the initial settings with reference to the Instruction Manual.

(Refer to the Instruction Manual (Connection) for the switching of the control logic of the inverter, and the Instruction Manual (Function) for the rated frequency.)

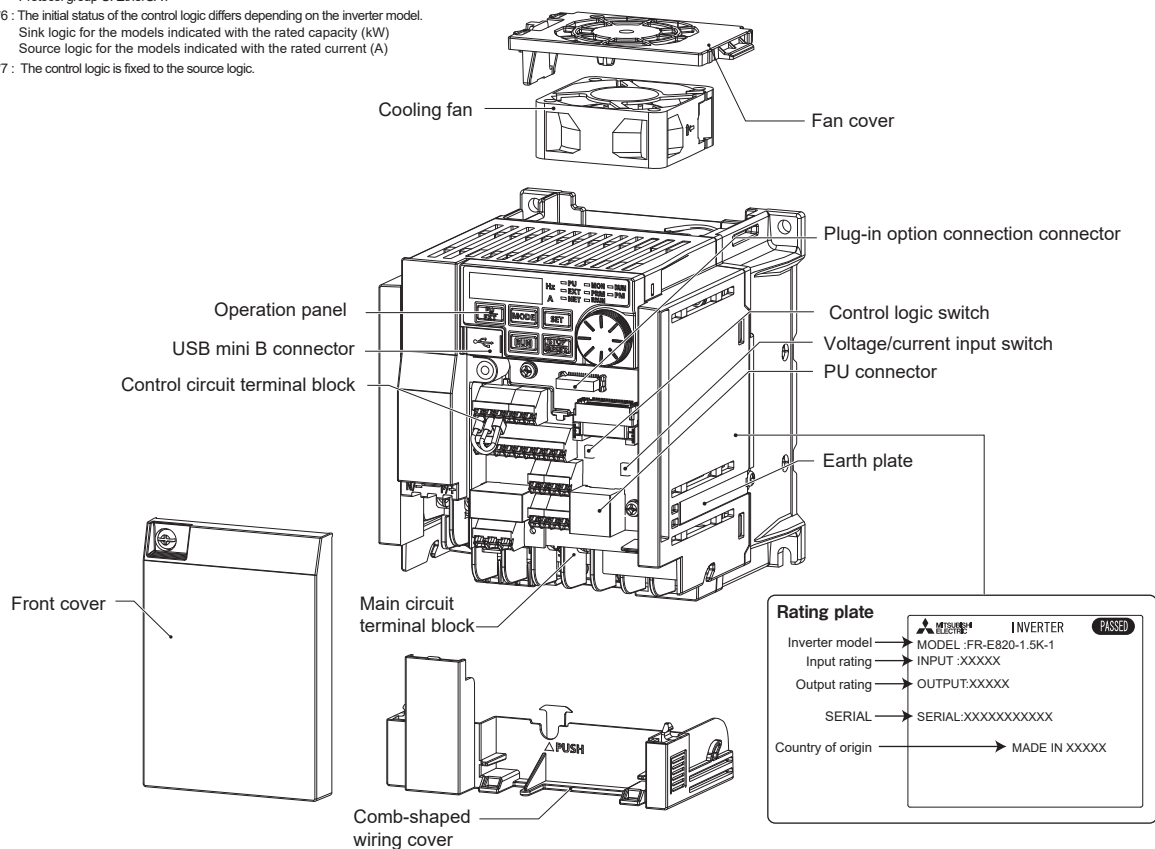
*5 : Selectable protocols differ depending on the group.
 Protocol group A: CC-Link IE TSN, CC-Link IE Field Network Basic, MODBUS/TCP, EtherNet/IP, and BACnet/IP
 Protocol group B: CC-Link IE TSN, CC-Link IE Field Network Basic, MODBUS/TCP, and PROFINET
 Protocol group C: EtherCAT

*6 : The initial status of the control logic differs depending on the inverter model.

Sink logic for the models indicated with the rated capacity (kW)

Source logic for the models indicated with the rated current (A)

*7 : The control logic is fixed to the source logic.



Memo

CHAPTER 2 MOTOR CHARACTERISTICS AT INVERTER DRIVE

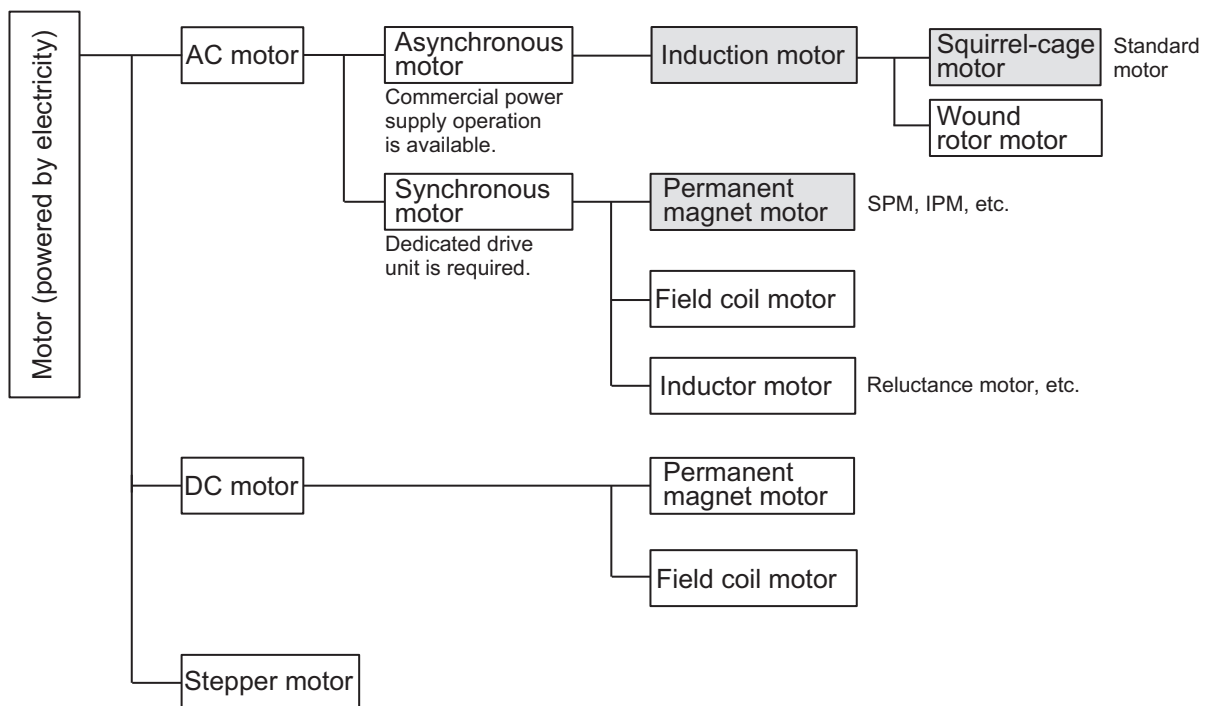
This chapter describes the basic characteristics that are of importance when selecting motor capacity and when operating a standard motor by inverter.

Motor characteristics differ when operating by commercial power supply, and when operating by inverter. It is important that the user understands these differences.

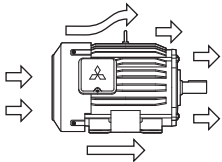
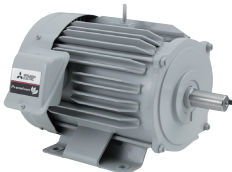
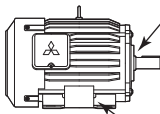
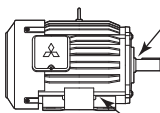
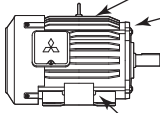
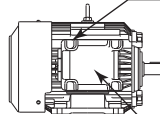
2.1 Motor classifications

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 mainly a standard motor (cage-induction motor).

In addition, there is an energy-saving drive high-efficiency magnetic motor (IPM) for further energy saving.



2 MOTOR CHARACTERISTICS AT INVERTER DRIVE

Model	Description	Appearance
Totally-enclosed fan-cooled type (inside installation) (SF-PR) (SF-JR)	<p>Designed to prevent dust and other foreign material from entering the inside of the motor.</p>  <p>Cooling air flows outside the frame.</p>	
Outdoor type (SF-PRO) (SF-JRO)	<p>Designed to prevent water from entering the inside of the motor. Called "outdoor type" as it can be used outdoors.</p>  <p>Fringers and end covers are installed to the shafts to prevent water from entering.</p> <p>PF screw (conduit and cable gland) is mounted.</p>	
Water-proof type (SF-PRP) (SF-JRP)	<p>Designed for use in places subjected to more water exposure than the outdoor type.</p>  <p>V-rings and end covers are installed to the shafts to prevent water from entering.</p> <p>PF screw (conduit and cable gland) is mounted.</p>	
Corrosion-proof type (SF-P) (CF-P) (SF-J) (CF-J)	<p>Designed for use in environment with corrosive materials such as gas, oil mist, and liquid.</p>  <p>Anti-corrosive coating is applied.</p> <p>External parts (such as frames and brackets) are made of thick cast iron.</p> <p>PF screw (conduit and cable gland) is mounted.</p>	
Pressure-resistant explosion-proof type *1 (XF-NE)	<p>Designed for use in environment with explosive gas. Even if sparks occur inside the motor, the motor withstands the pressure of the explosion and prevents external explosive gas from igniting.</p>  <p>Bolts are used. The bolts are large and securely tightened.</p> <p>The terminal box is large.</p>	

*1 Inverter-driven motors are used in combination with inverters designed for pressure-resistant explosion-proof type motors, which have passed the explosion-proof test by the Japanese Ministry of Health, Labour and Welfare.

2 MOTOR CHARACTERISTICS AT INVERTER DRIVE

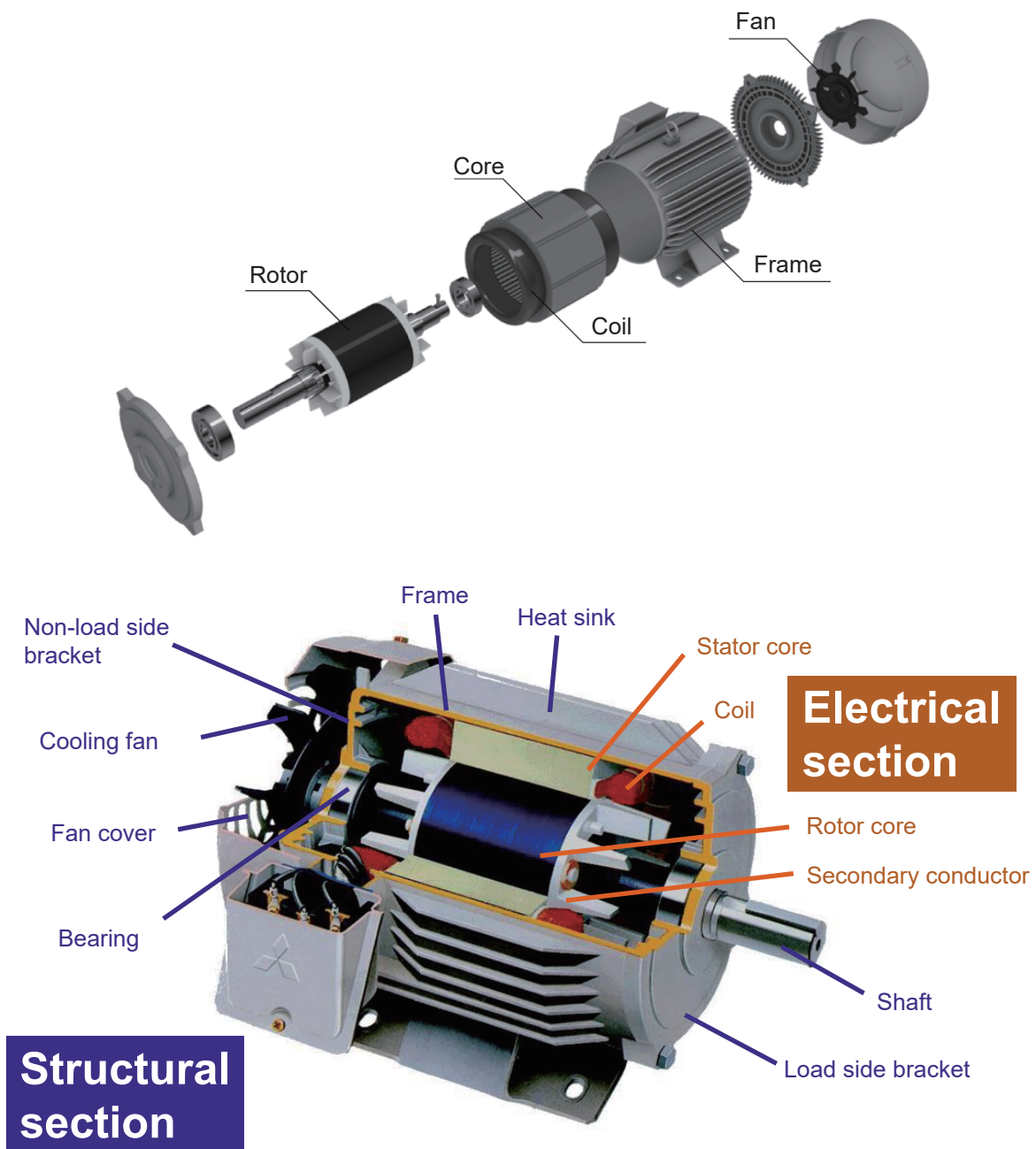
2.2 Structure of motor

When the power supply is connected to the motor, a current flows through the stator coil in the motor, producing a revolving magnetic field.

This revolving magnetic field causes the rotor to rotate. The motor rotation speed is proportional to the power supply frequency.

In addition, a cooling fan connected to the shaft is provided to cool the heat generated by the motor itself.

When the inverter is operated at a low speed, the motor rotates slowly, and the cooling effect of the fan is reduced.



Example of totally-enclosed fan-cooled type

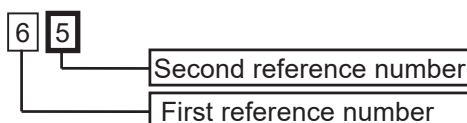
2.2.1 Outer sheath form of motor

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 following shows classifications by JIS and IEC.

Classifications 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



For the SF-PR, the indoor/outdoor type is compatible with IP44, and the dust-proof / water-proof type with IP55.

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 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

2.2.2 Torque and current curves

Fig. 2.1 shows the torque and current characteristics at direct power ON of a standard motor.

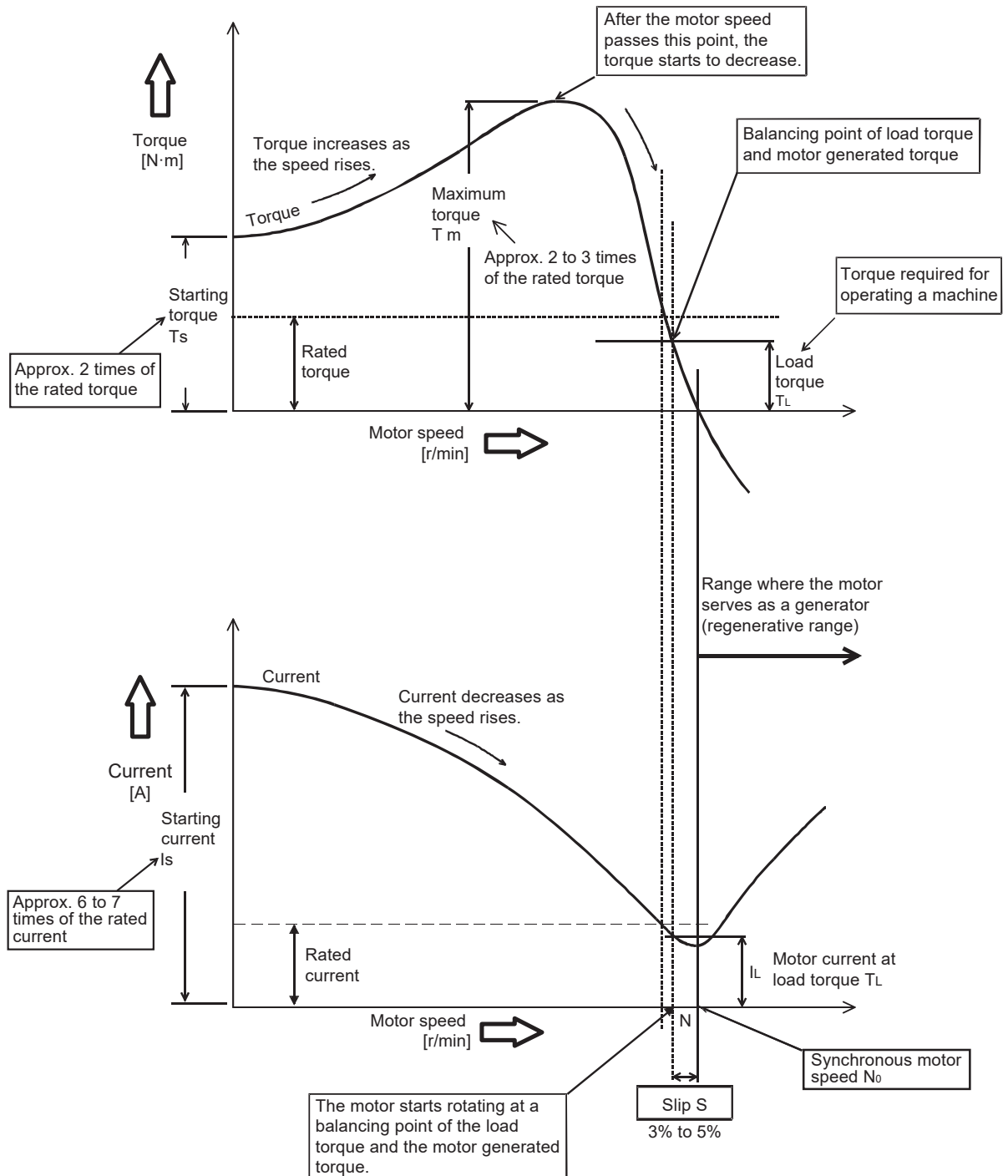


Fig. 2.1 Relationship of a standard motor speed, current, and torque

2.2.3 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. When using inverter control, the motor speed can be changed by adjusting the inverter output frequency.

$$\text{Motor speed } N = \frac{120 \times \text{Frequency [Hz]}}{\text{Number of poles } P} \times (1 - S) \quad [\text{r/min}]$$

2.2.4 Slip

When a load is applied, the motor speed becomes mismatched with (or reduced from) the synchronous speed. The indicated degree of the gap with the synchronous speed is called "slip".

$$\text{Slip } S = \frac{\text{Synchronous speed [r/min]} - \text{Motor speed [r/min]}}{\text{Synchronous speed}} \times 100 [\%]$$

Slip at the rated torque is approx. 3% to 5%.

Calculation example of slip (S)

Example: When a motor with synchronous speed of 1800 r/min is rotating at 1728 r/min

$$\begin{aligned} \text{Slip } S &= \frac{1800 - 1728}{1800} \times 100 \\ &= 4 [\%] \end{aligned}$$

When the load torque is large, the motor rotates slowly.

Unlike synchronous motors, "slip" occurs for induction motors.

2.2.5 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. 2.1.

(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.)

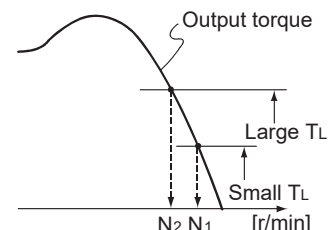


Fig. 2.2 Load fluctuation and motor speed

(2) When the motor applied voltage (power supply voltage) varies (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.

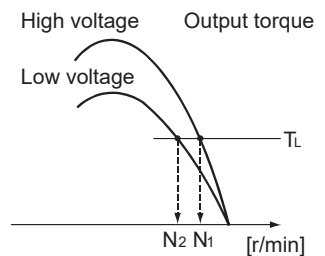


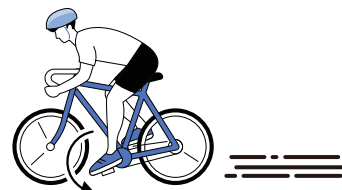
Fig. 2.3 Voltage fluctuation and motor speed

2 MOTOR CHARACTERISTICS AT INVERTER DRIVE

2.2.6 Rated motor torque

Torque

Torque is the force that causes the motor to rotate, i.e. the rotational force. To put it simply, for a bicycle, the force applied to the pedals is the torque for the wheels.



The rated torque refers to the torque generated when operating at the rated voltage and the rated frequency (rotation speed).

$$\text{Rated torque } T_M = 9550 \times \frac{\text{Rated motor output [kW]}}{\text{Rated speed [r/min]}} \quad [\text{N} \cdot \text{m}]$$

Calculation example of the rated torque

Example: When the rated motor output is 30 kW and the rated speed is 1800 r/min

$$\text{Rated torque } T_M = 9550 \times \frac{30 \text{ [kW]}}{1800 \text{ [r/min]}} = 159.2 \quad [\text{N} \cdot \text{m}]$$

Remark

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.

The term "rating" refers to the limit value that must not be exceeded when the motor is operated for a long time.

When the rated voltage is 200 V, operating the motor at a voltage exceeding 200 V for a long time leads to a failure or damage of the motor.

2.2.7 Characteristics comparison with the inverter operation

The motor torque and current characteristics in the commercial operation and the inverter operation are compared as shown in Fig. 2.4. [%] indicates the ratio to the rated torque and rated current. (Example: For four poles)

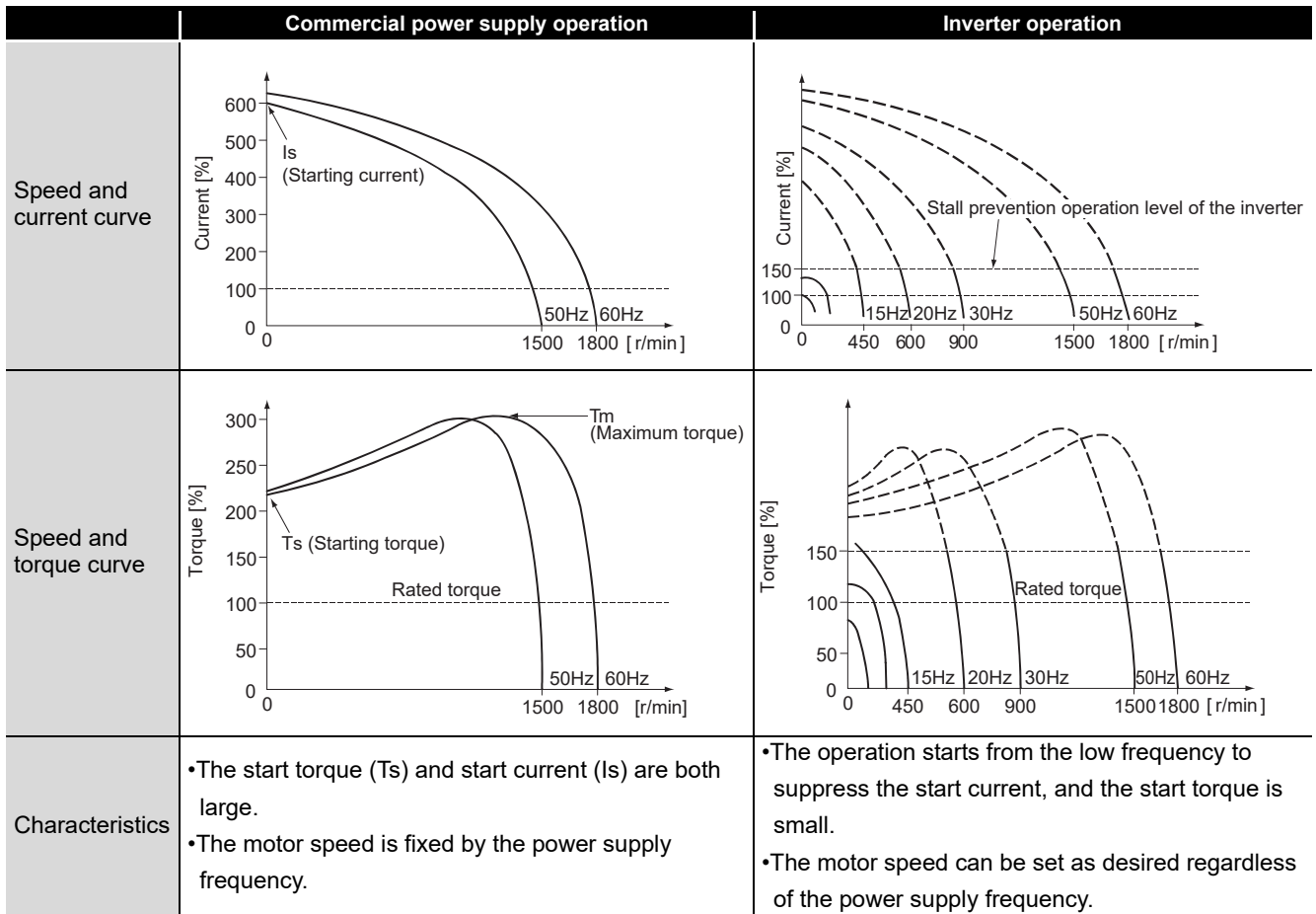


Fig. 2.4 Motor current and torque characteristics comparison (when the inverter is performing V/F control)

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

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

2.2.8 Features of 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 50 Hz with little margin for the specified temperature. This is why "Reduce the load torque to 85% at 50 Hz" 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 60 Hz, even if the current increases, the temperature stays within the specified value.

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

2 MOTOR CHARACTERISTICS AT INVERTER DRIVE

2.3 Relationship between the motor applied voltage (V), frequency (f), and torque

Although the standard motor speed can be changed by changing only the frequency, setting the output frequency to 50 Hz or less with the constant voltage increases the motor magnetic flux. Increase of the (saturated) magnetic flux increases the current, causing the motor to overheat and then burn out. To prevent burnout, it is necessary to make the magnetic flux constant. Since the magnetic flux is proportional to the voltage and inversely proportional to the frequency, this problem can be resolved by applying a voltage to the motor so that this relationship is always satisfied. If the rotation speed is halved (60 Hz to 30 Hz), V/f is as follows:

$$\text{Magnetic flux} \propto \frac{\text{Voltage } V}{\text{Frequency } f} = \text{Constant}$$

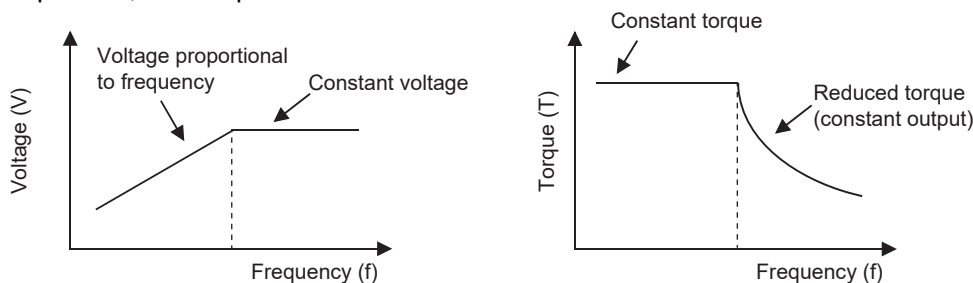
$$\frac{V}{f} = \frac{220 \text{ [V]}}{60 \text{ [Hz]}} = \frac{110 \text{ [V]}^*}{30 \text{ [Hz]}} = \text{Constant}$$

* Actually, set the voltage slightly larger considering the voltage drop compensation in the motor.

The relationship between the motor applied voltage (V), frequency (f), and torque is as follows:

$$\text{Torque } T = K \times \frac{V}{f} \times I \quad K: \text{Constant} \quad I: \text{Current}$$

The following diagrams show the relationship between the voltage or torque and the change of the frequency. The relationship between the output voltage and output frequency of the inverter, called "V/F pattern", is an important factor to control the motor.



2.3.1 Operation at frequencies exceeding 50 Hz or 60 Hz

The inverter output voltage cannot exceed the power supply voltage (twice or more of the power supply voltage for a single-phase 100 V power input model), therefore the output voltage is constant for frequency that exceeds 50 Hz or 60 Hz. (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. This area is called "constant output range".

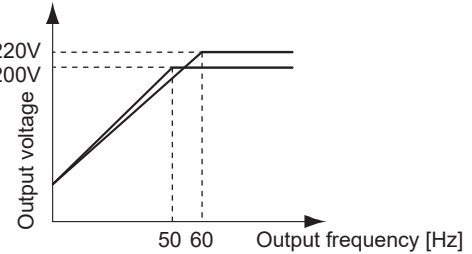
☒ Good to know for checking an inverter

Base frequency (G001 (Pr.3))

This frequency represents the frequency at the rated torque of the motor.

Since the standard motor is designed for use at either 50 Hz or 60 Hz, set the base frequency to either 50 Hz or 60 Hz.

It is recommended to set 60 Hz regardless of the power supply frequency.



V/F pattern and base frequency

2.4 Standard motor output characteristics in inverter operation

The following shows the output characteristics for the combination of the standard motor (4 poles) and an inverter of the same capacity.

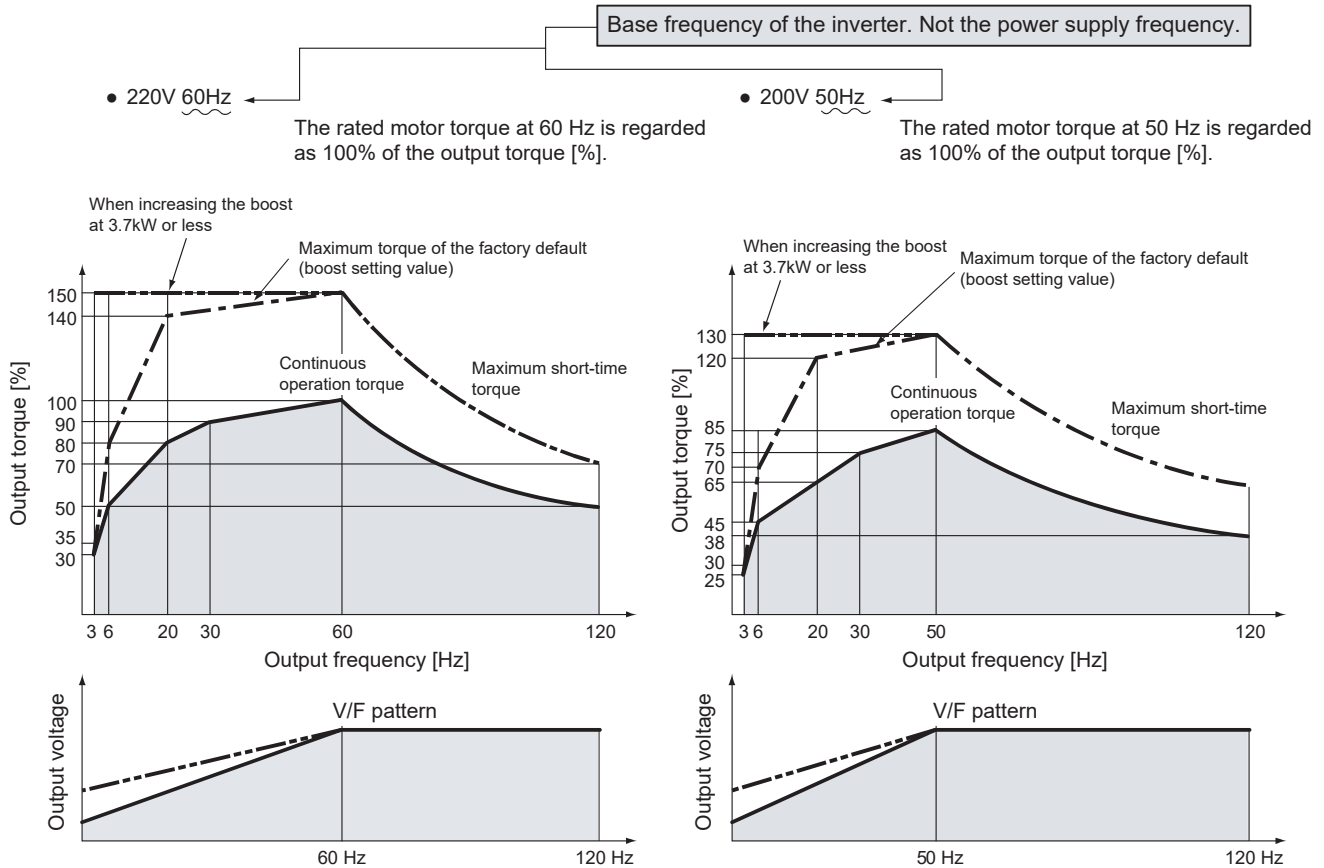


Fig. 2.5 Output characteristics of a standard motor (in V/F control)

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

- (2) The maximum short-time 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 maximum short-time 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.

Remark

- The above characteristics are those of a typical standard motor (standard efficiency).
- When using the Mitsubishi Electric constant-torque motor, set the constant-torque motor in C100 (Pr.71) Applied motor referring to the Instruction Manual. (Even if the motor is changed, the temperature characteristics will be that of the standard motor when the applied motor setting is not configured (initial value).)

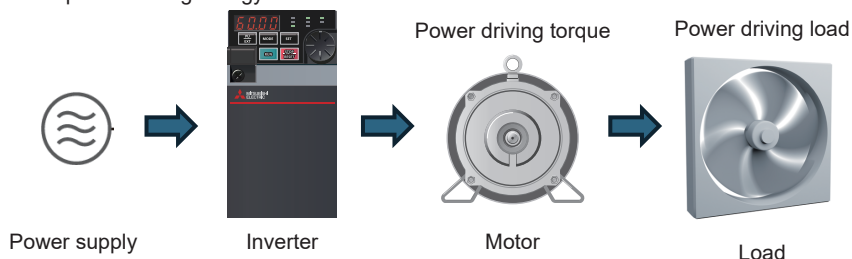
2 MOTOR CHARACTERISTICS AT INVERTER DRIVE

2.5 Power driving and regenerative driving

This section describes the power driving and regenerative driving operations of the motor.

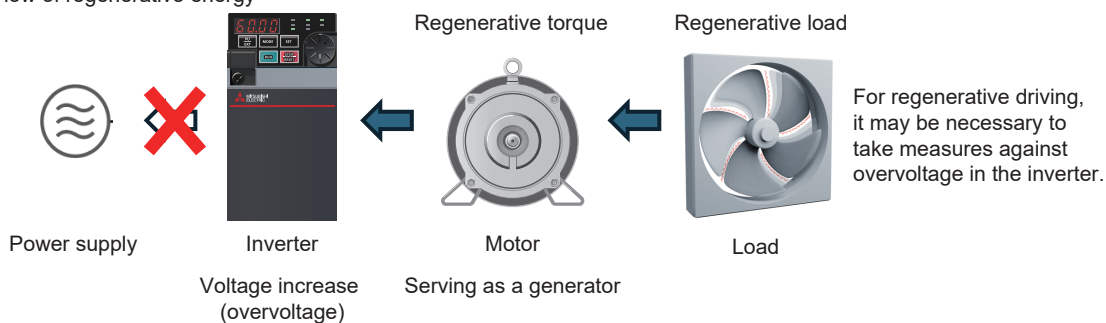
1) Power driving Energy flows from the inverter to the motor.

Flow of power driving energy



2) Regenerative driving Energy is returned from the motor to the inverter.

Flow of regenerative energy



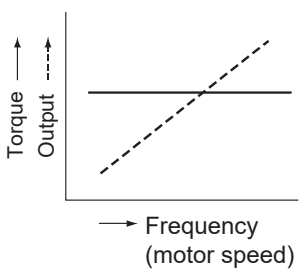
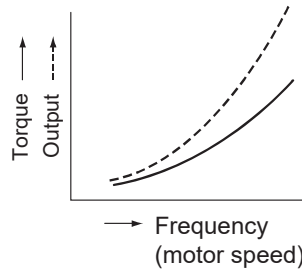
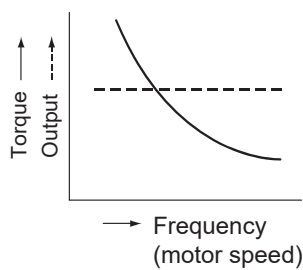
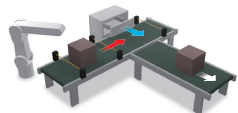
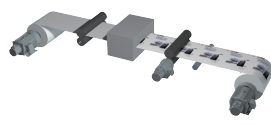
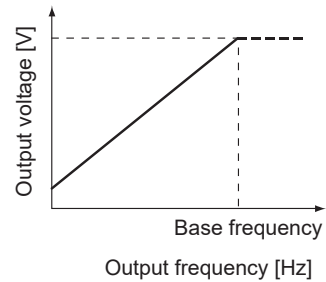
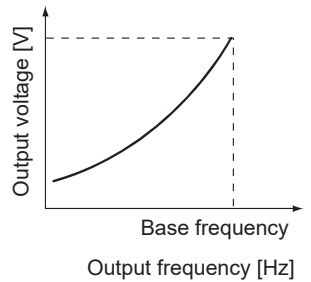
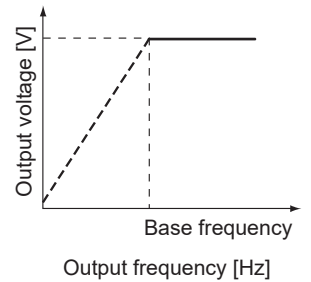
Remark

The direction of energy (current) is different between power driving and regenerative driving.

2 MOTOR CHARACTERISTICS AT INVERTER DRIVE

2.6 Load torque types and V/F patterns

For the inverter operation, the V/F pattern can be selected according to the load characteristics. The V/F pattern can be changed using the parameter (Pr.14 (G003)).

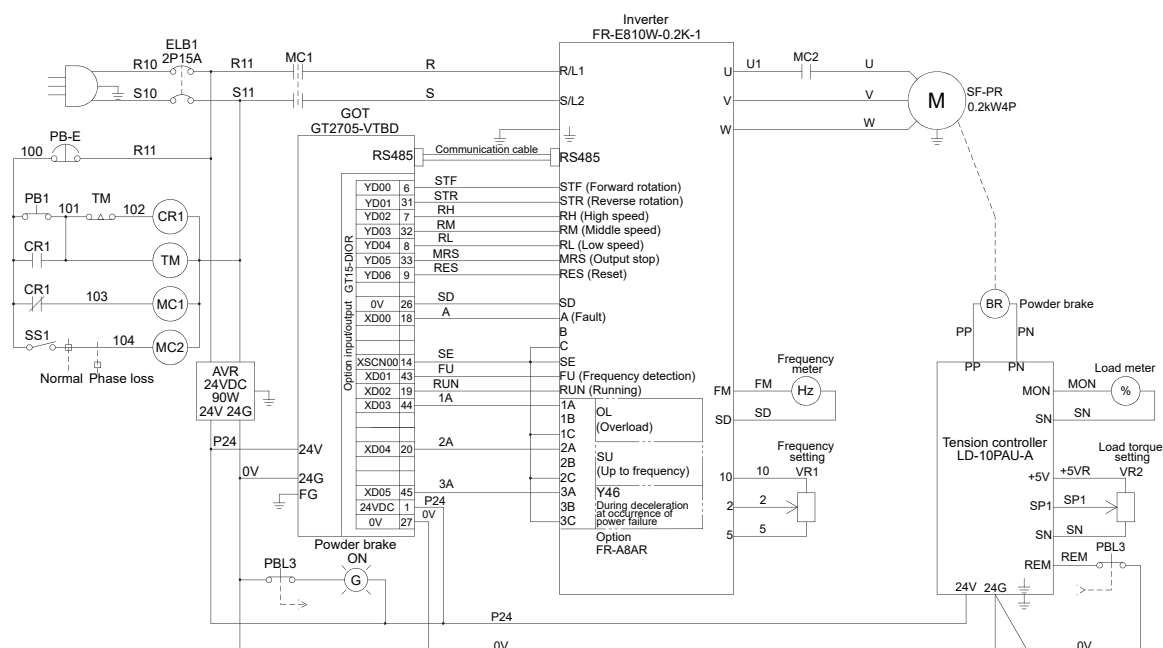
Load torque type			
	Constant-torque load	Variable-torque load	Constant-output load
Main applications	 Conveyor Cart Roll driving	 Fan Pump Blower	 Machine tool (main spindle drive) Winding machine (center drive)
Inverter output voltage	Constant-torque pattern 	Variable-torque pattern 	Constant-torque pattern 
	$T = \text{Constant}$: Constant torque load	$T/N^2 = \text{Constant}$: Square variable-torque load	$T \times N = \text{Constant}$: Constant output load

Load types and V/F patterns

2 MOTOR CHARACTERISTICS AT INVERTER DRIVE

2.7 Demonstration machine configuration

The following shows the configuration of the inverter demonstration machine used for training.



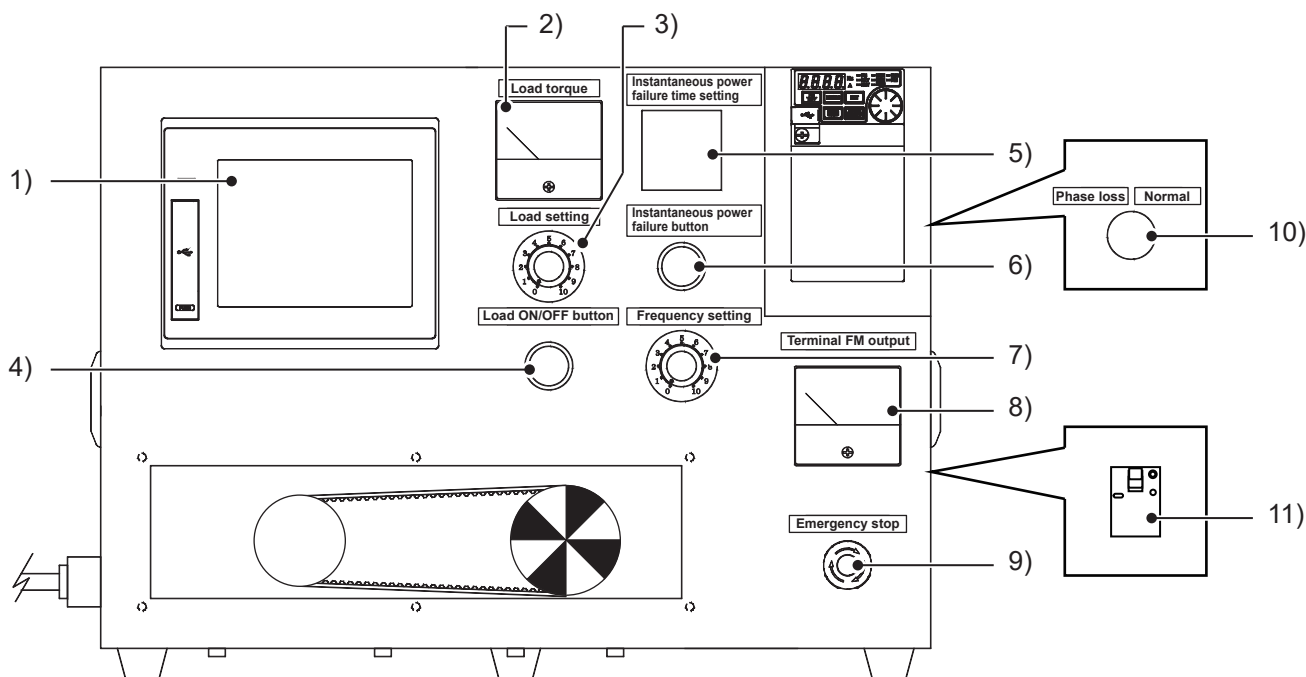
Remark

Magnetic contactor (MC): Switch for the motor. Used to start and stop the current flow.

Earth leakage circuit breaker (ELB): Circuit breaker to interrupt the current flow in an electrical circuit before an electric leakage accident occurs.

2 MOTOR CHARACTERISTICS AT INVERTER DRIVE

2.8 Appearance of demonstration machine



No.	Name	Description
1)	GOT	On the screen, you can operate the inverter.
2)	Load torque	Indicates the load torque applied to the motor.
3)	Load setting	Sets the load applied to the motor.
4)	Load ON/OFF button	Turns ON or OFF the load applied to the motor.
5)	Instantaneous power failure time setting	Sets the instantaneous power failure time of when the instantaneous power failure button is pressed.
6)	Instantaneous power failure button	Shuts OFF the power supply for the inverter.
7)	Frequency setting	Outputs the set frequency with analog voltage.
8)	Terminal FM output	Displays the output frequency (pulse output) from the inverter.
9)	Emergency stop	Shuts OFF the power in case of emergency.
10)	Phase loss generation switch	Used in the inverter trouble shooting course.
11)	Power switch	Turn ON the power of the demonstration machine.

2 MOTOR CHARACTERISTICS AT INVERTER DRIVE

2.9 Basic parameter settings

To configure the inverter settings, it is essential to understand the parameters.

To ensure smooth motor operation, the motor must start by rotating slowly.

Configuring the inverter parameters enables smooth motor rotation.

2.9.1 Parameters

Parameters are numerical values that determine the operation of the inverter. The type and number of parameters (referred to as "Pr.") vary depending on the inverter model. For basic variable-speed operation, the initial parameter values can be used as they are. Set the necessary parameters to meet the load and operational specifications. Parameter's setting, change and check can be made on the operation panel.

2.9.2 Typical parameters

The following table lists the commonly used parameters.

Pr.	Name	Minimum setting increments	Initial value	Setting range	Description
0 G000	Torque boost	0.1%	6% *1	0 to 30%	Set this parameter to obtain a higher starting torque under V/F control. Also set this when a loaded motor cannot be driven, the warning "OL" occurs, and the inverter output is shut off with the fault indication "E.OC1".
			5% *1		
			4% *1		
			3% *1		
			2% *1		
1 H400	Maximum frequency	0.01 Hz	120 Hz	0 to 120 Hz	Set the upper limit for the output frequency.
2 H401	Minimum frequency	0.01 Hz	0 Hz	0 to 120 Hz	Set the lower limit for the output frequency.
3 G001	Base frequency	0.01 Hz	60 Hz	0 to 590 Hz	Set this parameter when the rated motor frequency is 50 Hz. Check the rating plate of the motor.
4 D301	Multi-speed setting (high speed)	0.01 Hz	60 Hz	0 to 590 Hz	Pre-set the speeds that will be switched among by terminals.
5 D302	Multi-speed setting (middle speed)	0.01 Hz	30 Hz	0 to 590 Hz	
6 D303	Multi-speed setting (low speed)	0.01 Hz	10 Hz	0 to 590 Hz	
7 F010	Acceleration time	0.1 s	5 s *2	0 to 3600 s	Set the acceleration time.
			10 s *2		
			15 s *2		
8 F011	Deceleration time	0.1 s	5 s *2	0 to 3600 s	Set the deceleration time.
			10 s *2		
			15 s *2		
9 H000, C103	Electronic thermal O/L relay	0.01 A	Inverter rated current *3	0 to 500 A	Protects the motor from heat. Set the rated motor current.
79 D000	Operation mode selection	1	0	0	External/PU switchover mode
				1	Fixed to PU operation mode
				2	Fixed to External operation mode
				3	External/PU combined operation mode 1 (Start command from External, frequency command from PU)
				4	External/PU combined operation mode 2 (Frequency command from External, start command from PU)
				6	Switchover mode
				7	External operation mode (PU operation interlock)

Pr.	Name	Minimum setting increments	Initial value	Setting range	Description
Pr.CL	Parameter clear	1	0	(0), 1	0: Initial display (Parameters are not cleared.) 1: The settings of parameters except for calibration parameters and terminal function selection parameters are initialized.
ALLC	All parameter clear	1	0	(0), 1	0: Initial display (Parameters are not cleared.) 1: The settings of all the parameters, including calibration parameters and terminal function selection parameters, are initialized.

*1 Differs depending on the capacity.

6%: FR-E820-0050(0.75K) or lower, FR-E840-0026(0.75K) or lower, FR-E820S-0050(0.75K) or lower, FR-E810W-0050(0.75K) or lower, FR-E846-0026(0.75K)

5%: FR-E860-0017(0.75K)

4%: FR-E820-0080(1.5K) to FR-E820-0175(3.7K), FR-E840-0040(1.5K) to FR-E840-0095(3.7K), FR-E820S-0080(1.5K) or higher, FR-E846-0040(1.5K) or higher

3%: FR-E820-0240(5.5K), FR-E820-0330(7.5K), FR-E840-0120(5.5K), FR-E840-0170(7.5K), FR-E860-0027(1.5K), FR-E860-0040(2.2K)

2%: FR-E820-0470(11K) or higher, FR-E840-0230(11K) or higher, FR-E860-0061(3.7K) or higher

*2 Differs depending on the capacity.

5 s: FR-E820-0175(3.7K) or lower, FR-E840-0095(3.7K) or lower, FR-E860-0061(3.7K) or lower, FR-E820S-0110(2.2K) or lower, FR-E810W-0050(0.75K) or lower, FR-E846-0095(3.7K) or lower

10 s: FR-E820-0240(5.5K), FR-E820-0330(7.5K), FR-E840-0120(5.5K), FR-E840-0170(7.5K), FR-E860-0090(5.5K) or higher

15 s: FR-E820-0470(11K) or higher, FR-E840-0230(11K) or higher

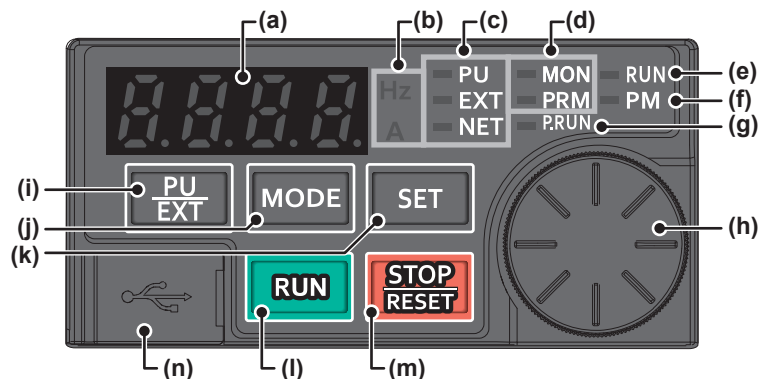
*3 The initial value for the FR-E820-0050(0.75K) or lower, FR-E840-0026(0.75K) or lower, FR-E860-0017(0.75K), FR-E820S-0050(0.75K) or lower, FR-E810W-0050(0.75K) or lower is set to the 85% of the inverter rated current.

POINT

The initial parameter values are preset and can be used as they are to start operation. It is also possible to set parameters according to the applicable motor or equipment environment.

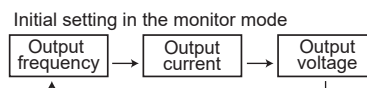
2 MOTOR CHARACTERISTICS AT INVERTER DRIVE

2.10 Operation panel



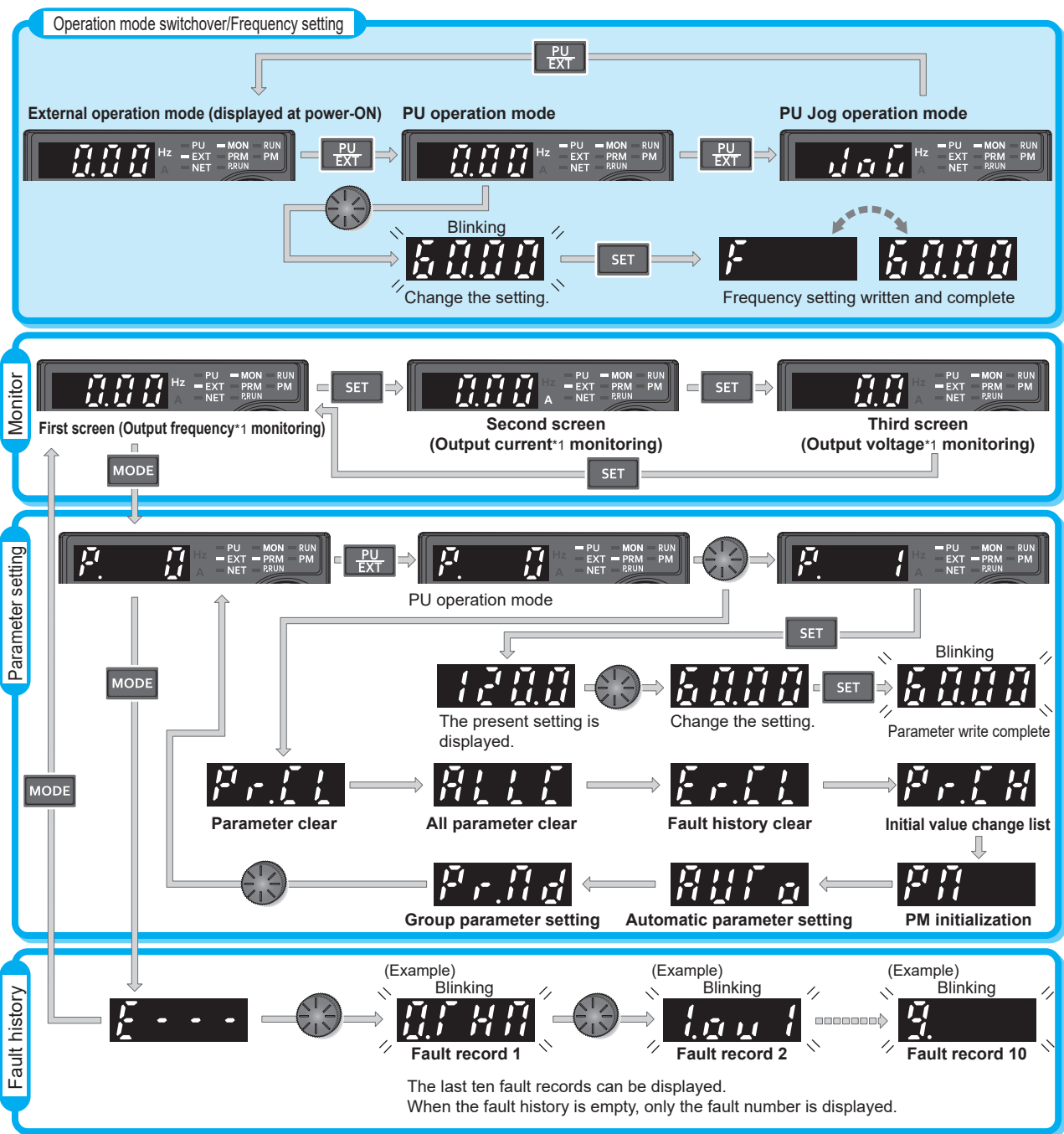
No.	Appearance	Name	Description
(a)		Monitor (4-digit LED)	Shows the frequency, parameter number, etc. (The monitor item can be changed according to the settings of M100 (Pr.52), M101 (Pr.774) to M103 (Pr.776).)
(b)		Unit indication	Hz: ON when the actual frequency is monitored. (Blinks when the set frequency is monitored.)
			A: ON when the current is monitored. (Both "Hz" and "A" are OFF to indicate a value other than the frequency or the current.)
(c)		Operation mode indicator	PU: ON when the inverter is in the PU operation mode. EXT: ON when the inverter is in the External operation mode. (ON when the inverter in the initial setting is powered ON.)
			NET: ON when the inverter is in the Network operation mode. PU and EXT: ON when the inverter is in the External/PU combined operation mode 1 or 2.
(d)		Operation panel mode LED indicator	MON: ON or blinks only when the first, second, or third monitor is displayed.
			PRM: ON when the operation panel is in the parameter setting mode. The indicator blinks when the inverter is in the easy setting mode.
(e)		Operating status indicator	ON or blinks during inverter running. ON: During forward rotation operation.
			Blinks slowly (1.4-second cycle): During reverse rotation operation. Blinks quickly (0.2-second cycle): Operation is disabled although the start command is given. *1
(f)		Control motor indicator	ON when the PM sensorless vector control is selected.
			The indicator blinks during test operation. The indicator is OFF when the inverter controls the induction motor.
(g)		PLC function indicator	ON when the PLC function is valid. (The indicator blinks when a fault occurs while the PLC function is valid.)
			The setting dial of the Mitsubishi Electric inverters. Used to change the setting of frequency or parameter. Press the setting dial to perform the following operations: • To display a set frequency in the monitor mode (the setting can be changed using M104 (Pr.992)) • To display the present setting during calibration

No.	Appearance	Name	Description
(i)		PU/EXT key	Switches between the PU operation mode, the PUJOG operation mode, and the External operation mode. The easy setting of the inverter operation mode is enabled by pressing this key simultaneously with the MODE key. Also cancels the PU stop warning.
(j)		MODE key	Switches the operation panel to a different mode. The easy setting of the inverter operation mode is enabled by pressing this key simultaneously with the PU/EXT key. Every key on the operation panel becomes inoperable by holding this key for two seconds. The key lock function is disabled when E200 (Pr.161) = "0 (initial setting)".
(k)		SET key	Confirms each selection. When this key is pressed during operation, the monitor item changes. (The monitor item can be changed according to the settings of M100 (Pr.52), M101 (Pr.774) to M103 (Pr.776).)
(l)		RUN key	Start command The direction of motor rotation depends on the E202 (Pr.40) setting.
(m)		STOP/RESET key	Stops the operation commands. Used to reset the inverter when the protective function is activated.
(n)		USB connector	FR Configurator2 is available by USB connection.



*1 Situations such as when the MRS/X10 signal is input, during the automatic restart after instantaneous power failure, after auto tuning is complete, when "SE" (incorrect parameter setting) alarm occurs.

2 MOTOR CHARACTERISTICS AT INVERTER DRIVE



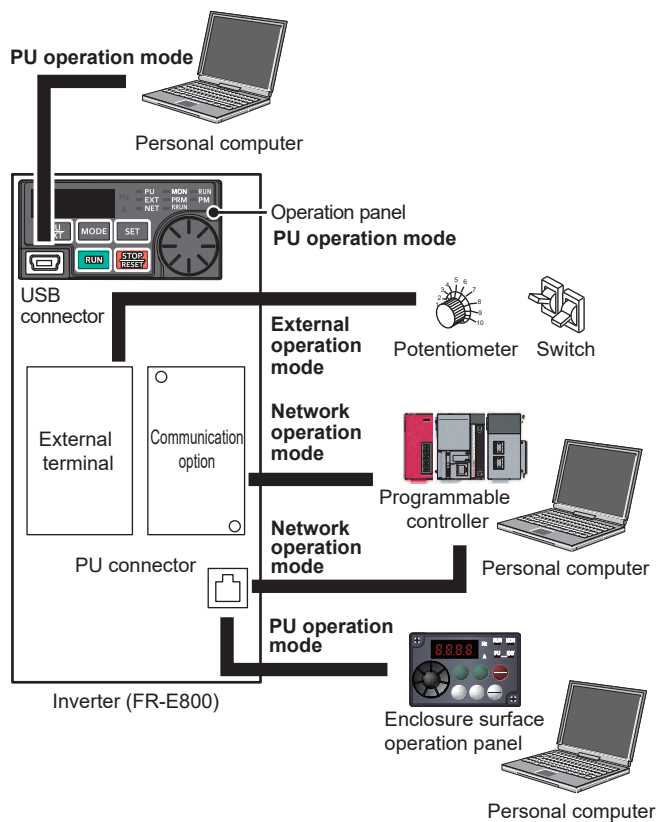
*1 The monitor item can be changed.

2 MOTOR CHARACTERISTICS AT INVERTER DRIVE

2.11 Operation mode

The inverter can be operated with various signals.

The operation mode specifies the source of the start command and the frequency command for the inverter.



2 MOTOR CHARACTERISTICS AT INVERTER DRIVE

2.12 Types of operation methods

This chapter explains the operations (start, stop, and speed variation) that can be operated with the inverter.

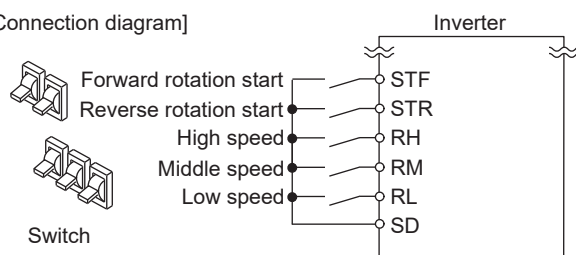
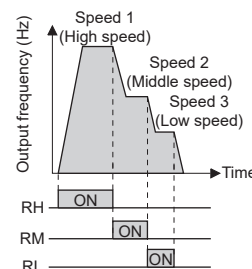
2.12.1 External operation mode (D000 (Pr.79) = "0 (initial value) or 2")

Operate the inverter with a frequency setting potentiometer or start switch connected to the control circuit terminals of the inverter.

(In this demonstration machine, the start switch is operated on the GOT screen.)

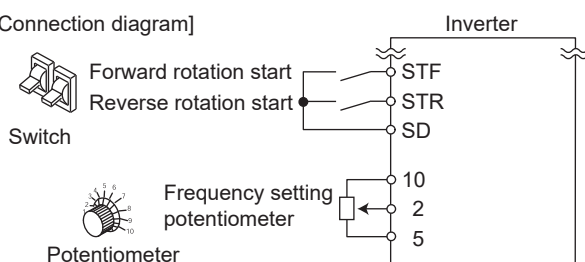
- Setting the frequency and giving a start command with switches (multi-speed setting)

[Connection diagram]



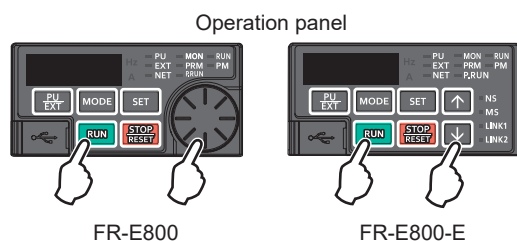
- Setting the frequency using an analog signal (voltage input)

[Connection diagram]



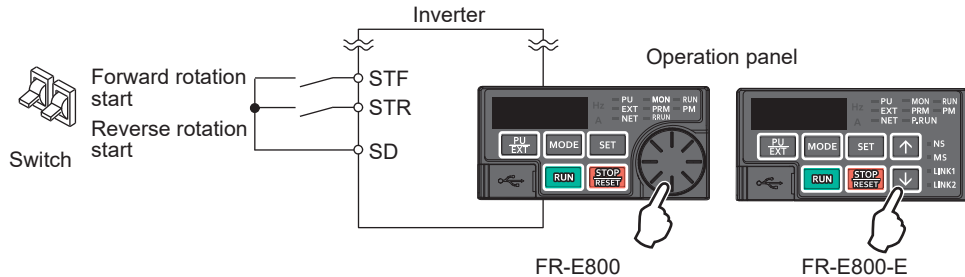
2.12.2 PU operation mode (D000 (Pr.79) = "0 (initial value) or 1")

Select the PU operation mode when giving start and frequency commands by only the key operation of the operation panel or the parameter unit.



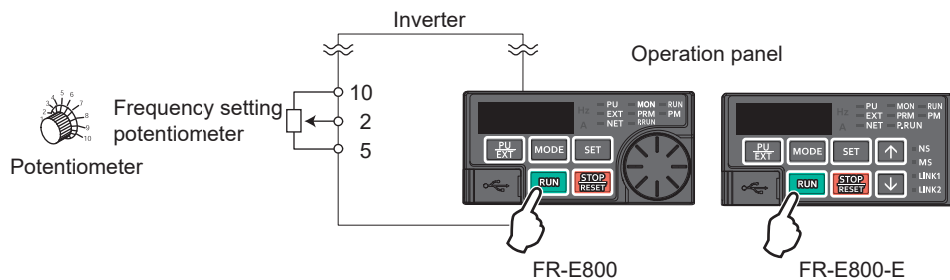
2.12.3 PU/External combined operation mode 1 (D000 (Pr.79) = "3")

Select the PU/External combined operation mode 1 when giving a frequency command from the operation panel or the parameter unit and giving a start command with the external start switches. (In this demonstration machine, the start switch is operated on the GOT screen.)



2.12.4 PU/External combined operation mode 2 (D000 (Pr.79) = "4")

Select the PU/External combined operation mode 2 when giving a frequency command from the external potentiometer or using multi-speed and other signals, and giving a start command by key operation of the operation panel or the parameter unit.



2.13 Parameter clear / All parameter clear

Set "1" in Pr.CL Parameter clear or ALLC All parameter clear to initialize the parameter. (The parameter cannot be cleared when E400 (Pr.77) Parameter write selection = "1".)

[Operating procedure]

1. Selecting the parameter setting mode
Press the MODE key to choose the parameter setting mode.
2. Selecting the parameter
Turn the setting dial until "Pr.CL" appears for Parameter clear or "ALLC" for All parameter clear, and press the SET key. "0 (initial value)" appears.
3. Parameter clear
Turn the setting dial to change the value to "1". Press the SET key to confirm the setting. "1" and "Pr.CL" ("ALLC") are displayed alternately after parameters are cleared.
 - Turn the setting dial to read another parameter.
 - Press the SET key to show the setting again.
 - Press the SET key twice to show the next parameter.

Setting	Description	
	Pr.CL Parameter clear	ALLC All parameter clear
0	Initial display (Parameters are not cleared.)	
1	The settings of parameters except for calibration parameters and terminal function selection parameters are initialized.	The settings of all the parameters, including calibration parameters and terminal function selection parameters, are initialized.

4. Turn OFF then ON the power of the demonstration machine for the option settings.

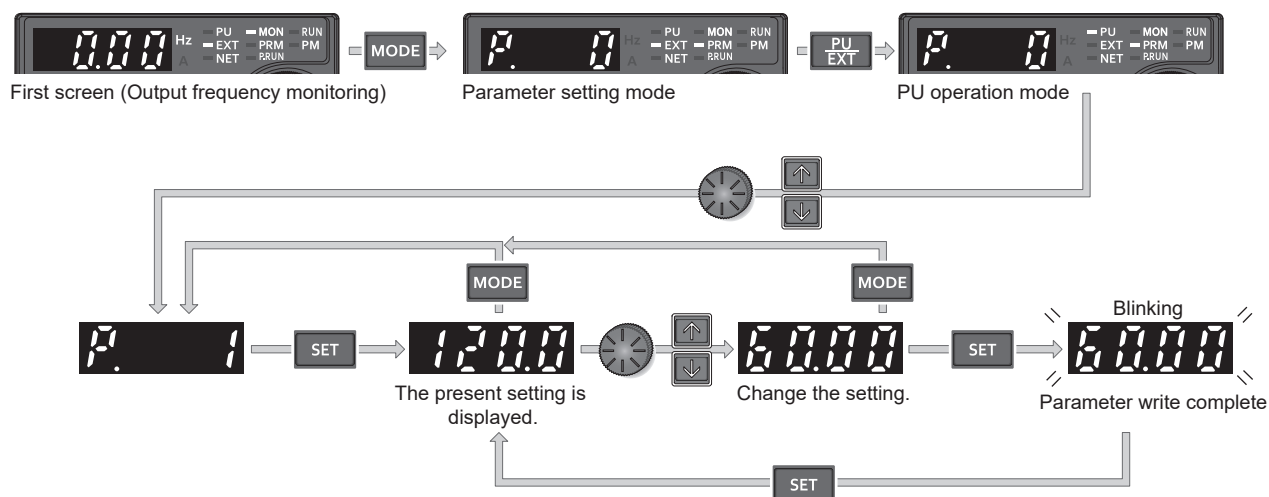
Remark

- "1" and "Er4" are displayed alternately when the operation mode is other than the PU operation mode.
- Stop the inverter first. Writing error occurs if Parameter clear is attempted while the inverter is running.
- To clear the parameter, the inverter must be in the PU operation mode even if "2" is set in E400 (Pr.77).

2 MOTOR CHARACTERISTICS AT INVERTER DRIVE

2.14 Parameter setting procedure (parameter display in numerical order)

This section explains how to change the setting value of H400 (Pr.1) Maximum frequency from 120 Hz to 60 Hz.



Set the following initial values for the demonstration machine.

- 1) Maximum frequency (H400 (Pr.1)) = 60 Hz
- 2) Electronic thermal O/L relay (H000 (Pr.9)) = 1.16 A
- 3) Terminal 2 frequency setting gain frequency (T022 (Pr.125)) = 60 Hz (The setting needs not be changed as 60 Hz is initially set.)
- 4) Base frequency voltage (G002 (Pr.19)) = 200 V

Remark

- If a parameter write condition is not satisfied, a parameter write error appears.

Error indication	Description
E r 1	Parameter write error
E r 2	Write error during operation
E r 3	Calibration error
E r 4	Mode designation error

- When E400 (Pr.77) Parameter write selection = "0 (initial setting)", the parameter setting change is only available while the inverter is stopped and under the PU operation mode. To enable the parameter setting change while the inverter is running or under the operation mode other than PU operation mode, change the E400 (Pr.77) setting.

2.15 Parameter display by function group

Parameter numbers can be displayed by function group.
Since the parameter numbers are grouped by function, related parameters can be set easily.

(1) Changing to parameter numbers grouped by function

Pr.MD setting	Description
0	Default parameter display
1	Parameter display in numerical order
2	Parameter display by function group

[Operating procedure]

1. Selecting the parameter
Turn the setting dial until "Pr.MD" (Group parameter setting) appears. Press the SET key to confirm the selection. "0 (initial value)" will appear.
2. Changing to the group parameter display
Turn the setting dial to change the value to "2" (group parameter display). Press the SET key to confirm the Group parameter setting. "2" blinks after the setting is completed.

(2) Changing the parameter setting value with group parameter display

The following explains how to change the setting value of H400 (Pr.1) Maximum frequency from 120 Hz to 60 Hz.

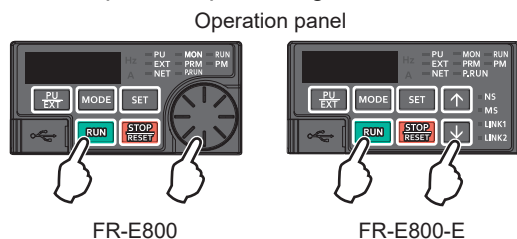
[Operating procedure]

1. Enabling the function group selection
Turn the setting dial until "H4.." (Protective function parameter 4) appears. Press the SET key to confirm the selection. "H4--" will appear, which shows that the operation panel is ready for selection of a number in the group of monitor parameter 4.
2. Selecting the parameter
Turn the setting dial until "H400" (P.H400 Maximum frequency) appears. Press the SET key to display the present set value. "120.0 (initial value)" appears.
3. Changing the setting value
Turn the setting dial to change the value to "60.00". Press the SET key to confirm the setting. "60.00" blinks after the setting is completed.

2 MOTOR CHARACTERISTICS AT INVERTER DRIVE

2.16 Operation using the operation panel

Use the operation panel to give a start command and a frequency command. (PU operation)



The following shows the procedure to operate at 30 Hz.

[Operating procedure]

- 1.** Turning ON the power of the inverter
The operation panel is in the monitor mode.
- 2.** Changing the operation mode
Press the PU/EXT key to choose the PU operation mode. The PU LED turns ON.
- 3.** Setting the frequency
Turn the setting dial until the target frequency "30.00" (30.00 Hz) appears. The indication blinks for about 5 seconds.
While the value is blinking, press the SET key to enter the frequency. "F" and "30.00" are displayed alternately. After about 3 seconds of alternate display, the indication returns to "0.00" (the indication of a monitored value). (If the SET key is not pressed, the indication of the value returns to "0.00" (0.00 Hz) after about 5 seconds of blinking. In that case, turn the setting dial and set the frequency again.)
- 4.** Start → acceleration → constant speed
Press the RUN key to start running. The frequency value on the monitor increases according to the setting of F010 (Pr.7) Acceleration time, and "30.00" (30.00 Hz) appears on the monitor. (To change the set frequency, perform the operation in above step 3. The previously set frequency appears.)
- 5.** Deceleration → stop
Press the STOP/RESET key to stop.

Remark

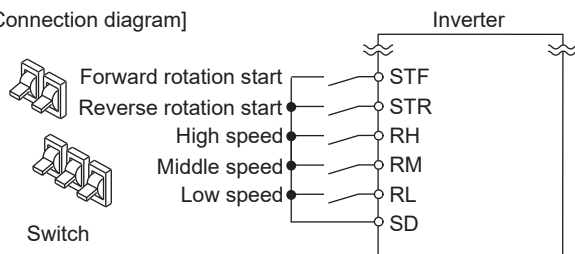
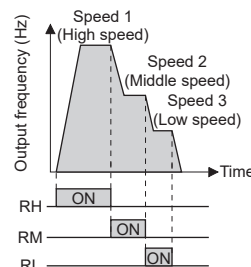
- To display the set frequency in the standard model, press the setting dial while the inverter runs in the PU operation mode or in the External/PU combined operation mode 1 (D000 (Pr.79) = "3").
- The frequency can be set without pressing the SET key when E200 (Pr.161) Frequency setting/key lock operation selection = "1 or 11".
- For operation with the operator panel, the motor rotation direction can be changed with E202 (Pr.40) RUN key rotation direction selection. (Initial value: "0" (forward))

2.17 Operation using external switches (External operation)

Turn ON the STF/STR signal to give a start command. (In this demonstration machine, the start switch is operated on the GOT screen.)

Turn ON the RH, RM, or RL signal to give a frequency command (multi-speed setting).

[Connection diagram]



The following shows the procedure to operate at a low speed (10 Hz).

[Operating procedure]

1. Turning ON the power of the inverter
The operation panel is in the monitor mode.
2. Changing the operation mode
Press the PU/EXT key to choose the External (EXT) operation mode. The EXT LED turns ON.
3. Setting the frequency
Turn ON the low-speed switch (RL signal).
4. Start → acceleration → constant speed
Turn ON the start switch (STF/STR signal). "10.00" (10.00 Hz) appears.
5. Deceleration → stop
Turn OFF the start switch (STF/STR signal).
Turn OFF the low-speed switch (RL).

Remark

- When both the forward rotation start switch (STF signal) and the reverse rotation start switch (STR signal) are turned ON, the motor cannot be started. If both are turned ON while the inverter is running, the inverter decelerates the motor to a stop.
- The initial value is 60 Hz for terminal RH in Group 1 (50 Hz in Group 2), 30 Hz for terminal RM, and 10 Hz for terminal RL. (To change the settings, use D301 (Pr.4), D302 (Pr.5), and D303 (Pr.6).)
- In the initial setting, if two or more speed switches (signals) are simultaneously turned ON, priority is given to the switch (signal) for the lower speed. For example, when both RH and RM signals turn ON, the RM signal (D302 (Pr.5)) has the higher priority.
- Up to 15-speed switching operation can be performed.
- Up to two external input terminals are available for the Ethernet model and the IP67 model. Use T700 (Pr.178) STF/DI0 terminal function selection and T701 (Pr.179) STR/DI1 terminal function selection to assign the functions to terminals DI0 and DI1.

2.18 Monitoring the status of the inverter

(1) Monitoring of output current and output voltage

Press the SET key on the operation panel in the monitor mode to switch the monitor item between output frequency, output current, and output voltage.

[Operating procedure]

- 1.** Press the MODE key during operation to monitor the output frequency. The [Hz] LED turns ON.
- 2.** Press the SET key to monitor the output current. This operation is valid during running or stopping under any operation mode. The [A] LED turns ON.
- 3.** Press the SET key to monitor the output voltage. Unit LEDs are both OFF.

(2) First priority monitor screen

The first priority monitor screen, which is displayed first when the operation panel switches to the monitor mode, is selectable.

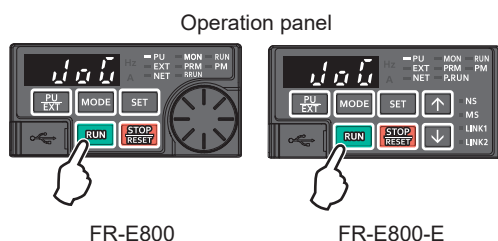
To set it, press the SET key for a while when the desired monitor item is displayed on a monitor screen. The following show the procedure to set the monitor screen displaying the output current as the first priority monitor screen.

[Operating procedure]

- 1.** Change the mode of the operation panel to the monitor mode, and switch the monitor screen to the one on which the output current can be monitored.
- 2.** Press the SET key for a while (1 second). The output current monitor screen is set as the first priority monitor screen.
- 3.** When the operation panel is in the monitor mode next time, the output current monitored value is displayed first.

2.19 Giving a start command from the operation panel for JOG operation

JOG operation is performed while the RUN key on the operation panel is pressed.



The following shows the procedure to operate at 5 Hz.

[Operating procedure]

1. Changing the operation mode
Press the PU/EXT key twice to choose the PUJOG operation mode. The display shows "JOG", and the PU LED is ON.
2. Start → acceleration → constant speed
Hold down the RUN key. The frequency value on the monitor increases according to the setting of F002 (Pr.16) Jog acceleration/deceleration time, and "5.00" (5.00 Hz) appears on the monitor.
3. Deceleration → stop
Release the RUN key. The frequency value on the monitor decreases according to the setting of F002 (Pr.16) Jog acceleration/deceleration time, "0.00" (0.00 Hz) appears on the monitor, and the motor stops rotating.

Remark

- To change the frequency, change the setting of D200 (Pr.15) Jog frequency (initial value: 5 Hz).
- To change the acceleration/deceleration time, change the setting of F002 (Pr.16) Jog acceleration/deceleration time (initial value: 0.5 second).
- The PU JOG operation is not available for the IP67 model as neither the operation panel keys or the parameter unit can be used.

2.20 Operation mode selection

Select the operation mode of the inverter.

The mode can be changed among operation using external signals (External operation), operation by the operation panel or parameter unit (PU operation), combined operation of PU operation and External operation (External/PU combined operation), and Network operation (via RS-485 communication or Ethernet communication, or when a communication option is used).

Pr.	Name	Initial value	Setting range	Description
79 D000	Operation mode selection	0	0 to 4, 6, 7	Selects the operation mode.

The following table lists valid and invalid commands in each operation mode.

D000 (Pr.79) setting	Description			LED indicator ■: OFF ■: ON
0 (initial value)	External/PU switchover mode. The inverter operation mode can be selected by pressing the PU/EXT key. At power ON, the inverter is in the External operation mode.			PU operation mode  External operation mode  NET operation mode 
1	Operation mode	Frequency command	Start command	PU operation mode 
	Fixed to PU operation mode.	Sent from the operation panel or parameter unit.	Input using the RUN key on the operation panel or the FWD/REV key on the parameter unit	
2	Fixed to External operation mode. However, the inverter operation mode can also be changed to the Network operation mode.	Sent using external signals (input via terminal 2 or 4, using the JOG signal, using the multi-speed setting function, etc.).	Sent using external signals (via terminal STF or STR).	External operation mode  NET operation mode 
3	External/PU combined operation mode 1	Sent from the operation panel or parameter unit, or sent using external signals (input using the multi-speed setting function or via terminal 4).*1	Sent using external signals (via terminal STF or STR).	External/PU combined operation mode 
4	External/PU combined operation mode 2	Sent using external signals (input via terminal 2 or 4, using the JOG signal, using the multi-speed setting function, etc.).	Input using the RUN key on the operation panel or the FWD/REV key on the parameter unit	

D000 (Pr.79) setting	Description	LED indicator ■: OFF ■: ON
6	Switchover mode. Switching of PU, External, and NET operation modes can be performed during operation.	PU operation mode ■ PU ■ EXT ■ NET
7	External operation mode (PU operation interlock). X12 signal ON: Switchover to PU operation mode enabled (signal is OFF during External operation). X12 signal OFF: Switchover to PU operation mode disabled.	External operation mode ■ PU ■ EXT ■ NET NET operation mode ■ PU ■ EXT ■ NET

*1 The following is the frequency commands listed in descending order of priority when "3" is set in D000 (Pr.79): Multi-speed setting function (RL/RM/RH/REX signal) > PID control (X14 signal) > terminal 4 analog input (AU signal) > set frequency (digital input from the PU).

2.21 Operation of the inverter (principles)

An inverter is a device that can change the rotation speed of a standard motor freely. Inside the inverter, the circuit converts AC voltage to DC voltage and then generates AC at the required frequency for output to the motor. (Details are described in Chapter 3.)

During power driving described in 2.5, the DC voltage produced by the AC power supply is converted to AC voltage at the required frequency and supplied to the motor. During regenerative driving, the energy generated by the motor as AC voltage is converted to DC voltage for reuse.

(1) Checking the behavior of inverter DC voltage (V/F control)

Find out how the DC voltage in the inverter changes in the following conditions. Read the DC voltage on the monitor.

Operating status	DC voltage (V)	Reference value (three-phase 200 V class)
1) When the inverter is stopped		313 V
2) During operation at 60 Hz (without load)		303 V
3) During operation at 60 Hz (with 100% load)		290 V

[Operating procedure]

1. Changing the operation mode
Press the PU/EXT key to choose the PU operation mode. The PU LED turns ON.
2. Selecting the parameter setting mode
Press the MODE key to choose the parameter setting mode. (The parameter number read previously appears.)
3. Enabling the function group selection
Turn the setting dial until "M1.." (group 1: item and output signal for monitoring) appears. Press the SET key to confirm the selection. "M1--" will appear, which shows that the operation panel is ready for selection of a number in group 1 for item and output signal for monitoring.
4. Selecting the parameter
Turn the setting dial until "M100" (M100 (Pr.52) Operation panel main monitor selection) appears. Press the SET key to display the present set value. "0 (initial value)" appears.
5. Changing the setting value
Turn the setting dial to change the value to "8". Press the SET key to confirm the setting. "8" blinks after the setting is completed.

(2) Checking the regenerative voltage during regenerative driving

Check the magnitude of the DC voltage when the deceleration time (F011 (Pr.8)) is set to 0.3 second and the motor is decelerated from 60 Hz to a stop. (Display the peak of DC voltage on the monitor.)

Set M100 (Pr.52) Operation panel main monitor selection to "12".

For how to change the parameter setting, refer to (1).

	DC voltage (V)
1) Without load	
2) With 100% load	

Restore the settings of the deceleration time and operation panel main monitor selection.

2.22 Frequently-used parameters (simple mode parameters)

Parameters that are frequently used for the FR-E800 series are grouped as simple mode parameters.

When E440 (Pr.160) User group read selection = "9999", only the simple mode parameters are displayed on the operation panel.

(1) Simple mode parameter list

For simple variable-speed operation of the inverter, the initial values of the parameters may be used as they are. Set the necessary parameters to meet the load and operational specifications. Parameter's setting, change and check can be made on the operation panel.

Pr.	Pr. group	Name	Increment	Initial value *1		Range	Application
				Gr.1	Gr.2		
0	G000	Torque boost	0.1%	6% *2		0 to 30%	Set this parameter to obtain a higher starting torque under V/F control. Also set this when a loaded motor cannot be driven, the warning "OL" occurs, and the inverter output is shut off with the fault indication "E.OC1".
				5% *2			
				4% *2			
				3% *2			
				2% *2			
1	H400	Maximum frequency	0.01 Hz	120 Hz		0 to 120 Hz	Set the upper limit for the output frequency.
2	H401	Minimum frequency	0.01 Hz	0 Hz		0 to 120 Hz	Set the lower limit for the output frequency.
3	G001	Base frequency	0.01 Hz	60 Hz	50 Hz	0 to 590 Hz	Set this parameter when the rated motor frequency is 50 Hz. Check the rating plate of the motor.
4	D301	Multi-speed setting (high speed)	0.01 Hz	60 Hz	50 Hz	0 to 590 Hz	Pre-set the speeds that will be switched among by terminals.
5	D302	Multi-speed setting (middle speed)	0.01 Hz	30 Hz		0 to 590 Hz	
6	D303	Multi-speed setting (low speed)	0.01 Hz	10 Hz		0 to 590 Hz	
7	F010	Acceleration time	0.1 s	5 s *3		0 to 3600 s	Set the acceleration time.
				10 s *3			
				15 s *3			
8	F011	Deceleration time	0.1 s	5 s *3		0 to 3600 s	Set the deceleration time.
				10 s *3			
				15 s *3			
9	H000 C103	Electronic thermal O/L relay	0.01 A	Inverter rated current *4		0 to 500 A	Protects the motor from heat. Set the rated motor current.
79	D000	Operation mode selection	1	0		0 to 4, 6, 7	Select the start and frequency command sources.
125	T022	Terminal 2 frequency setting gain frequency	0.01 Hz	60 Hz	50 Hz	0 to 590 Hz	Change the frequency at the maximum potentiometer setting (5 V in the initial setting).
126	T042	Terminal 4 frequency setting gain frequency	0.01 Hz	60 Hz	50 Hz	0 to 590 Hz	Change the frequency at the maximum current input (20 mA in the initial setting).

2 MOTOR CHARACTERISTICS AT INVERTER DRIVE

Pr.	Pr. group	Name	Increment	Initial value *1		Range	Application
				Gr.1	Gr.2		
160	E440	User group read selection	1	0		0, 1, 9999	This function restricts the parameters that are read by the operation panel and parameter unit.
998	E430	PM parameter initialization	1	0		0, 3024, 3044, 3124, 3144, 8009, 8109, 9009, 9109	Select the PM sensorless vector control and set the parameters that are required to drive a PM motor.
999	E431	Automatic parameter setting	1	9999		10, 12, 20, 21, 9999	Changes parameter settings as a batch. The target parameters include communication parameters for the Mitsubishi Electric human machine interface (GOT) connection and the parameters for the rated frequency settings of 50/60 Hz.

*1 Gr.1 and Gr.2 are the parameter initial value groups.

*2 Differs depending on the capacity.

6%: FR-E820-0050(0.75K) or lower, FR-E840-0026(0.75K) or lower, FR-E820S-0050(0.75K) or lower, FR-E810W-0050(0.75K) or lower, FR-E846-0026(0.75K)

5%: FR-E860-0017(0.75K)

4%: FR-E820-0080(1.5K) to FR-E820-0175(3.7K), FR-E840-0040(1.5K) to FR-E840-0095(3.7K), FR-E820S-0080(1.5K) or higher, FR-E846-0040(1.5K) or higher

3%: FR-E820-0240(5.5K), FR-E820-0330(7.5K), FR-E840-0120(5.5K), FR-E840-0170(7.5K), FR-E860-0027(1.5K), FR-E860-0040(2.2K)

2%: FR-E820-0470(11K) or higher, FR-E840-0230(11K) or higher, FR-E860-0061(3.7K) or higher

*3 Differs depending on the capacity.

5 s: FR-E820-0175(3.7K) or lower, FR-E840-0095(3.7K) or lower, FR-E860-0061(3.7K) or lower, FR-E820S-0110(2.2K) or lower, FR-E810W-0050(0.75K) or lower, FR-E846-0095(3.7K) or lower

10 s: FR-E820-0240(5.5K), FR-E820-0330(7.5K), FR-E840-0120(5.5K), FR-E840-0170(7.5K), FR-E860-0090(5.5K) or higher

15 s: FR-E820-0470(11K) or higher, FR-E840-0230(11K) or higher

*4 The initial value for the FR-E820-0050(0.75K) or lower, FR-E840-0026(0.75K) or lower, FR-E860-0017(0.75K), FR-E820S-0050(0.75K) or lower, FR-E810W-0050(0.75K) or lower is set to the 85% of the inverter rated current.

Remark

Basic tasks before starting up an inverter

- Clear all parameters (to use an inverter that has previously been used).
For the method, refer to 2.13.

- Set the basic parameters.

Examples:

1) Maximum frequency (H400 (Pr.1)) = 60 Hz

2) Electronic thermal O/L relay (H000 (Pr.9)) = 1.16 A

3) Terminal 2 frequency setting gain frequency (T022 (Pr.125)) = 60 Hz
(Since the initial value is 60 Hz, no setting change is required.)

For the parameter setting method, refer to 2.14.

- Check the motor rotation direction with JOG operation.

1) Changing the operation mode

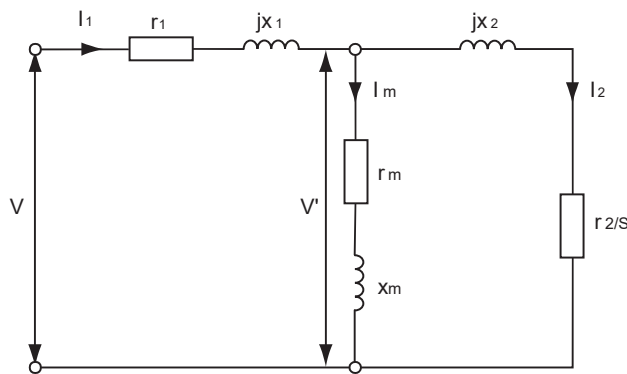
2) Start → acceleration → constant speed

3) Deceleration → stop

Refer to 2.19.

2.23 Torque boost

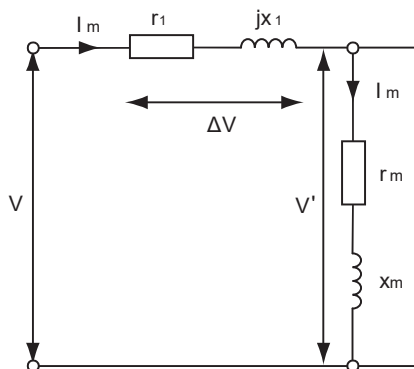
In order to understand torque boost, first the fundamental equivalent circuit of motor is described.



- V: Primary voltage
- V': Primary induced voltage
- I1: Primary current
- I2: Secondary current (primary converted value)
- r1: Primary resistance
- r2: Secondary resistance (primary converted value)
- rm: Iron loss resistance
- xm: Excitation reactance
- x1: Primary leakage reactance
- x2: Secondary leakage reactance
- S: Slip

Fig. 2.6 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. 2.7.



Im: Excitation current

Fig. 2.7 Equivalent circuit (secondary open without load)

Voltage equation is shown in Formula (2.6).

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

If it is replaced with $\Delta V = (-jI_m)(r_1 + jx_1)$, the formula can be simplified as shown in Formula (2.7).

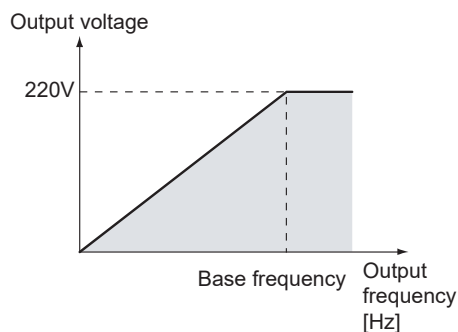
$$V' = V - \Delta V \dots\dots\dots (2.7)$$



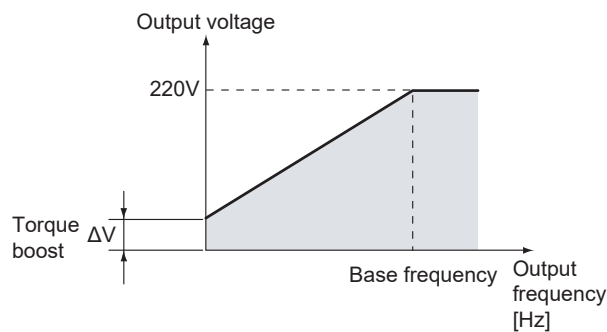
The motor generated torque is affected by the primary resistance and primary leak reactance inside the motor or the voltage drop caused by the cable impedance of the motor wiring.

2 MOTOR CHARACTERISTICS AT INVERTER DRIVE

Under V/F control, the torque required for starting may not be obtained as the voltage is low when the rotation speed is low. Therefore, when the speed is low, the voltage is increased to obtain torque. This is called torque boost.

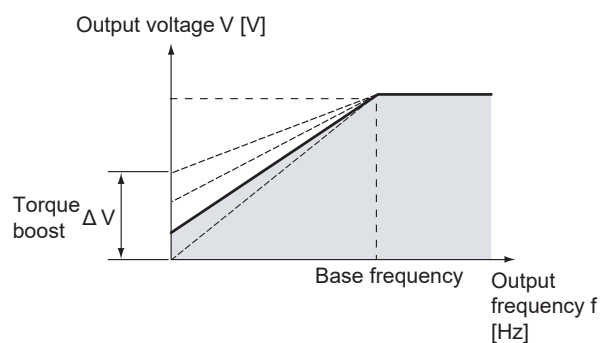


**V/F pattern of standard motor
(without torque boost)**



**V/F pattern of standard motor
(with torque boost)**

Torque boost is as follows.



Torque boost

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

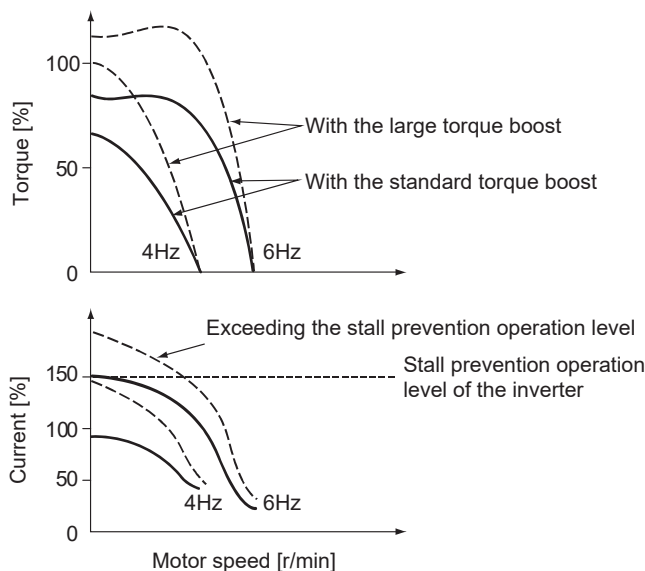
2.24 Torque boost setting

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.
- (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 the following figure.

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.



Example of motor torque and current at a start

2 MOTOR CHARACTERISTICS AT INVERTER DRIVE

Remark

- Overcurrent: The status that the output current exceeds the reference percentage of the rated output current
- Trip: Shutting off the power supplied to the motor from the inverter by the inverter's protective function against overvoltage, overcurrent, etc.
- Stall prevention: If the output current exceeds the stall prevention operation level, the output frequency of the inverter is automatically changed to reduce the output current.

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

- 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.

Check the output voltage (V/F control).

Check the output voltage when G000 (Pr.0) Torque boost is set to 6% and 0%.

Read the output voltage on the monitor.

Monitored value 1): Value when G000 (Pr.0) = "6" (6%)

Monitored value 2): Value when G000 (Pr.0) = "0" (0%)

Output frequency (Hz)	Monitored value 1) (V)	Monitored value 2) (V)
6		
10		
20		
30		
50		
60		

2.25 Operation check under V/F control (torque boost function)

(1) Check the current and voltage changes depending on the torque boost setting under V/F control.

Calculate the output current and output voltage when changing the torque boost setting.

- 1) Use the multi-speed setting signal in the External operation mode to operate the inverter at each frequency.

Parameter setting		D304 (Pr.24) = 6 Hz	D303 (Pr.6) = 10 Hz	D305 (Pr.25) = 20 Hz	D302 (Pr.5) = 30 Hz	D306 (Pr.26) = 40 Hz	D307 (Pr.27) = 50 Hz	D301 (Pr.4) = 60 Hz
Terminal input	RL	ON	ON	ON	OFF	OFF	ON	OFF
	RM	ON	OFF	OFF	ON	ON	ON	OFF
	RH	OFF	OFF	ON	OFF	ON	ON	ON

Conditions: V/F control, G003 (Pr.14) = "0" (constant-torque load), G002 (Pr.19) = 200 V

Condition		Item	Output frequency (Hz)							Abbreviation
			6	10	20	30	40	50	60	
Without load	G000 (Pr.0) = 6	Voltage (V)								V1
		Current (A)								A1
		V/F								
	G000 (Pr.0) = 12	Voltage (V)								V2
		Current (A)								A2
		V/F								
With 100% load	G000 (Pr.0) = 6	Voltage (V)								V3
		Current (A)								A3
		V/F								
G030 (Pr.60) = "9" (optimum excitation control) (Voltage and current values vary.)										
Without load	G000 (Pr.0) = 6	Voltage (V)								V4
		Current (A)								A4

- 2) Operate the inverter at 2 Hz in the PU operation mode.

Conditions: V/F control, G003 (Pr.14) = "0" (constant-torque load), G002 (Pr.19) = 200 V, G030 (Pr.60) = "0"

Torque boost setting		Output current (A)	Output voltage (V)	Whether the motor rotates
Without load	G000 (Pr.0) = 0%			
	G000 (Pr.0) = 6%			
	G000 (Pr.0) = 12%			
With 100% load	G000 (Pr.0) = 0%			
	G000 (Pr.0) = 6%			
	G000 (Pr.0) = 12%			

NOTE

If the torque boost setting is large, a protective function such as E.THM may occur, resulting in output shutoff.

Especially in the External operation, check the data and turn OFF the start switch (STF, STR), then perform a reset. (If the start switch remains ON, the operation will immediately start after restoration.)

Good to know for checking an inverter

Calibration procedure for terminal FM when using the operation panel

[Operating procedure]

1. Changing the operation mode
Press the PU/EXT key to choose the PU operation mode. The PU LED turns ON.
Calibration is also possible in the External operation mode.
* In the PU operation mode, set the command frequency to 60 Hz in advance.
 2. Selecting the parameter setting mode
Press the MODE key to choose the parameter setting mode. (The parameter number read previously appears.)
 3. Selecting a calibration parameter
Turn the setting dial until "C..." appears. Press the SET key to display "C---".
 4. Selecting the parameter
Turn the setting dial until "C0" (M310 (C0 (Pr.900)) FM terminal calibration) appears. Press the SET key to enable the parameter setting.
The monitored value of the item (initially the output frequency) selected by M300 (Pr.54) FM terminal function selection will appear.
 5. Pulse output via terminal FM
If stopped, press the RUN key to start the inverter operation. (To monitor the output frequency, motor connection is not required.)
When a monitor that does not require inverter operation is set in M300 (Pr.54), calibration is also possible during a stop status.
* In the External operation mode, operate the inverter at 60 Hz (high-speed RH).
 6. Scale adjustment
Turn the setting dial to move the meter needle to a desired position.
 7. Setting completed
Press the SET key to confirm the setting. The monitor indicator blinks.
After completing the setting, stop the operation.
 - Turn the setting dial to read another parameter.
 - Press the SET key to return to the "C---" display.
 - Press the SET key twice to show the next parameter.
-

2 MOTOR CHARACTERISTICS AT INVERTER DRIVE

Remark

Precautions for setting the SF-PR in C100 (Pr.71) Applied motor under V/F control

- When the initial value is set in G000 (Pr.0) under V/F control, the G000 (Pr.0) setting is automatically changed by changing the C100 (Pr.71) Applied motor or C102 (Pr.81) Number of motor poles setting. (When a value other than the initial value is set in G000 (Pr.0), the setting is not automatically changed.)
- For the FR-E810W, the G000 (Pr.0) setting is automatically changed to 8.6% when C102 (Pr.81) = "2, 4, or 6", and 5.5% when C102 (Pr.81) ≠ "2, 4, or 6". (For details or the descriptions for the other models, refer to the FR-E800 Instruction Manual (Function).)
- When selecting the automatic change of torque boost for the SF-PR motor, set G003 (Pr.14) Load pattern selection = "0 (initial value)".
- When the SF-PR motor is selected (C100 (Pr.71) = "70 or 73"), setting C102 (Pr.81) Number of motor poles according to the number of the SF-PR motor poles changes the G000 (Pr.0) setting to 8.6% and enables output of the 6 Hz 150% torque. However, the output current may become large due to a small load.

1

BASICS OF
INVERTERS

2

MOTOR
CHARACTERISTICS
AT INVERTER DRIVE

3

PRINCIPLE AND
FUNCTIONS OF
INVERTER

4

ENERGY SAVING
WITH INVERTERS

5

CAPACITY SELECTION
FOR MOTOR AND
INVERTER

APP

APPENDIX

Memo

This image shows a blank sheet of white paper with horizontal ruling lines. The lines are evenly spaced and run across the width of the page, typical of notebook or legal stationery. There are no margins, text, or other markings present.

CHAPTER 3 PRINCIPLE AND FUNCTIONS OF INVERTER

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.

3.1 Configuration of inverter

An inverter consists of mainly three sections: converter section, inverter section, and control circuit.

(1) Converter section

Converts the AC power supply's current to DC and smooths the pulsating current.

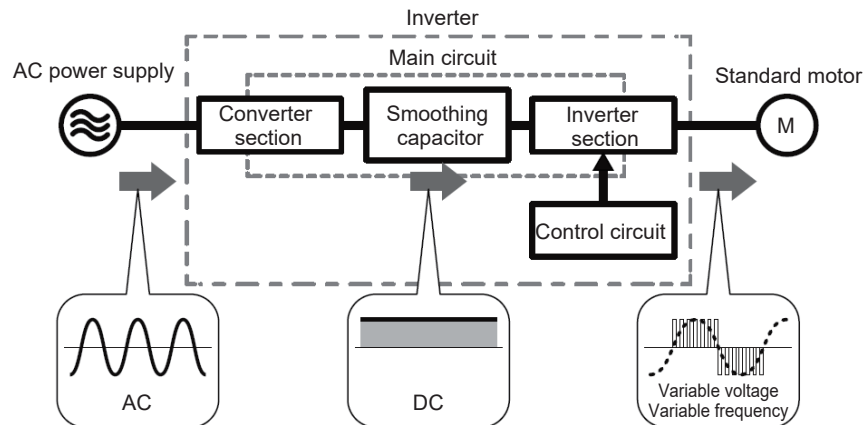
(2) Inverter section

Converts the DC current converted in the converter section to AC pulse current with variable frequency.

* Pulse current: Current that flows instantaneously in a short time

(3) Control circuit

Controls the converter section and the inverter section.



3.2 Configuration of converter section

The converter section consists of the following parts as Fig. 3.1 shows:

- 1) Converter
- 2) Smoothing capacitor
- 3) Inrush current limit circuit

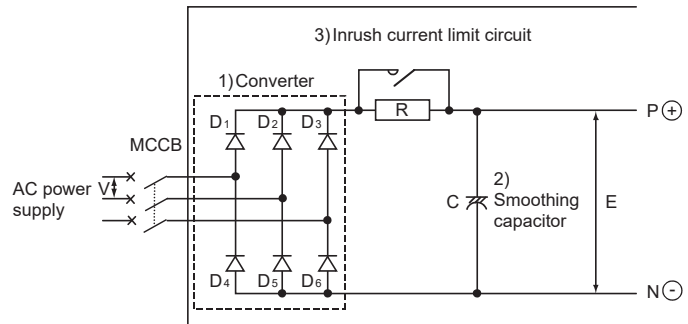


Fig. 3.1 Configuration of converter section

(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. 3.3 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. A diode has the property of allowing current to flow based on the direction of the applied voltage as shown in Fig. 3.2.

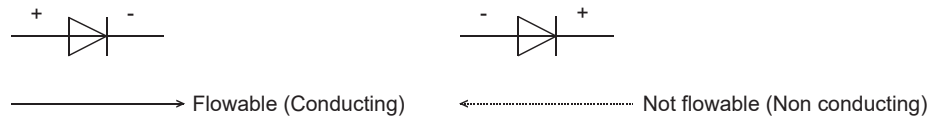


Fig. 3.2 Diode

This property allows the following: When AC voltage is applied between A and B of the circuit shown in Fig. 3.3, the voltage is always applied to the load in the same direction shown in Table 3.1.

Thus AC is converted to DC.

(The process of converting AC to 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 dashed line	Same direction

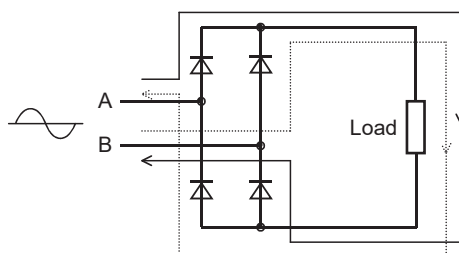


Fig. 3.3 Rectifier circuit (full-wave rectification)

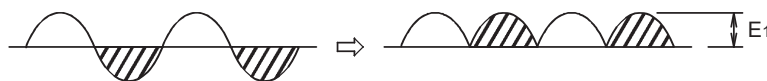
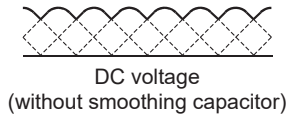


Fig. 3.4 (Continuous waveforms for Table 3.1)

(2) Principle of smoothing capacitor

The following waveform shows the three-phase DC voltage (without smoothing capacitor).



The following waveform shows the DC voltage smoothed by a smoothing capacitor.



The following waveform shows the converter output current.



* The DC voltage produced in the converter section in this way is called the bus voltage. (It is also called the P-N voltage from the name of the inverter terminals for DC voltage (P+ and N-).)

(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. 3.5.

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

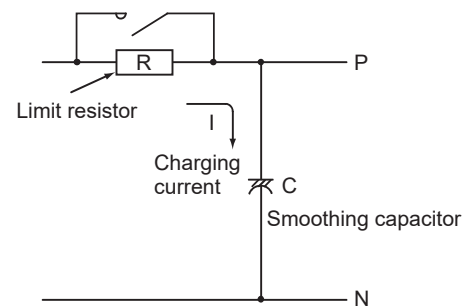
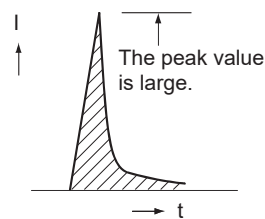
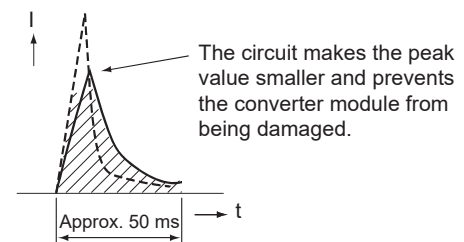


Fig. 3.5 Inrush current limit circuit

Without inrush current limit circuit



With inrush current limit circuit



Inrush current flowing in the converter (diode)

Do not switch ON/OFF the inverter power frequently with a magnetic contactor (MC), etc. Doing so allows 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 limit circuit, and therefore the number of switching times should be limited within several times a day.

3.3 Configuration of inverter section

(1) Method to create AC from DC

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

Fig. 3.6 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 the DC power supply, are alternately turned ON/OFF, AC is created as shown in Fig. 3.7.

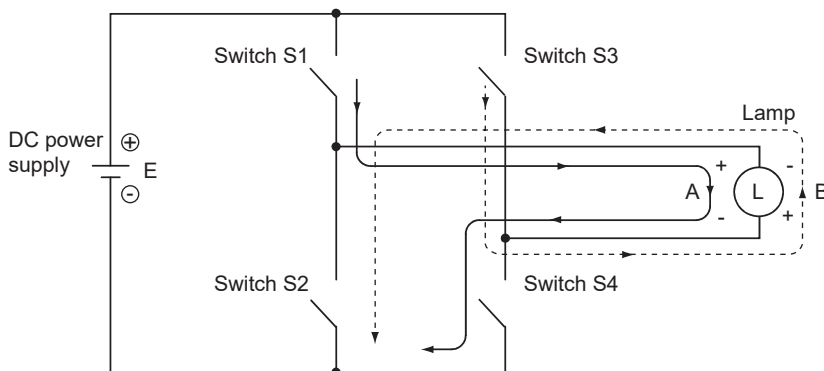


Fig. 3.6 Creating AC

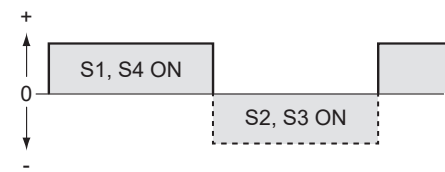


Fig. 3.7 Current waveform

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 generated, causing the direction of the current flowing through the lamp L to alternate.

(2) Method to change frequency

The frequency is changed by changing the period to turn ON and OFF the switches.

For example, repeating turning ON the switches S1 and S4 for 0.5 second then the switches S2 and S3 for 0.5 second produces the AC that reverses direction once a second, i.e., the AC with a frequency of 1 Hz.

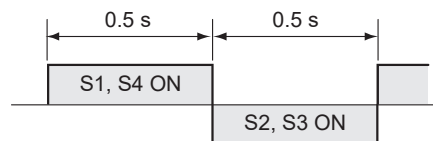


Fig. 3.8 1 Hz AC waveform

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:

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

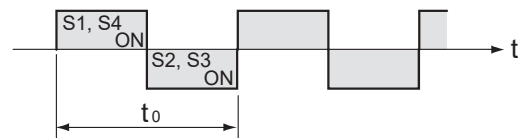


Fig. 3.9 Frequency

3 PRINCIPLE AND FUNCTIONS OF INVERTER

(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 the switches for the longer period. To obtain a lower voltage, turn ON the switches for the shorter period.



Fig. 3.10 Voltage waveform of $E/2$

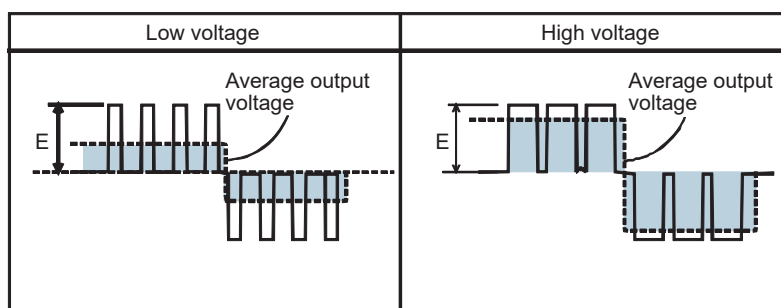


Fig. 3.11 Method to change voltage

Voltage in the inverter section is controlled by the following systems.

Table 3.2 Control systems for voltage source inverters

Control system	Output frequency-Low (low voltage)	Output frequency-High (high voltage)	Characteristics
Sine wave approximation PWM system	<p>Output voltage waveform</p> <p>Average output voltage</p> <p>One carrier</p>		<ul style="list-style-type: none"> •Smooth operation at low speed •Lower cost than PAM •Low-degree high-frequency is less. •High frequency noises from a standard motor

(E: DC voltage)

(4) Configuration of inverter section

Instead of switches, six transistors are used as shown in the configuration of Fig. 3.12. The connected standard motor is rotated by turning ON/OFF the transistors alternately. To change the motor rotation direction, change the order that the transistors are turned ON/OFF. Recently, IGBTs (Insulated Gate Bipolar Transistors), which can support high frequencies, are used in the transistor section.

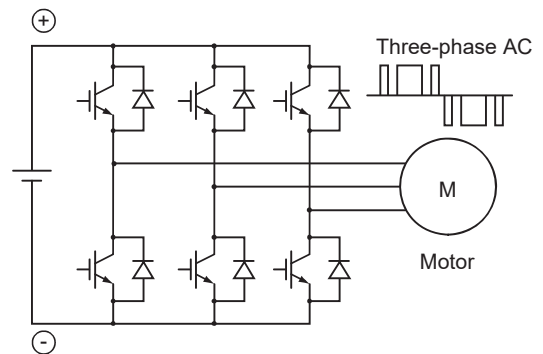


Fig. 3.12 Transistor inverter

3 PRINCIPLE AND FUNCTIONS OF INVERTER

3.4 Inverter control methods and auto tuning function

Inverters offer several control methods.

V/F control (initial setting), Advanced magnetic flux vector control, Real sensorless vector control, Vector control, and PM sensorless vector control are available.

Control		Speed control	Torque control	Position control	Motor
Easy ↑ ↓ High-performance	V/F control	•	—	—	Induction motor (SF-PR, etc.)
	Advanced magnetic flux vector control	•	—	—	
	Real sensorless vector control	•	•	—	
	PM sensorless vector control	•	—	•	PM motor (MM-GKR, EM-A)
	Vector control (with FR-A8AP E kit)	•	•	•	Induction motor (SF-PR-SC, SF-V5RU)

•: Supported

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 following figure. For this reason, this system is called V/F control.

In this control method, 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 the voltage drop is estimated and added to the output voltage (torque boost *) as indicated with the solid line in the figure to compensate the torque shortage at low speed.

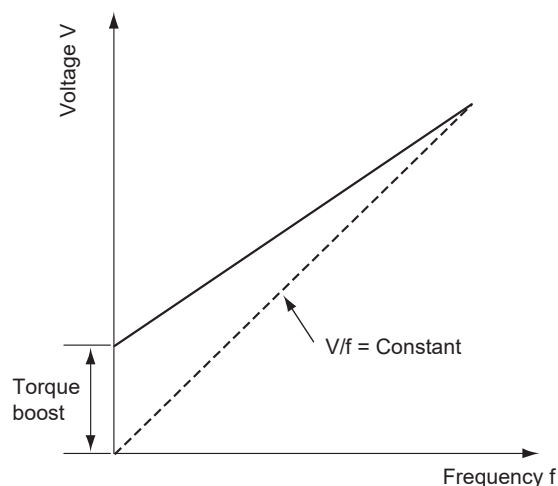


Fig. 3.13 V/F control

- * When the torque boost is increased too much, the sufficient torque is provided securely. However, an excessive current flows and the overcurrent trip (OCT) is likely to occur in the inverter. To solve this, there are other control methods available such as the Real sensorless vector control or Advanced magnetic flux vector control.

3.4.2 Real sensorless vector control

- As the inverter estimates the motor speed and controls the output current more accurately, a high-level control of the speed and the torque is enabled. Select Real sensorless vector control for a high-accuracy, fast-response control. The offline auto tuning is required initially.
- This control method is useful for the following purposes:
 - To minimize the speed fluctuation even at a severe load fluctuation
 - To generate a low speed torque
 - To prevent machine from damage due to a too large torque (torque control)
 - To control the torque
- Real sensorless vector control requires the following conditions.

If these conditions are not satisfied, select V/F control. Otherwise, malfunctions such as insufficient torque, uneven rotation may occur.
- For the motor capacity, the rated motor current should be equal to or less than the rated inverter current. If a motor with substantially low rated current compared with the inverter rated current is used, speed and torque accuracies may deteriorate due to torque ripples, etc. Set the rated motor current to about 40% or higher of the inverter rated current. (For details on the inverter rated current, refer to the inverter rated specifications in the Instruction Manual (Connection).)
- Offline auto tuning is performed.

Offline auto tuning is required under Real sensorless vector control even when the Mitsubishi Electric motor is used since the wiring length affects the operation.
- Single-motor operation (one motor to one inverter) is performed.
- A surge voltage suppression filter (FR-ASF/FR-BMF) is not used.

The following shows the comparison of the torque characteristics between V/F control and Real sensorless vector control.

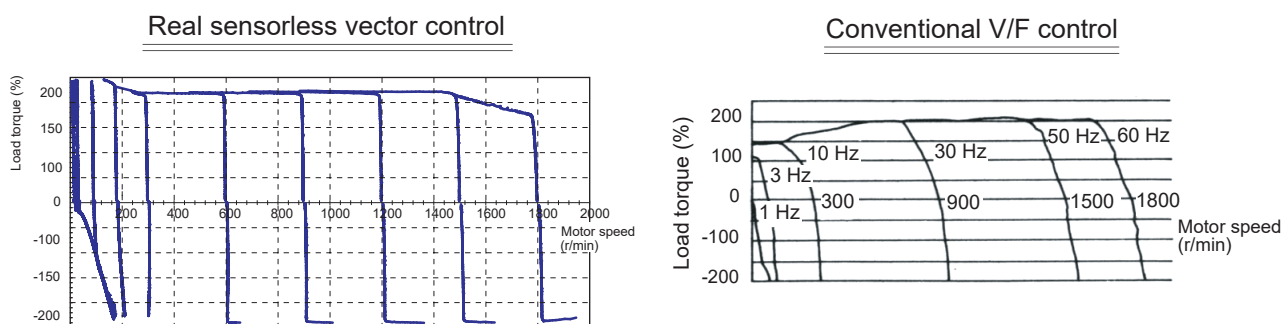


Fig. 3.14 Speed/torque characteristics under Real sensorless vector control of the standard motor 3.7kW4P

3.4.3 Offline auto tuning function

This function enables the optimal operation of a motor.

Under Advanced magnetic flux vector control, Real sensorless vector control, or Vector control, automatic measurement of motor constants enables optimal operation of motors even when motor constants vary, when a motor of another company is used, or when the wiring distance is long. (For details, refer to the Instruction Manual.)

3 PRINCIPLE AND FUNCTIONS OF INVERTER

3.5 Parameter settings using FR Configurator2 [Training]

FR Configurator2 (SW1DND-FRC2-E)

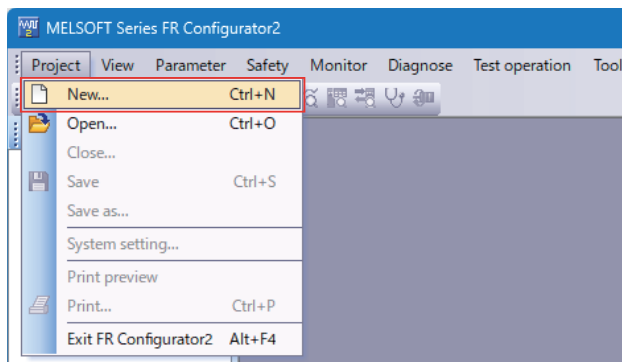
Inverter setup software provides a comfortable environment for operating the inverter as a support tool for the inverter operations from startup to maintenance.

Parameter setting and monitoring can be managed efficiently using a personal computer (Windows OS).

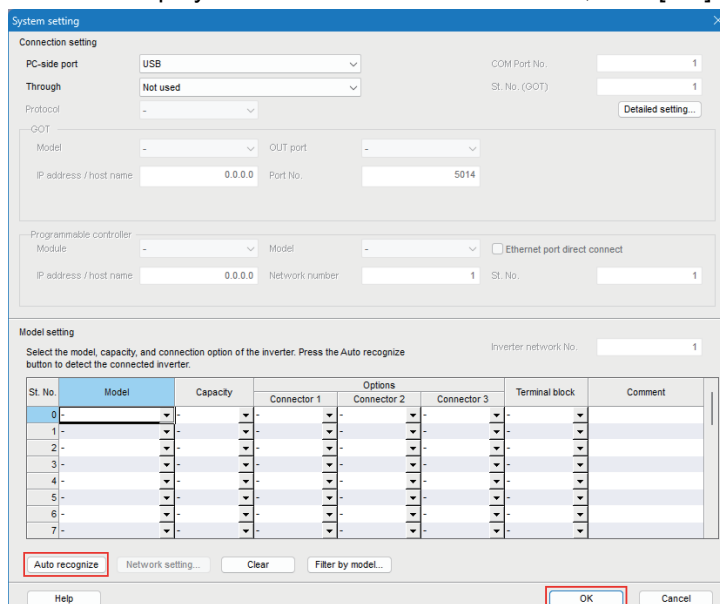
Function	Description
Parameter list	Displays the parameter list and the initial value change list, and allows editing and setting of the parameters. Parameters can also be set by function in the "Settings by function" window.
Safety parameter setting	Displays the safety parameter list and the initial value change list, and allows editing and setting of the safety parameters.
Convert	Parameter settings of the conventional models can be copied to the 800 series parameter settings.
Diagnosis	Shows the fault history, serial number, life check, diagnosis result output, Ethernet status, and online status.
AI fault diagnosis	When a fault occurs and the fault indication is displayed, probable causes of the fault are determined using AI technology to suggest corrective actions.
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.
I/O terminal monitor	Displays the I/O terminal status 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.
Ethernet parameter setting	Used for setting parameters of the inverter for Ethernet communication.
iQSS backup file conversion	Used for converting a file in the backup/restore format generated by the Mitsubishi Electric GOT (Human Machine Interface). The file is converted into the format that can be used for editing the USB memory parameter copy file or in Developer.
Firmware update	The inverter firmware can be updated by using Firmware Update Tool.
Help	Displays contents of the inverter and software instruction manuals.

Parameter setting

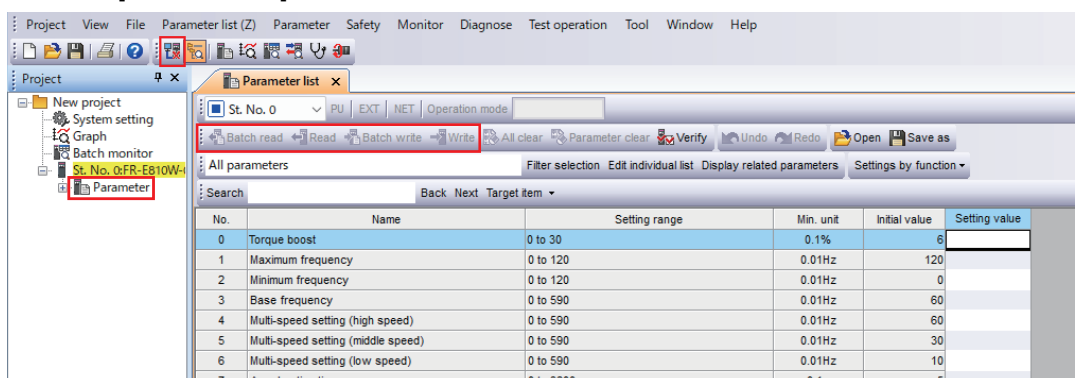
- 1) Start FR Configurator2 and select [New] from the menu.



- 2) In the "System setting" window, click [Auto recognize] button. The connected inverter model is detected and displayed. After the inverter is detected, click [OK].



- 3) In the project tree area, click [Parameter] to display the "parameter list" window. Click the [Online/offline] button to switch to online.



To read and write the parameters, use the following buttons.

- [Read]: Reads the set value of the selected parameter only.
- [Batch read]: Reads the set values of all parameters.
- [Write]: Writes the set value of the selected parameter.
- [Batch write]: Writes the set values of all parameters.

To display the explanation about a parameter on the help window (e-Manual Viewer), double-click the parameter, or press the F1 key of the computer while the parameter is selected.

3.6 Auto tuning under Real sensorless vector control [Training]

(1) Parameter settings

- | | |
|---|--|
| 1) Motor type setting | C100 (Pr.71) = "3" (for a standard motor) |
| 2) Setting the motor capacity and the number of motor poles | C101 (Pr.80) = 0.2 (kW)
C102 (Pr.81) = 4 (P) |
| 3) Control method | G200 (Pr.800) = "10" (for speed control) |
| 4) Torque limit | H700 (Pr.810) = "0" (initial value)
H500 (Pr.22) = 200 (%) |
| 5) Tuning setting | C104 (Pr.83) = 200 (V) (initial value)
C105 (Pr.84) = 60 (Hz)
C110 (Pr.96) = "1" (tuning without the motor rotating) |

(2) Perform tuning.

- When the inverter is in the PU operation mode, press the RUN key on the operation panel to start tuning.
After the tuning is completed, "3" is displayed.
Then, press the STOP/RESET key to terminate the operation.
- When the inverter is in the External operation mode, turn ON the forward rotation or reverse rotation switch.
After tuning has finished, turn OFF the forward rotation or reverse rotation switch.

(3) Exiting Real sensorless vector control (Returning to V/F control)

- Set G200 (Pr.800) = "40".
For the parameter details, refer to the FR-E800 Instruction Manual (Function).

3.7 Operation under Real sensorless vector control [Training]

Operate the inverter under Real sensorless vector control and check the current, voltage, and frequency changes and motor rotation as follows.

Checking current, voltage, and frequency

(1) Operate the inverter at 2 Hz in the PU operation mode.

Condition: Real sensorless vector control

Load factor (%)	Output current (A)	Output voltage (V)	Output frequency (Hz)	Whether the motor rotates
0%				
100%				

Compared with V/F control, enough torque is output even at 2 Hz under Real sensorless vector control.

For continuous operation, however, output will be shut off after a while due to Motor overload trip (E.THM) by the electronic thermal relay function.

During operation, the increase in the "electronic thermal relay load factor" can be checked by batch monitoring by FR Configurator2. (For the protective functions, refer to Sections 3.8 and 3.9.)

3 PRINCIPLE AND FUNCTIONS OF INVERTER

In 3.6, C100 (Pr.71) Applied motor was set to "3" (standard motor) although the SF-PR motor is used in the demonstration machine. In the next step, change the applied motor setting and check how the operation changes.

(2) Change the applied motor to SF-PR (C100 (Pr.71) = "73") and check the operation.

1) Setting and writing parameters (changes only)

- Motor type setting C100 (Pr.71) = "73" (SF-PR: constant-torque characteristic)
- Tuning setting C110 (Pr.96) = "101" (tuning with the motor rotating)
 - * "101" will be displayed on the PU panel in the middle of writing.

2) Perform tuning. (* Procedure is the same as in 3.6.)

- When the inverter is in the PU operation mode, press the RUN key on the operation panel to start tuning.

After the tuning is completed, "103" is displayed.

Then, press the STOP/RESET key to terminate the operation.

- When the inverter is in the External operation mode, turn ON the forward rotation or reverse rotation switch.

After tuning has finished, turn OFF the forward rotation or reverse rotation switch.

3) Enable the PU operation mode and operate the inverter at 2 Hz.

Condition: Real sensorless vector control

Check changes in current, voltage, frequency, and electronic thermal relay load factor.

Load factor (%)	Output current (A)	Output voltage (V)	Output frequency (Hz)	Whether the motor rotates
0%				
100%				

Check that the motor rotates in the same way as in 3.6 and that the electronic thermal relay load factor does not increase even when the load is increased.

4) How to restore the settings (V/F control, standard motor, 6% torque boost)

- First, set H500 (Pr.22) = "150", C100 (Pr.71) = "0", C102 (Pr.81) = "9999", and G200 (Pr.800) = "40" and perform batch write.
 - Next, set G000 (Pr.0) = "6". (If 6% is already set, just confirm that.)

Explanation

Real sensorless vector control can improve the maximum torque in the low speed range, but the continuous operation torque is the same as of the original motor characteristics.

Changing the applied motor setting (C100 (Pr.71)) from "3" to "73" changes the motor thermal characteristic to that for low torque, achieving 100% torque of the continuous operation characteristic in the low speed range.

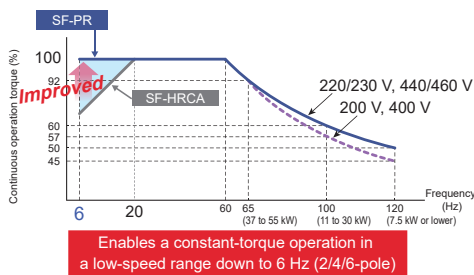
• SF-PR motor optimum for Mitsubishi Electric inverters

Enables a constant-torque operation in the low-speed range (expanding the constant-torque range)

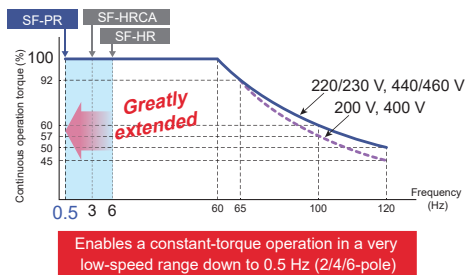
- Combining with the standard motor SF-PR enables a constant-torque operation in the low-speed range.
- The SF-PR has superior performance to the SF-HRCA.
- The 400 V class motors are insulation-enhanced motors as standard.
- V/F control: 6 to 60 Hz (1:10)
- Advanced magnetic flux vector control: 0.5 to 60 Hz (1:120)
- Real sensorless vector control: 0.3 to 60 Hz (1:200)

Continuous operation characteristics

[V/F control]

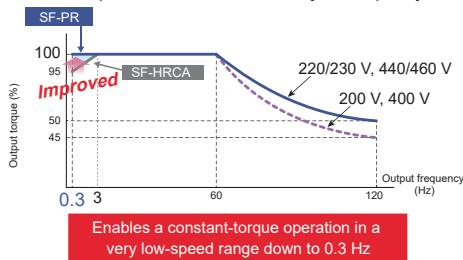


[Advanced magnetic flux vector control]



[Real sensorless vector control] (3.7 kW *)

* The torque characteristics differ by the capacity.



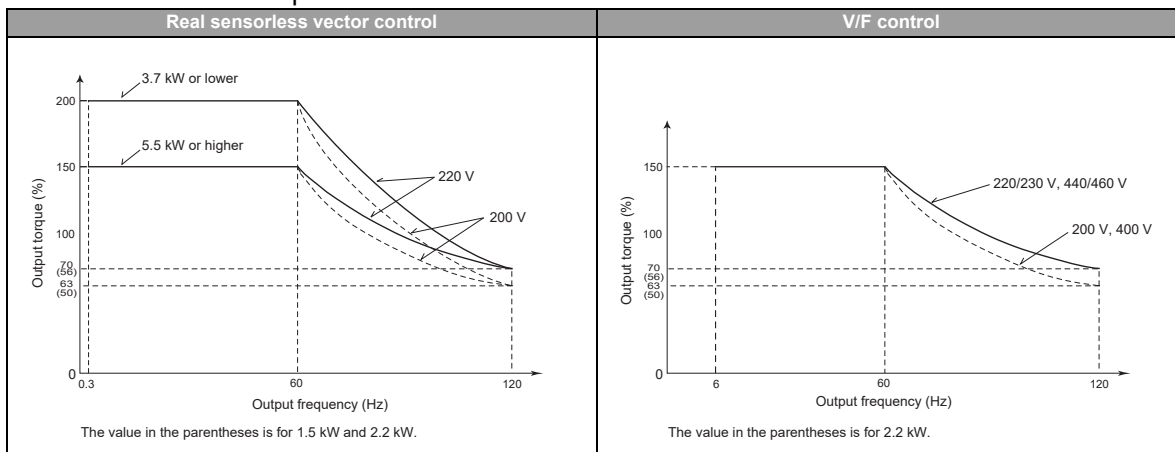
The rated motor torque at 60 Hz is regarded as 100%.

3

PRINCIPLE AND FUNCTIONS OF INVERTER

The following shows torque characteristics of the high-performance, energy-saving motor (SF-PR, 4-pole) in combination with the inverter with the ND rating. The overload capacity decreases for the LD rating. Observe the specified range of the inverter.

Maximum short-time torque



* When the SF-PR is set (C100 (Pr.71) = "70 or 73") under V/F control, the torque boost (G000 (Pr.0)) and the DC injection brake operation voltage (G110 (Pr.12)) may be automatically set depending on other settings. For details, refer to the FR-E800 Instruction Manual (Function).

3.7.1 Inverter check point

(1) Changing the control method and mode

Set the control method and the control mode.

V/F control, Advanced magnetic flux vector control, Real sensorless vector control, Vector control, and PM sensorless vector control are the control methods available for selection.

The available control modes are speed control, torque control, and position control modes.

- Select a control method and a control mode by setting G200 (Pr.800) / G300 (Pr.451) Control method selection.
- The control mode can be switched using a mode switching signal (MC).

Pr.	Name	Initial value	Setting range	Description
71 C100	Applied motor	0	0, 3, 5, 6, 10, 13, 15, 16, 20, 23, 30, 33, 40, 43, 50, 53, 70, 73, 540 *4, 1140 *5, 1800, 1803, 8090, 8093, 9090, 9093 *1	By selecting a standard motor or constant-torque motor, the thermal characteristic and motor constant of each motor are set.
80 C101	Motor capacity	9999	0.1 to 30 kW 9999	Set the applied motor capacity. No motor capacity setting
81 C102	Number of motor poles	9999	2, 4, 6, 8, 10, 12 9999	Set the number of motor poles. No number of motor poles setting
83 C104	Rated motor voltage	200/400/575 V *2	0 to 1000 V	Set the rated motor voltage (V).
84 C105	Rated motor frequency	9999	10 to 400 Hz 9999	Set the rated motor frequency (Hz). The setting value of G001 (Pr.3) Base frequency is used. *3
800 G200	Control method selection	40	0 to 5 9 10 11, 12 13, 14 19 20 40	Vector control Vector control test operation Real sensorless vector control / PM sensorless vector control Real sensorless vector control PM sensorless vector control PM sensorless vector control test operation Advanced magnetic flux vector control V/F control
451 G300	Second motor control method selection	9999	10 11, 12 13, 14 20 40 9999	Real sensorless vector control / PM sensorless vector control Real sensorless vector control PM sensorless vector control Advanced magnetic flux vector control V/F control Control selected in G200 (Pr.800)

*1 The setting range for the 575 V class is "0, 3, 5, 6, 10, 13, 15, 16, 30, 33, 8090, 8093, 9090, and 9093".

*2 The initial value differs according to the inverter's voltage class (100/200 V, 400 V, or 575 V).

*3 The inverter internal data is used under PM sensorless vector control.

*4 The value is valid only when the FR-E820-0080(1.5K) or lower, the FR-E820S-0080(1.5K) or lower, or FR-E810W-0050(0.75K) or lower is used and C101 (Pr.80) / C201 (Pr.453) ≤ 0.75 kW. Under other conditions, "SE" (Incorrect parameter setting) is displayed when the start command is turned ON.

*5 The value is valid in any of the following conditions. Under other conditions, "SE" (Incorrect parameter setting) is displayed when the start command is turned ON.

The FR-E820-0470(11K) or lower is used and C101 (Pr.80) / C201 (Pr.453) ≤ 7.5 kW.

The FR-E840-0230(11K) or lower is used and C101 (Pr.80) / C201 (Pr.453) = 0.4 to 7.5 kW.

The FR-E820S-0110(2.2K) or lower is used and C101 (Pr.80) / C201 (Pr.453) ≤ 2.2 kW.

The FR-E810W-0050(0.75K) or lower is used and C101 (Pr.80) / C201 (Pr.453) ≤ 0.75 kW.

The FR-E846-0095(3.7K) or lower is used and C101 (Pr.80) / C201 (Pr.453) = 2.2 or 3.7 kW.

(2) Setting the motor capacity and the number of motor poles (C101 (Pr.80), C102 (Pr.81))

- Motor specifications (the motor capacity and the number of motor poles) must be set to select Advanced magnetic flux vector control, Real sensorless vector control, Vector control, or PM sensorless vector control.
- Set the motor capacity (kW) in C101 (Pr.80) Motor capacity and set the number of motor poles in C102 (Pr.81) Number of motor poles.

(3) Selection of the control method and the control mode

- Select a control method (and a control mode) from V/F control, Advanced magnetic flux vector control (speed control), Real sensorless vector control (speed control, torque control), Vector control (speed control, torque control, position control), and PM sensorless vector control (speed control, position control).
- To enable the control method and the control mode selected in G200 (Pr.800) / G300 (Pr.451), the condition to start operation must be satisfied as shown in the following table. Otherwise the operation does not start due to the setting error (SE) alarm when the start signal is input.

G200 (Pr.800) setting	G300 (Pr.451) setting	Control method	Control mode	Condition to start operation		MC signal	
				C101 (Pr.80), C201 (Pr.453), C102 (Pr.81), C202 (Pr.454)	C100 (Pr.71), C200 (Pr.450)		
0	—	Vector control *3	Speed control	Other than 9999	Induction motor	—	
1	—		Torque control			—	
2	—		Speed control / torque control switchover			ON: Torque control OFF: Speed control	
3	—		Position control			—	
4	—		Speed control / position control switchover			ON: Position control OFF: Speed control	
5	—		Position control / torque control switchover			ON: Torque control OFF: Position control	
9	—	Vector control test operation				—	
10		Real sensorless vector control / PM sensorless vector control	Speed control		Other than 9999	— *1	—
11		Real sensorless vector control	Torque control			Induction motor	—
12			Speed control / torque control switchover				ON: Torque control OFF: Speed control
13		PM sensorless vector control	Position control			PM motor (MM-GKR, EM-A)	—
14			Speed control / position control switchover				ON: Position control OFF: Speed control
19	—	PM sensorless vector control test operation				PM motor	—
20		Advanced magnetic flux vector control	Speed control			Induction motor	—
40 (initial value)	40	V/F control	—	— *2			—
—	9999 (initial value)	Control method and control mode selected in G200 (Pr.800) (provided that they are selectable with G300 (Pr.451))					

*1 The control method depends on the motor selected in C100 (Pr.71) / C200 (Pr.450): Real sensorless vector control for the induction motor, and PM sensorless vector control for the PM motor.

*2 Operation can start regardless of the setting.

*3 A Vector control compatible option is required. Vector control is not available for the IP67 model as plug-in options are not available.

Remark

For details, refer to the FR-E800 Instruction Manual (Function).

3.8 Protective functions

3.8.1 Purposes and types of protective functions

When the inverter detects a fault, depending on the nature of the fault, the operation panel displays an error message or warning, or a protective function is activated to shut off the inverter output.

- When any fault occurs, take an appropriate corrective action, then reset the inverter, and resume the operation. Restarting the operation without a reset may break or damage the inverter.
- When a protective function is activated, note the following points.

Item	Description
Fault output signal	Opening the magnetic contactor (MC) provided on the input side of the inverter at a fault occurrence shuts off the control circuit power to the inverter, therefore, the fault output will not be retained.
Fault or alarm indication	When a protective function is activated, the operation panel displays a fault indication.
Operation restart method	While a protective function is activated, the inverter output is kept shutoff. Reset the inverter to restart the operation.

- Inverter fault or alarm indications are categorized as follows.

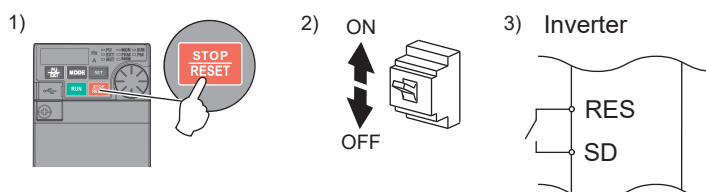
Displayed item	Description
Error message	A message regarding operational fault or setting fault on the operation panel is displayed. The inverter output is not shut off.
Warning	The inverter output is not shut off even when a warning is displayed. However, failure to take appropriate measures will lead to a fault.
Alarm	The inverter output is not shut off. An Alarm (LF) signal can also be output with a parameter setting.
Fault	When a protective function is activated, the inverter output is shut off and a Fault (ALM) signal is output.

3.8.2 Reset method for the protective functions

Reset the inverter by performing any of the following operations. Note that the accumulated heat value of the electronic thermal relay function and the number of retries are cleared (erased) by resetting the inverter.

The inverter recovers about 1 second after the reset is released.

- 1) On the operation panel, press the STOP/RESET key to reset the inverter. (This operation is valid only when the protective function for a fault is activated.)
- 2) Switch the power OFF once, then switch it ON again.
- 3) Turn ON the Reset (RES) signal for 0.1 second or more. (If the RES signal is kept ON, "Err" appears (blinks) to indicate that the inverter is in a reset status.)



- OFF status of the start signal must be confirmed before resetting the inverter fault. Resetting an inverter fault with the start signal ON restarts the motor suddenly.

3 PRINCIPLE AND FUNCTIONS OF INVERTER

3.8.3 Retry function

This function allows the inverter to reset itself and restart at activation of the protective function (fault indication). The retry generating protective functions can also be selected. When the retry function is set enabled, stay away from the motor and machine in the case of an output shutoff. The motor and machine will start suddenly (after the reset time has elapsed) after the shutoff.

3.8.4 Emergency drive

The inverter can continue driving the motor in case of emergency such as a fire, since protective functions are not activated even if the inverter detects a fault. Using this function may damage the motor or inverter because driving the motor is given the highest priority. Use this function for emergency operation only. The operation can be switched to the commercial power supply operation at the occurrence of a fault which may cause damage of the inverter.

* To perform emergency drive operation (in the commercial mode), preparations such as circuit wiring are required in advance. For the connection diagram, refer to the FR-E800 Instruction Manual (Function).

Remark

When the emergency drive function is enabled, the operation is continued or the retry operation (automatic reset and restart) is repeated even if a fault occurs, which may damage or burn this product and the motor. Before restarting the normal operation after using this function, make sure that the inverter and motor have no fault. Any damage of the inverter or the motor caused by using the emergency drive function is not covered by the warranty even within the guarantee period.

3.9 Protecting the inverter (V/F control) [Training]

Perform the training under V/F control. Check the following parameter settings.

C101 (Pr.80) = "9999", C102 (Pr.81) = "9999", G000 (Pr.0) = 6%, G002 (Pr.19) = "9999"

(1) Electronic thermal O/L relay (Motor overheat protection)

1) Start operating the electronic thermal O/L relay.

Set H000 (Pr.9) (Electronic thermal O/L relay) to 0.7 A, and operate the inverter at 6 Hz without load in the External operation mode. The inverter output will be shut off after approximately 20 to 30 seconds.

While **MON** is ON, press **SET** then **SET** to check the Hz, I, and V values when the inverter output is shut off.

2) Use the retry function.

Set H301 (Pr.67) to three times and H302 (Pr.68) to five seconds, and then operate the inverter.

Check the result.

A retry is performed.

3) Check the operation status of the electronic thermal O/L relay during operation (electronic thermal relay load factor).

Set M100 (Pr.52) (Operation panel main monitor selection) to "10", and then operate the inverter.

Check the display status on the monitor.

4) Check the pre-alarm function.

In addition to step 3), set M401 (Pr.191) (Output terminal function selection) to "8" so that the FU lamp can turn ON.

Check the timing of when FU turns ON. It turns ON when the accumulated thermal value reaches 85%.

5) Reset signal

With the following methods, external reset signal input during normal operation is disabled so that only the external signal input during abnormal operation can be accepted.

- Use the RESET key on the operation panel to input the reset signal.
- Check that E100 (Pr.75) (Reset selection) is set to "15".

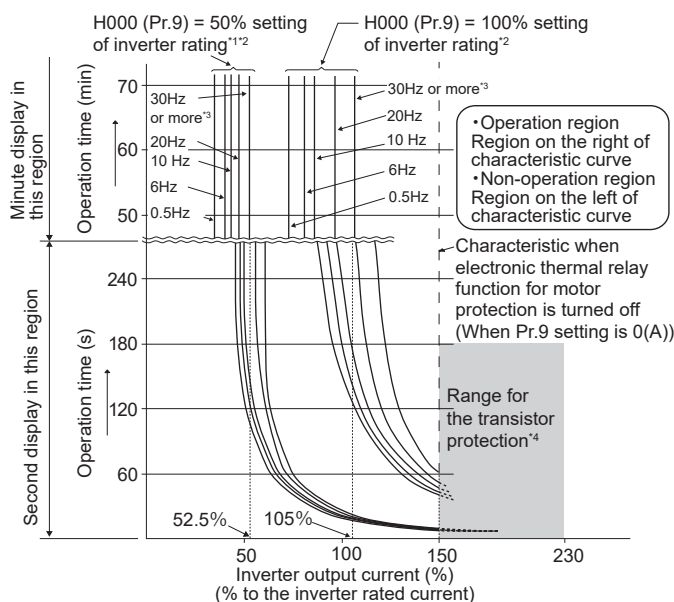
After the above training, restore the setting of H000 (Pr.9) (Electronic thermal O/L relay) to 1.16 A.

Remark

◆ Electronic thermal O/L relay operation characteristic for induction motor (H000 (Pr.9))

Set the current of the electronic thermal relay function to protect the motor from overheating. Such settings provide the optimum protective characteristic considering the low cooling capability of the motor during low-speed operation.

- This function detects the overload (overheat) of the motor and shuts off the inverter output by stopping the operation of the transistor at the inverter output side.
- Set the rated current (A) of the motor in H000 (Pr.9) Electronic thermal O/L relay. (If the motor has both 50 Hz and 60 Hz ratings and G001 (Pr.3) Base frequency is set to 60 Hz, set to 1.1 times the 60 Hz rated motor current.)
- Set "0" in H000 (Pr.9) to avoid activating the electronic thermal relay function; for example, when using an external thermal relay for the motor. (Note that the output transistor protection of the inverter is activated. (E.THT))
- When using the Mitsubishi Electric constant-torque motor, set the constant-torque motor in C100 (Pr.71) Applied motor referring to the Instruction Manual (Function). (This setting enables the 100% constant-torque characteristic in the low-speed range.)



*1 When setting H000 (Pr.9) to a value (current value) of 50% of the inverter rated current

*2 The % value denotes the percentage to the rated inverter current. It is not the percentage to the rated motor current.

*3 When the electronic thermal relay function dedicated to the Mitsubishi Electric constant-torque motor is set, this characteristic curve applies to operation. (For selection of the operation characteristic, refer to the Instruction Manual (Function).)

*4 Transistor protection is activated depending on the temperature of the heat sink. The protection may be activated even with less than 150% depending on the operating conditions.

3 PRINCIPLE AND FUNCTIONS OF INVERTER

[Note]

- The internal accumulated heat value of the electronic thermal O/L relay is reset to the initial value by the inverter's power reset or reset signal input. Avoid unnecessary reset and power-OFF.
 - Install an external thermal relay (OCR) between the inverter and motors to operate several motors, a multi-pole motor or a dedicated motor with one inverter. When setting an external thermal relay, note that the current indicated on the motor rating plate is affected by the line-to-line leakage current. The cooling effect of the motor drops during low-speed operation. Use a motor with built-in thermal protector. (For details of the line-to-line leakage current, refer to the Instruction Manual (Connection).)
 - When the difference between the inverter and motor capacities is large and the set value is small, the protective characteristics of the electronic thermal relay function will be deteriorated. Use an external thermal relay in such cases.
 - A dedicated motor cannot be protected by an electronic thermal O/L relay. Use an external thermal relay.
 - The transistor protection thermal O/L relay is activated early when the E600 (Pr.72) PWM frequency selection setting is increased.
-

1

BASICS OF
INVERTERS

2

MOTOR
CHARACTERISTICS
AT INVERTER DRIVE

3

PRINCIPLE AND
FUNCTIONS OF
INVERTER

4

ENERGY SAVING
WITH INVERTERS

5

CAPACITY SELECTION
FOR MOTOR AND
INVERTER

APP

APPENDIX

3.10 Acceleration/operating characteristics of inverter

3.10.1 Start

By inputting the inverter start signal (turning ON the switch across terminals STF/STR and SD) and the frequency command signal to the inverter, the inverter outputs the starting frequency and the motor generates torque.

The motor starts rotating when the motor starting torque at the starting frequency is larger than the starting torque of the load. If the load torque is larger than the motor starting torque, the motor stays locked. In such a case, increase the output frequency gradually. The motor starts rotating when the motor starting torque exceeds the load torque T_L as shown in Fig. 3.15. Note that setting the starting frequency higher increases the motor locking current and may result in an overcurrent trip (E.OC1) or overload trip (E.THT).

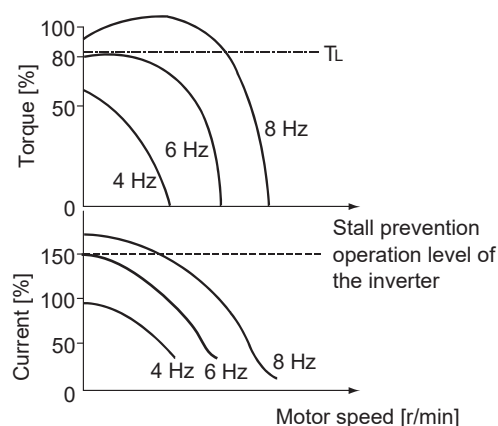


Fig. 3.15 Starting torque (standard boost)

3.10.2 Acceleration

After startup, the inverter gradually increases the output frequency to the frequency command value in accordance with the acceleration time setting.

As described in 2.2.4 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-generating torque. When the acceleration time is set sufficiently long, the output frequency f and motor rotation speed N increase in proportion to each other. (Refer to Fig. 3.16.)

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. 3.17.). This makes a motor current larger and may cause an overcurrent, resulting in protective functions, such as the stall prevention function or the overcurrent trip. (When an inverter capacity is increased while the motor capacity remains the same, 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.

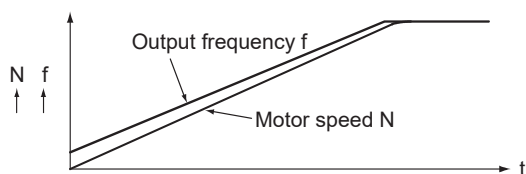


Fig. 3.16 Acceleration characteristics (with sufficient acceleration time)

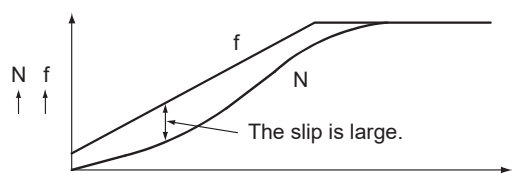


Fig. 3.17 Acceleration characteristics (with insufficient acceleration time)

☒ Good to know for checking an inverter

Stall prevention: If the output current exceeds the stall prevention operation level, the output frequency of the inverter is automatically changed to reduce the output current.

3.10.3 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.

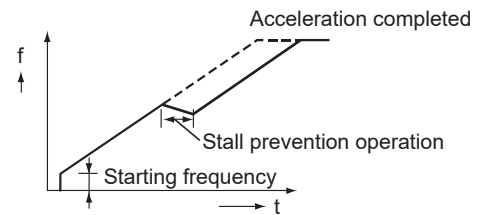


Fig. 3.18 Stall prevention operation during acceleration

3.10.4 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 the motor current exceeds 150% (stall prevention operation level), the inverter decreases the output frequency once to prevent an overcurrent trip from occurring. The inverter returns the output frequency to the original value when the motor current becomes 150% or less.

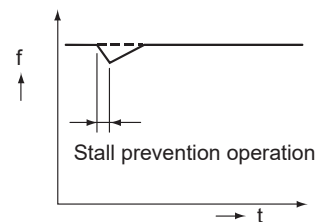


Fig. 3.19 Stall prevention operation at a constant speed

3.10.5 Deceleration

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

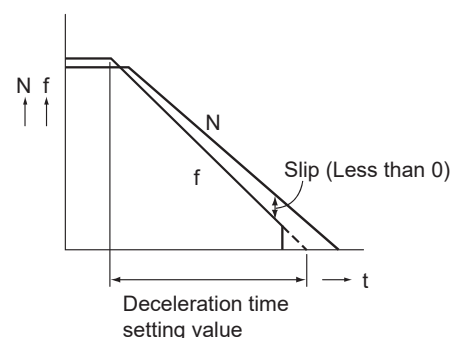


Fig. 3.20 Deceleration characteristics

During deceleration, the motor rotation speed is faster than the synchronous speed equivalent to the inverter output frequency. In this condition, the motor functions as a generator and returns the energy to the inverter, which increases DC voltage (voltage of the smoothing capacitor). This operation is called regeneration.

Overvoltage stall prevention

If the DC voltage becomes even higher, the inverter stops decreasing the output frequency to prevent the regenerative overvoltage trip.

Overcurrent stall prevention

If the motor current exceeds the specified value during deceleration, the output frequency is increased to prevent an overcurrent trip.

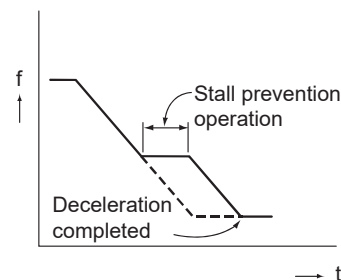


Fig. 3.21 Stall prevention operation during deceleration

Remark

The FR-E800 does not have a built-in brake. For the models with 0.4 kW or higher capacity, optional brake resistors and the multifunction regeneration converter are available to improve regenerative braking capability. For details, refer to the FR-E800 Instruction Manual (Connection).

3.10.6 Stop

- (1) When the inverter start signal (STF/STR) is turned OFF, the motor decelerates as shown in Fig. 3.22. When the output frequency becomes the DC injection brake operation frequency or less, the DC voltage is applied to the motor, and then the motor stops. This is called DC injection brake.

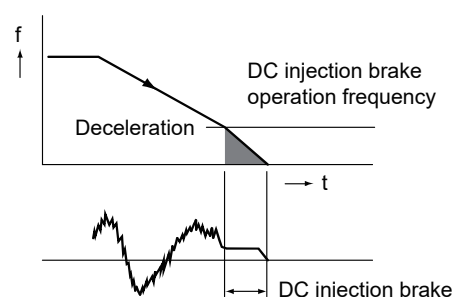


Fig. 3.22 DC injection brake operation

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.

Note that activating the DC injection brake for a long time may cause overheating of the motor. (The operation frequency, operation time, and operation voltage can be changed.)

3.10.7 Stall prevention operation [Training]

Set H500 (Pr.22) (Stall prevention operation level) = 90% and operate the inverter at 10 Hz with 150% load in the External operation mode.

When H501 (Pr.156) (Stall prevention operation selection) = "0" and the load factor is set to approx. 150%, "oLC" (stall prevention) is displayed and the frequency is decreased. When H501 (Pr.156) = "16", "E.oLT" (stop due to stall prevention) is output and the operation stops at the same timing of stall prevention as that with the setting value "0".

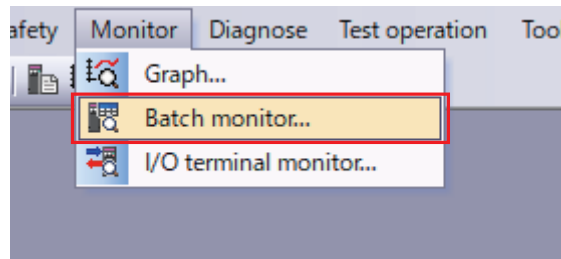
After the training, restore the settings (H500 (Pr.22) to 150% and H501 (Pr.156) to "0" (initial value)).

3 PRINCIPLE AND FUNCTIONS OF INVERTER

3.11 Batch monitor, test operation, and diagnosis using FR Configurator2 [Training]

(1) Batch monitor

- 1) From the [Monitor] menu, select [Batch monitor].

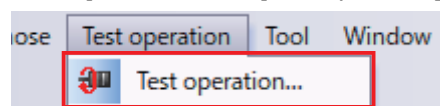


- 2) The "Batch monitor" window appears. The status of the inverter can be monitored.

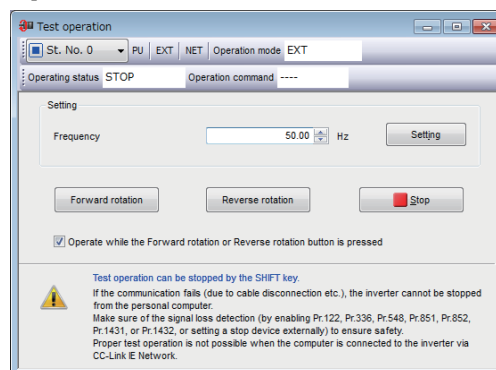
No.	Item	St. No. 0
1	Output frequency	----
2	Output current	----
3	Output voltage	----
4	Frequency setting value	----
5	Speed/machine speed	----
6	Motor torque	----
7	Converter output voltage	----
8	Regenerative brake duty	----
9	Electronic thermal O/L relay load factor	----
10	Output current peak value	----

(2) Test operation

- 1) From the [Test operation] menu, select [Test operation].



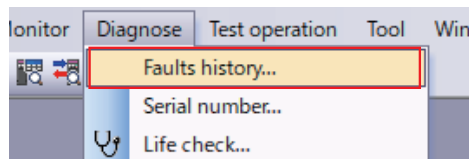
- 2) The "Test operation" window appears. When "Operate while the Forward rotation or Reverse rotation button is pressed" is selected, the motor rotates only while the [Forward rotation] or [Reverse rotation] button is held down.



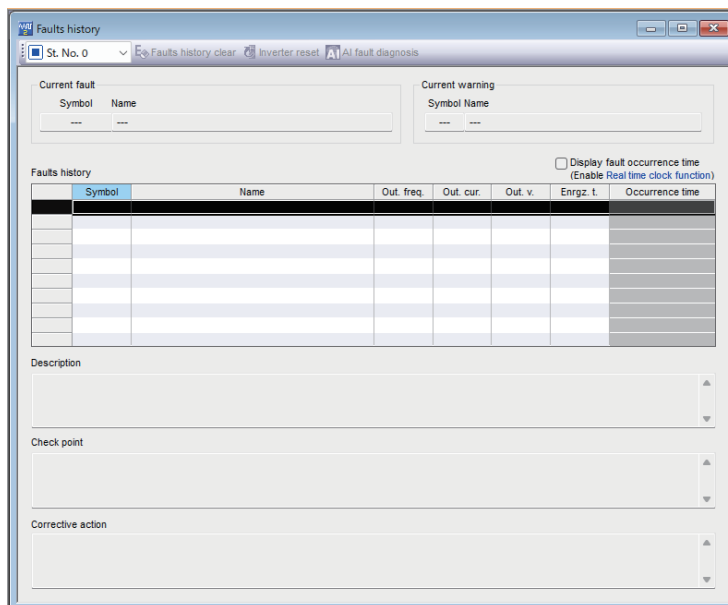
3 PRINCIPLE AND FUNCTIONS OF INVERTER

(3) Fault history

1) From the [Diagnose] menu, select [Faults history].



2) The "Faults history" window appears. Faults currently occurring and the fault history can be checked.



(4) AI fault diagnosis

The AI fault diagnosis function can suggest probable causes of faults using AI technology. The inverter is connected to the engineering software FR Configurator2 (USB/Ethernet connection). Maisart*1 (Mitsubishi Electric's AI technology) is integrated in the software to analyze data and help identify the cause of a fault*2 (this function is enabled during speed control).

This function enables the fastest troubleshooting procedure without requiring any special skills, which contributes to downtime reduction.

*1 Maisart is Mitsubishi Electric's brand of AI technology. The name stands for "Mitsubishi Electric's AI creates the State-of-the-ART in technology". This means that it is using our proprietary AI technology to make everything smarter.

*2 Diagnosable faults: Overcurrent trip, overvoltage trip, inverter overload trip (electronic thermal relay function), motor overload trip (electronic thermal relay function). (Other faults will be applicable later.)

**AI fault diagnosis result screen**

Example: E.OC1 (Overcurrent trip during acceleration)

FR-E820-0.4K(0030)-1 | E.OC1 Overcurrent trip during acceleration

Output short circuit or main circuit failure in the inverter.

Turn OFF the power of the devices and check the wiring.
Turn OFF the power of the devices and check the inverter.

Offline auto tuning is not performed.

The motor constant parameter setting is improper

Output phase loss

Increase of the power driving load

Cause

Insufficient torque in the present control method causes an overcurrent.
As the stall prevention operation level is set too high or the fast-response current limit operation is disabled, an overcurrent occurs under heavy load conditions.
The load of the machine driven by the motor gradually increases, resulting in an overcurrent.

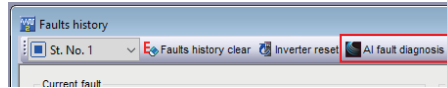
Corrective action

Change the control method.
Lower the stall prevention operation level.
Enable the fast-response current limit function.
Eliminate the cause of the load increase.
Consider using a larger-capacity inverter and a larger-capacity motor.

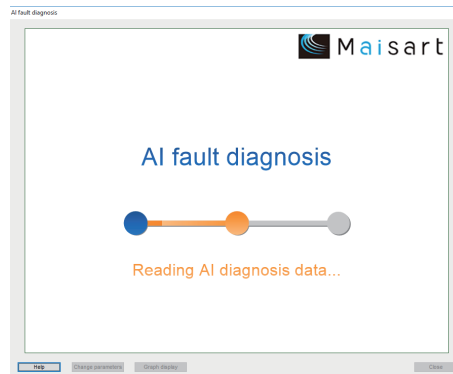
Parameter	Name	Setting range	Set value	Initial value	Default value
22	Stall prevention operation level (stall prevention level)	0 to 400	0.1%	100	100
23	Stall prevention operation level (stall prevention level) at startup	0 to 400 (0.000)	0.1%	100	100
45	Stall prevention operation level	0 to 400 (0.000)	0.1%	100	100
52	Stall prevention operation level (stall prevention level) during standby	0 to 100	0.1%	10	10
80	Motor capacity	0.1 to 10.000	0.100	0.100	0.100
81	Motor capacity	0.1 to 10.000	0.100	0.100	0.100
114	Voltage reduction operation during stall prevention operation	0 to 100	0	0	0
160	Stall prevention operation level	0 to 10.000	0.1	0.1	0.1
451	Second motor capacity reduction	0 to 10.000	0	0	0
460	Second motor capacity	0 to 10.000	0	0	0
461	Second motor capacity	0 to 10.000	0	0	0
462	Second motor capacity	0 to 10.000	0	0	0
463	Second motor capacity	0 to 10.000	0	0	0
464	Second motor capacity	0 to 10.000	0	0	0
465	Second motor capacity	0 to 10.000	0	0	0
466	Second motor capacity	0 to 10.000	0	0	0
467	Second motor capacity	0 to 10.000	0	0	0
468	Second motor capacity	0 to 10.000	0	0	0
469	Second motor capacity	0 to 10.000	0	0	0
470	Second motor capacity	0 to 10.000	0	0	0
471	Second motor capacity	0 to 10.000	0	0	0
472	Second motor capacity	0 to 10.000	0	0	0
473	Second motor capacity	0 to 10.000	0	0	0
474	Second motor capacity	0 to 10.000	0	0	0
475	Second motor capacity	0 to 10.000	0	0	0
476	Second motor capacity	0 to 10.000	0	0	0
477	Second motor capacity	0 to 10.000	0	0	0
478	Second motor capacity	0 to 10.000	0	0	0
479	Second motor capacity	0 to 10.000	0	0	0
480	Second motor capacity	0 to 10.000	0	0	0
481	Second motor capacity	0 to 10.000	0	0	0
482	Second motor capacity	0 to 10.000	0	0	0
483	Second motor capacity	0 to 10.000	0	0	0
484	Second motor capacity	0 to 10.000	0	0	0
485	Second motor capacity	0 to 10.000	0	0	0
486	Second motor capacity	0 to 10.000	0	0	0
487	Second motor capacity	0 to 10.000	0	0	0
488	Second motor capacity	0 to 10.000	0	0	0
489	Second motor capacity	0 to 10.000	0	0	0
490	Second motor capacity	0 to 10.000	0	0	0
491	Second motor capacity	0 to 10.000	0	0	0
492	Second motor capacity	0 to 10.000	0	0	0
493	Second motor capacity	0 to 10.000	0	0	0
494	Second motor capacity	0 to 10.000	0	0	0
495	Second motor capacity	0 to 10.000	0	0	0
496	Second motor capacity	0 to 10.000	0	0	0
497	Second motor capacity	0 to 10.000	0	0	0
498	Second motor capacity	0 to 10.000	0	0	0
499	Second motor capacity	0 to 10.000	0	0	0
500	Second motor capacity	0 to 10.000	0	0	0

Procedure for finding probable causes by AI fault diagnosis

- 1) From the [Diagnose] menu, select [Faults history].
- 2) Display the fault history window front and select [AI fault diagnosis] in the [Faults history (Z)] menu. Alternatively, select [AI fault diagnosis] on the taskbar in the fault history window.



- 3) The AI fault diagnosis function is activated to find probable causes and display corrective actions for the fault in the fault history using AI technology.



- 4) Select one of the probable causes suggested in the result screen to check corrective actions to be taken.



- 5) When the probable cause is related to parameter settings, click [More Info].

Increase of the power driving load

- Change the control method.
- Lower the stall prevention operation level.
- Enable the fast-response current limit function.
- Eliminate the cause of the load increase.
- Consider using a larger-capacity inverter and a larger-capacity motor.

More Info



6) Click [Batch read] to display current parameter settings of the inverter.

! Cause

- Insufficient torque in the present control method causes an overcurrent.
- As the stall prevention operation level is set too high or the fast-response current limit operation is disabled, an overcurrent occurs under heavy load conditions.
- The load of the machine driven by the motor gradually increases, resulting in an overcurrent.

+ Corrective action

- Change the control method.
- Lower the stall prevention operation level.
- Enable the fast-response current limit function.
- Eliminate the cause of the load increase.
- Consider using a larger-capacity inverter and a larger-capacity motor.

No.	Name	Setting range	Min. unit	Initial value	Setting value
22	Stall prevention operation level (torque limit level)	0 to 400	0.1%	150	150
23	Stall prevention operation level compensation factor at double speed	0 to 200.9999	0.1%	9999	9999
43	Second stall prevention operation level	0 to 400.9999	0.1%	9999	9999
66	Stall prevention operation reduction starting frequency	0 to 590	0.01Hz	60	60
80	Motor capacity	0.1 to 30.9999	0.01kW	9999	9999
81	Number of motor poles	2,4,6,8,10,12,9999	1	9999	9999
154	Voltage reduction selection during stall prevention operation	1,11	1	1	1
156	Stall prevention operation selection	0 to 31,100,101	1	0	0
451	Second motor control method selection	10 to 12,20,40,9999	1	9999	9999
800	Control method selection	10 to 12,19,20,40	1	40	40
858	Terminal 4 function assignment	0,4,9999	1	0	0

Help OK Cancel

7) Check the corrective actions and change parameter settings as required. After the change, click [Batch write] to write the setting values to the inverters.

! Cause

- Insufficient torque in the present control method causes an overcurrent.
- As the stall prevention operation level is set too high or the fast-response current limit operation is disabled, an overcurrent occurs under heavy load conditions.
- The load of the machine driven by the motor gradually increases, resulting in an overcurrent.

+ Corrective action

- Change the control method.
- Lower the stall prevention operation level.
- Enable the fast-response current limit function.
- Eliminate the cause of the load increase.
- Consider using a larger-capacity inverter and a larger-capacity motor.

No.	Name	Setting range	Min. unit	Initial value	Setting value
22	Stall prevention operation level (torque limit level)	0 to 400	0.1%	150	150
23	Stall prevention operation level compensation factor at double speed	0 to 200.9999	0.1%	9999	9999
43	Second stall prevention operation level	0 to 400.9999	0.1%	9999	9999
66	Stall prevention operation reduction starting frequency	0 to 590	0.01Hz	60	60
80	Motor capacity	0.1 to 30.9999	0.01kW	9999	9999
81	Number of motor poles	2,4,6,8,10,12,9999	1	9999	9999
154	Voltage reduction selection during stall prevention operation	1,11	1	1	1
156	Stall prevention operation selection	0 to 31,100,101	1	0	0
451	Second motor control method selection	10 to 12,20,40,9999	1	9999	9999
800	Control method selection	10 to 12,19,20,40	1	40	40
858	Terminal 4 function assignment	0,4,9999	1	0	0

Help OK Cancel

3.12 USB bus power connection [Training]

When the inverter is connected to a computer via USB, power is supplied and communication with FR Configurator2 is enabled even while the inverter power is OFF. This reduces startup time.

(1) Operating procedure

- 1) Turn OFF the inverter power.
- 2) Connect the inverter and the personal computer using the USB cable.
- 3) Check that the parameters can be read/written under the above condition.

(2) Restrictions for using USB bus power

The following table shows availability of functions while power is supplied via USB connection. Note that some functions are restricted.

Item	Description	Remarks
Parameters (except for calibration parameters)	Reading a parameter value Writing a parameter value	Parameters for options can be read or written regardless of whether options are connected.
FM/AM calibration parameters M310 (C0 (Pr.900)), M320 (C1 (Pr.901))	Setting (calibration) not available.	
Calibration parameters T200 (C2 (Pr.902)), T201 (C3 (Pr.902)), T202 (Pr.125 (Pr.903)), T203 (C4 (Pr.903)), T400 (C5 (Pr.904)), T401 (C6 (Pr.904)), T402 (Pr.126 (Pr.905)), T403 (C7 (Pr.905)), T410 (C38 (Pr.932)), T411 (C39 (Pr.932)), T412 (C40 (Pr.933)), T413(C41(Pr.933))	Adjustment is available only when applying analog voltage (current) is not necessary.	
Operation panel	Not available for operation. Only the PRM LED turns ON.	When power is supplied via main circuit terminals while the USB bus power is used, the operation panel will be reset automatically.
Fault	Partially supported.	
RS-485/Ethernet communication	Not guaranteed.	

CHAPTER 4 ENERGY SAVING WITH INVERTERS

Chapter 1 mentions that driving a motor by an inverter contributes to energy saving. This chapter describes the details of energy saving.

First, terms related to energy saving "efficiency" and "power factor" are generally described as follows.

Term	Description
Efficiency	Indicator that shows how much input power (energy) is output (or converted to power output) with less loss
Power factor	Indicator that shows how the input AC power is being used without waste

The details of each term are described in the following sections.

4.1 Efficiency

As described in Chapter 3, an inverter is a power supply conversion unit consisting of the converter section (performing forward conversion) and the inverter section (performing reverse conversion), and therefore losses are unavoidable for such conversion sections.

The following figure and formulas describe the relationship between the inverter input power and efficiency.

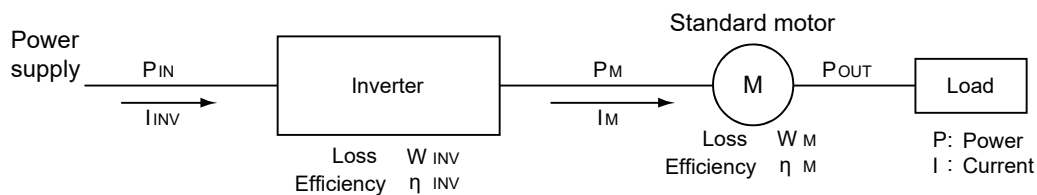


Fig. 4.1 I/O power relation chart

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}} = \frac{\text{Output}}{\text{Output} + \text{Loss}} \quad \dots\dots\dots (4.1)$$

$$\text{Inverter input power } P_{IN} = \text{Inverter output power } P_M + \text{Inverter loss } W_{INV} = \frac{\text{Inverter output power } P_M}{\text{Inverter efficiency } \eta_{INV}} \quad (4.2)$$

$$\text{Inverter input power } P_M = \text{Motor output } P_{OUT} + \text{Motor loss } W_M = \frac{\text{Motor output } P_{OUT}}{\text{Motor efficiency } \eta_M} \quad \dots\dots\dots (4.3)$$

$$\text{Motor output } P_{OUT} = \text{Motor output torque} \times \text{Motor speed} = \frac{\text{Machine force}}{\text{Machine efficiency}} \quad \dots\dots\dots (4.4)$$

- Formula (4.1): Efficiency can be expressed as the ratio of output to input, and input can be expressed by "output + loss".
- Formula (4.2): Formula for the inverter alone.
- Formula (4.3): Formula for the motor alone.
- Formula (4.4): The motor power (output) is generally expressed by "motor output torque × motor rotation speed" (generally, $P = NT$).

4 ENERGY SAVING WITH INVERTERS

As shown in Formula (4.1), input can also be expressed as output divided by efficiency. Therefore Formulas (4.2) to (4.4) can also be expressed by the formulas using efficiency. Recent inverters generate a loss of approximately 5%, resulting in an efficiency of approximately 95%.

Therefore the inverter input power is calculated as follows.

Inverter input power P_{IN}

$$= \text{Motor output } P_{OUT} + \text{Motor loss } W_M + \text{Inverter loss } W_{INV} = \frac{\text{Motor output } P_{OUT}}{\text{Total efficiency}} \dots\dots\dots (4.5)$$

$$\text{Total efficiency} = \text{Inverter efficiency } \eta_{INV} \times \text{Motor efficiency at inverter drive } \eta_M \dots\dots\dots (4.6)$$

As shown in Formula (4.5), the motor loss increases due to harmonics etc. during inverter operation compared to commercial power supply operation. As the inverter loss is added, inverter operation requires larger input power than commercial power supply operation to realize the same motor speed.

Here, think about the reason why using an inverter can save energy.

If the motor speed is decreased by an inverter, the motor output decreases proportionally as shown in Formula (4.4). Accordingly, the lower the speed becomes, the less input power is required even when the load torque is constant. (For variable-torque loads such as fans and pumps, input power used decreases significantly, leading to energy savings.)

Using efficient inverters and motors can save more energy.

4.2 Power factor

4.2.1 Power factor

A power factor is the indicator that shows how the input AC power is being used without waste.

For commercial power supply operation, a power factor can be expressed as $\cos\phi$ using ϕ , the phase difference between AC voltage and AC current.

However, since a smoothing capacitor is used in the converter section of the inverter as described in Chapter 3, the input current has a distorted waveform including harmonics as shown in the figure. Due to this, a power factor of the inverter cannot be expressed simply as $\cos\phi$.

(As voltage and current are in phase, a power factor meter indicates approximately 1.)

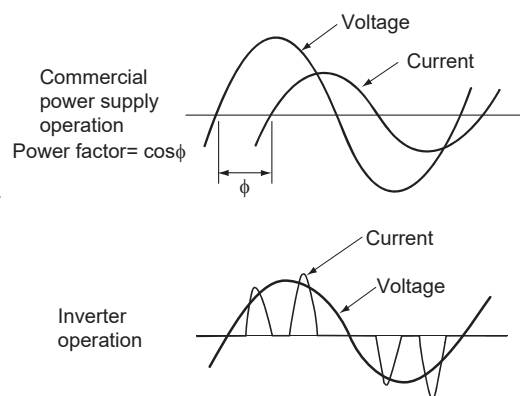


Fig. 4.2 Input voltage/current waveform (three-phase)

4 ENERGY SAVING WITH INVERTERS

In terms of electric power, a power factor indicates the efficiency of electric power, the ratio of the effectively used electric power to the supplied electric power, as mentioned first. It is calculated by the following formula:

$$\text{Power factor} = \frac{\text{Active power}}{\text{Apparent power}} \dots\dots (4.7)$$

The electric power supplied from the power supply is called "apparent power", the electric power actually consumed by the load is "active power", and the electric power not consumed by the load is "reactive power".

The figure on the right shows the relationship among these power.

The electric power is the product of voltage and current, and the phase difference changes depending on the impedance of the load.

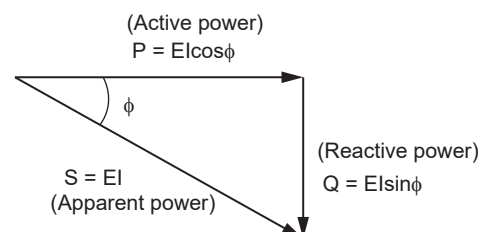


Fig. 4.3 Power relationship

Therefore, the inverter input power factor cannot be indicated accurately with a power factor meter. Calculate it using the active power and apparent power.

[Three-phase power supply]

$$\begin{aligned} \text{Total power factor of the inverter} &= \frac{\text{Active power}}{\text{Apparent power}} \\ &= \frac{\text{Three-phase input power found by the 3-wattmeter method}}{\sqrt{3} \times V (\text{power supply voltage}) \times I (\text{input current effective value})} \end{aligned}$$

[Single-phase power supply]

$$\begin{aligned} \text{Total power factor of the inverter} &= \frac{\text{Active power}}{\text{Apparent power}} \\ &= \frac{\text{Three-phase input power found by the 3-wattmeter method}}{V (\text{power supply voltage}) \times I (\text{input current effective value})} \end{aligned}$$

The power factor of the inverter alone is generally considered as approximately 60% to 80%.

Remark

For details on the inverter power supply (harmonics and instantaneous power failure), refer to Appendix 4.

4.2.2 Inverter input current and power factor improvement

In the waveform of the 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 the input current (effective) value. However, as described in Section 4.1, the power supply voltage and inverter input power do not change as long as the motor output does not change. Therefore, Formula (4.7) is used to change 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, in a case such as when an inverter is directly installed next to a high-capacity power transformer, the reactance is small, and the current is large, thus the power factor is low.

In order to improve the power factor, raise the power supply side reactance by installing 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.

☒ Good to know for checking an inverter

Installing a power factor improving reactor reduces the input current, which provides the following advantages.

- Downsizing the peripheral devices (MCCB, MC) at the inverter's input side
- Reducing the harmonic current
- Protecting the inverter from surge voltage from the power supply
- Suppressing the converter section's peak current at power-ON

The power factor improving ratio is up to about 88% by an AC reactor (FR-HAL), but about 93% by a DC reactor (FR-HEL).

(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 the fundamental wave according to the Architectural Standard Specifications (Electrical Installation) (2010 revisions) supervised by the Ministry of Land, Infrastructure, Transport and Tourism of Japan) (when load is 100%)

Operating environment

- Surrounding air temperature: -10°C to +50°C
- Ambient humidity: 90% RH or less
- Vibration: 5.9 m/s² or less
- Atmosphere: No dust and dirt, corrosive gas, flammable gas

Usage voltage Three-phase 200 to 240 VAC 50/60 Hz (380 to 480 V 50/60 Hz)

Connection method Connected to the inverter input side.

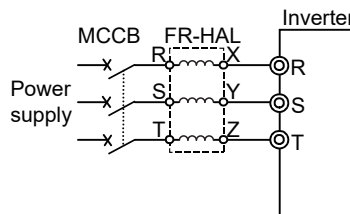


Fig. 4.4 FR-HAL connection example

(2) DC reactor FR-HEL(-H)

A DC reactor, having an effect similar to an AC reactor, is smaller and lighter and allows for less losses.

Improvement effect Power supply power factor 93% (94.4% when calculated with 1 power factor for the fundamental wave according to the Architectural Standard Specifications (Electrical Installation) (2010 revisions) supervised by the Ministry of Land, Infrastructure, Transport and Tourism of Japan) (when load is 100%)

Operating environment

- Surrounding air temperature: -10°C to +50°C
- Ambient humidity: 90% RH or less
- Vibration: 5.9 m/s² or less
- Atmosphere: No dust and dirt, corrosive gas, flammable gas

4 ENERGY SAVING WITH INVERTERS

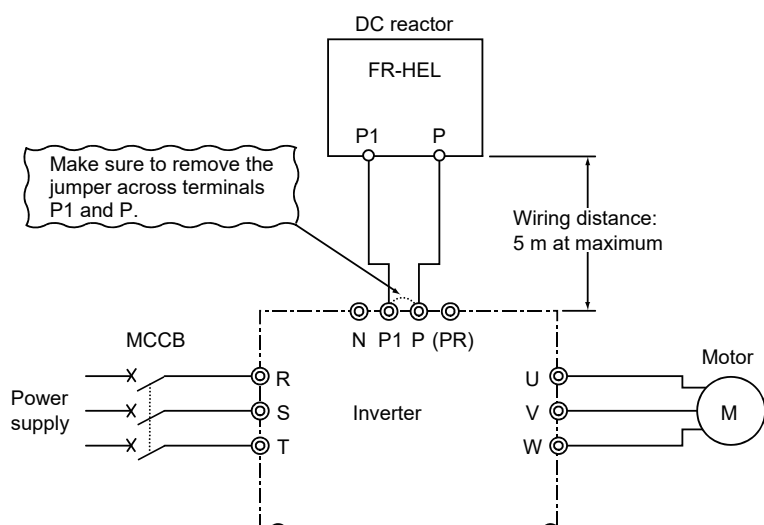


Fig. 4.5 FR-HEL connection example

NOTE

A DC reactor (FR-HEL) cannot be connected to the single-phase 100 V power input models as terminal P1 is not available. Connect an AC reactor (FR-HAL).

The following shows the input power, motor current, and inverter input current for the following conditions: when a conveyor (7.5 kW constant-torque load output) is operated at 30 m/min with a commercial power supply, and when a conveyor is operated at 30 m/min and 15 m/min with an inverter. It is assumed that the power supply is 200 V, 60 Hz, motor efficiency $\eta_M = 0.9$, motor power factor $\cos\phi = 0.88$.

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

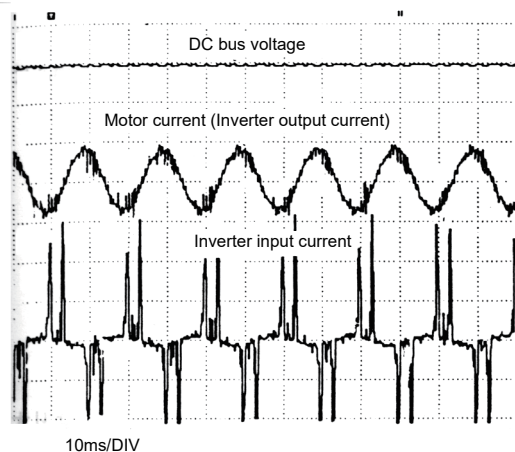


Fig. 4.6 Measurement example of I/O current waveform (50 Hz)

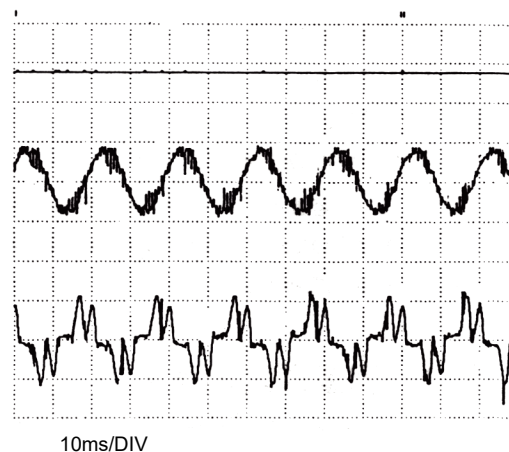


Fig. 4.7 Measurement example of I/O current waveform (50 Hz with a power factor improving reactor)

4 ENERGY SAVING WITH INVERTERS

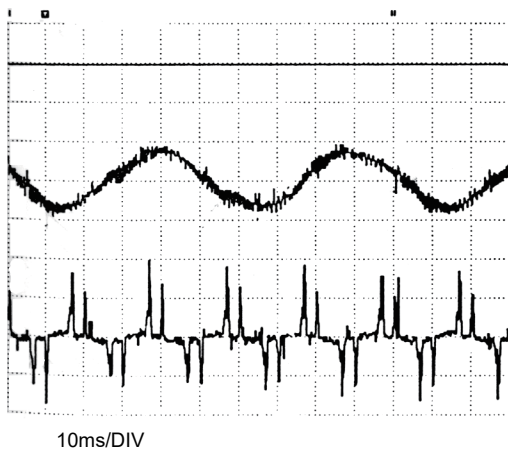


Fig. 4.8 Measurement example of I/O current waveform (20 Hz)

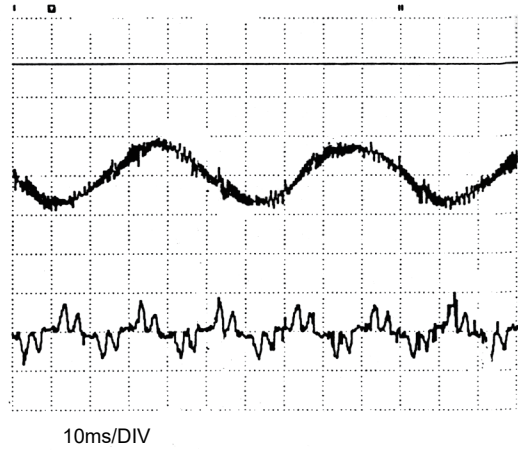


Fig. 4.9 Measurement example of I/O current waveform (20 Hz with a power factor improving reactor)

As shown in the waveforms above, installing a reactor lowers the peak value of the inverter input current, which reduces the effective value and improves the power factor.

4.3 Energy saving with inverters

As explained above, commercial power supply operation is more efficient when a motor is driven at the commercial frequency. This section describes why inverter operation enables energy saving.

4.3.1 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. 4.10 shows the relation between air volume and the input (power) to the motor under damper control and inverter control. Even if air volume is decreased under damper control, the input to the motor stays roughly the same.

In contrast, the input to the motor drastically reduces under inverter control.

The arrow in the figure indicates the amount of the energy saved by using inverter control instead of damper control.

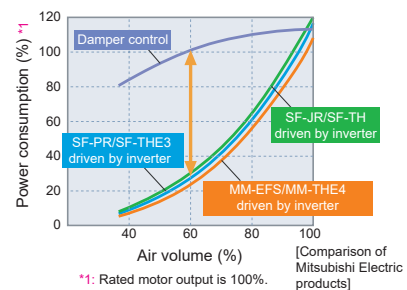


Fig. 4.10 Example of blower operation characteristic

4 ENERGY SAVING WITH INVERTERS

(2) Energy saving for constant-torque load

Energy saving for constant-torque load, such as conveyors, can also be expected by lowering the speed.

Based on the relation between the speed and load torque indicated in Fig. 4.11, the required power is estimated.

The required power is calculated by "speed $\times$ load torque", and indicated as the shaded area in the following figure.

The required power when air volume (flow rate) or moving speed is 50% for fans/pumps and conveyors are compared as follows.

• Fans and pumps

The required power amount is indicated as

 in the figure on the right, and is one-eighth the amount under 100% air volume (flow rate).

• Conveyors

The required power amount is indicated as

 in the figure on the right, 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.

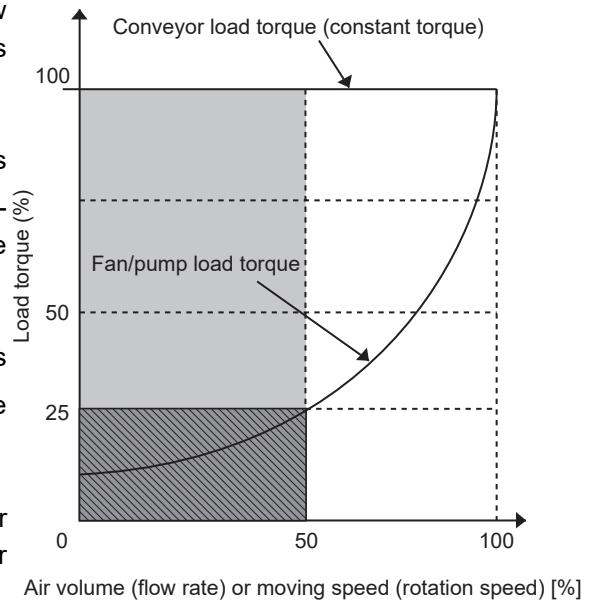


Fig. 4.11 Comparison of required power

4.3.2 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 as torque during low-speed operation is not required. Thus, the inverter's output current is divided into excitation current and torque current by vector calculation, and the excitation current is controlled so that the motor loss can be minimized.

An inverter controls a motor so that the ratio between the excitation current I_d and the torque current I_q brings the maximum motor efficiency.

With this method, energy saving effects can be expected during constant-speed operation as well as during acceleration/deceleration.

In addition, when Advanced magnetic flux vector control is selected, Advanced optimum excitation control is available, enabling more efficient operation.

Advanced optimum excitation control provides a large starting torque with the same motor efficiency as under the Optimum excitation control. Without the need of troublesome adjustment of parameters (acceleration/deceleration time, torque boost, etc.), acceleration is done in a short time. Also, energy saving operation with the utmost improved motor efficiency is performed during constant-speed operation.

For the FR-E800, set G030 (Pr.60) Energy saving control selection = "9" to select Optimum excitation control.

* Optimum excitation control will be enabled under V/F control and Advanced magnetic flux vector control.

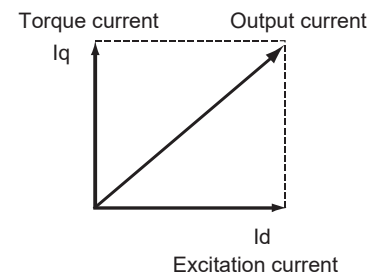
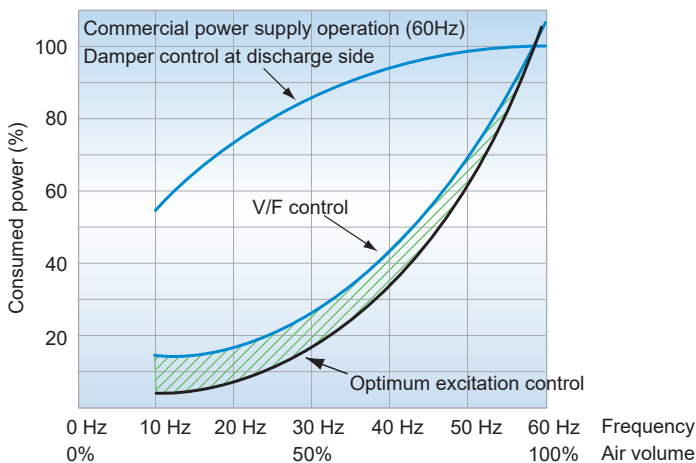


Fig. 4.12 Blower operation characteristics

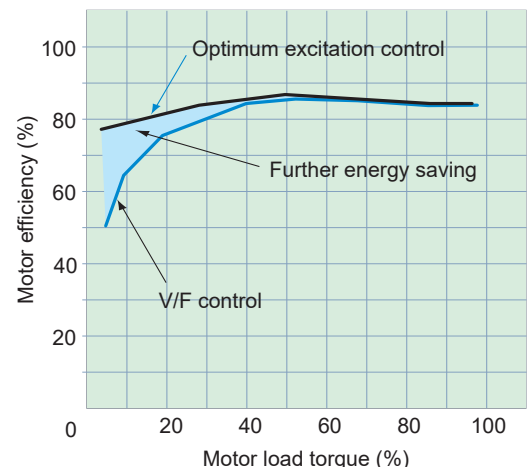


Fig. 4.13 Motor efficiency with FR-E800 Optimum excitation control

4 ENERGY SAVING WITH INVERTERS

4.3.3 Energy saving monitoring

From the difference between the power consumption estimated value during commercial power supply operation and the input power during operation, the energy saving effect by use of the inverter can be monitored and output. The energy saving effect can also be checked using an operation panel, output terminal, or network.

The output power amount measured by the inverter can be output in pulses. The cumulative power amount can be easily checked. (This function cannot be used as a meter to certify electricity billings.)



[Training]

To display the monitored value on the third monitor of the operator panel, set M100 (Pr.52) = "50". For batch monitoring by FR Configurator2, the monitored value can be checked with "Power saving effect / Energy saving effect".

* For details on the display conditions (parameter settings) and calculation formulas, refer to the FR-E800 Instruction Manual (Function).

4.4 Energy saving with motors

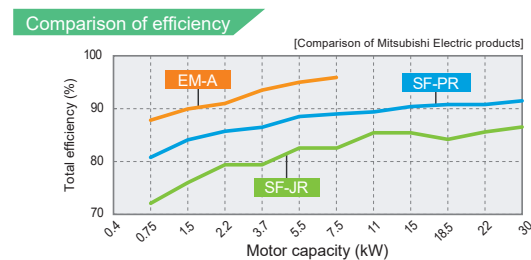
Further energy saving operation is enabled by using high-efficiency induction motors or PM motors.

4.4.1 General-purpose motor (SF-PR)

The Mitsubishi Electric SF-PR high-performance energy saving motor conforms to the Japanese domestic Top Runner Standard (IE3 equivalent). Its energy-saving operation contributes to reduction in the electricity charges, which in turn lowers the running cost.

Motor constants are stored in the inverter. Energy-saving operation can be started just by setting parameters.

Incurred loss of an IE3-compatible motor has been reduced by approximately 40% compared with an SF-JR motor.



Remark

For geared motors, a premium geared motor conforming to IE3 is available.
For details on model names and other information, refer to the Mitsubishi Electric FA Website or the catalogs.

4.4.2 PM motor (MM-GKR, EM-A)

The PM motor achieves even higher efficiency as compared to the general-purpose motor. The setting for driving PM motors is enabled just by setting parameters.

Why is a PM motor so efficient?

- 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.

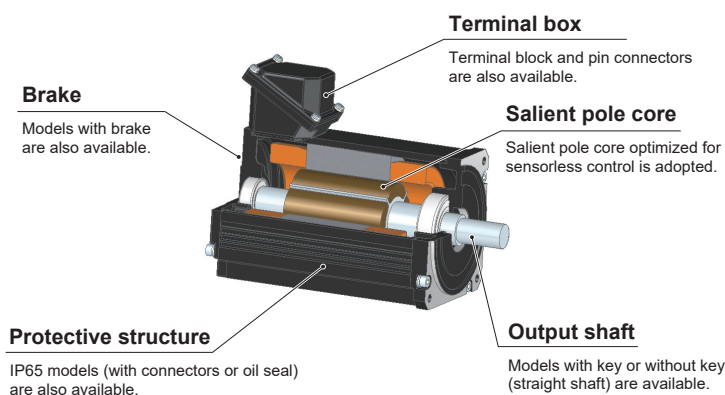
Motor achieving IE5 efficiency class for variable speed AC motors

Using the IE5 efficiency class motor reduces generating efficiency by approximately 60% compared with the SF-JR motor and approximately 20% compared with the SF-PR motor.

4 ENERGY SAVING WITH INVERTERS

4.4.3 Energy-saving high-accuracy PM motor EM-A series

Supported models: FR-E800, FR-A800 (for general industrial applications), etc.



This high-performance magnet motor has Mitsubishi Electric's unique salient pole core *1 and enables positioning and speed control without using sensors.

The volume has been reduced by 50% to 60% and the mass by 30% to 50% compared with induction motors with the same output capacity. As the rotor consists of a salient pole core and permanent magnets affixed to the surface, the motor inductance varies according to the rotation position. This inductance change is utilized for sensorless control. This new salient pole type magnet motor and Mitsubishi Electric's unique high-performance sensorless control technique enable highly accurate speed control and positioning without using an encoder.

*1 Japanese Patent No. 5646119

Motor structure (section view)

Induction motor	General magnet motor	Salient pole type magnet motor (EM-A series)
<p>Rotor conductor (aluminum)</p> <p>Stator coil (three-phase coil)</p> <p>Stator</p> <p>Shaft</p> <p>Rotor</p>	<p>Permanent magnet</p> <p>Stator coil (three-phase coil)</p> <p>Stator</p> <p>Shaft</p> <p>Rotor</p>	<p>Permanent magnet</p> <p>Salient pole core</p> <p>Stator coil (three-phase coil)</p> <p>Stator</p> <p>Shaft</p> <p>Rotor</p>

4 ENERGY SAVING WITH INVERTERS

4.4.4 Premium high-efficiency IPM motor MM-EFS series

Supported models: FR-F800 (for fans and pumps), etc.

- What is an IPM motor...

IPM stands for "Interior Permanent Magnet".

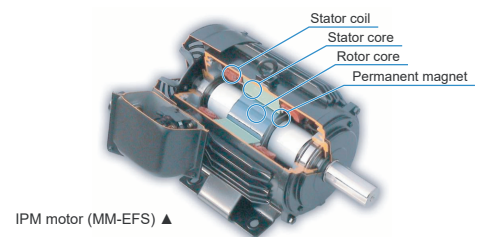
An IPM motor is a synchronous motor with permanent magnets embedded inside.

- What is IPM high-efficiency control...

A speed detector such as an encoder is not required as the inverter estimates the motor speed by the calculation from the inverter output voltage and current.

The inverter drives the IPM motor with the least required current for a load in order to achieve the highest motor efficiency.

IPM high-efficiency control can save more energy compared to the operation of high-performance energy-saving motors.

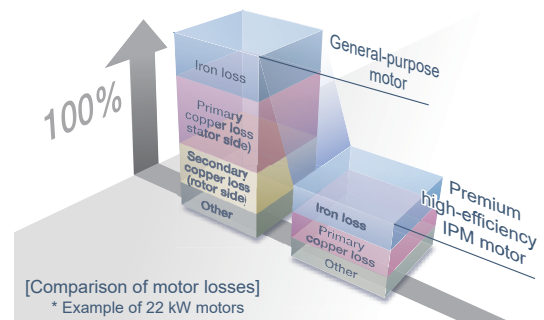


IPM motor (MM-EFS) ▲

Motor structure (section view)

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

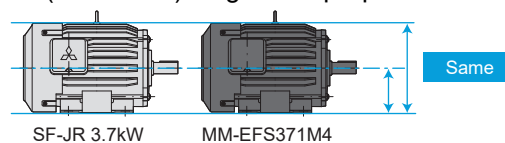
- No current flows to the rotor (secondary side), and no secondary copper loss is generated.
- Magnetic flux is generated with permanent magnets, and less motor current is required.



(1) Installation size compatible with general-purpose motors

The frame number is the same (same size) as the Mitsubishi Electric general-purpose motor SF-JR/SF-HR series (55 kW or lower) and SF-TH series (75 kW or higher). Replacement is easy as the installation sizes are compatible.

Same frame number (same size) as general-purpose motors



Remark

Note that a PM motor and IPM motor cannot be driven by the commercial power supply. Use the applicable inverter.

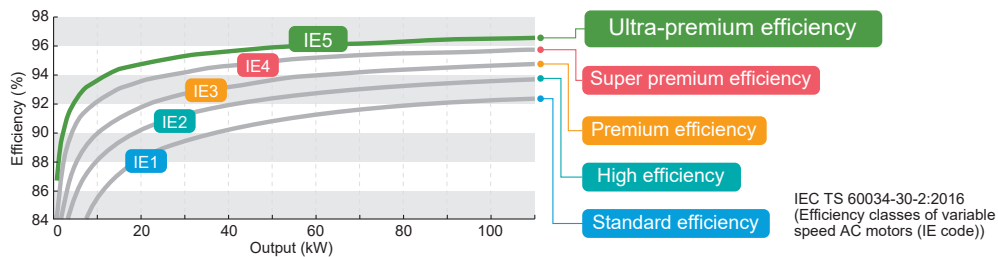
4 ENERGY SAVING WITH INVERTERS

(2) Efficiency level (efficiency class)

The PM motor (EM-A) and IPM motor (MM-EFS) achieve IE5, the highest-class efficiency standard.

	Commercial power supply operation	Variable-speed operation
IE5 Ultra-premium efficiency		Sustainable motor RF-SR Global PM motor EM-A Premium high-efficiency IPM motor MM-EFS
IE4 Super premium efficiency		
IE3 Premium efficiency	Superline premium series SF-PR	
IE2 High efficiency	Superline eco series SF-HR	
IE1 Standard efficiency	Superline series SF-JR	
(Substandard)		

The efficiency class is based on the following standards.
Commercial power supply operation: IEC 60034-30-1, variable-speed operation: IEC TS 60034-30-2:2016



Remark

Note that a PM motor and IPM motor cannot be driven by the commercial power supply. Use the applicable inverter.

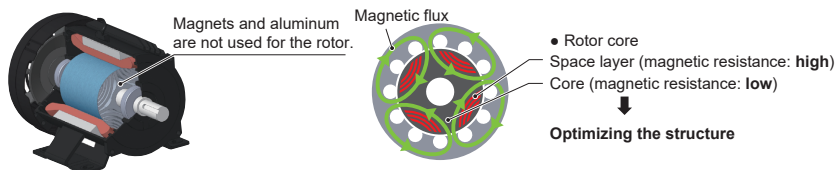
☒ Good to know for checking a motor



Mitsubishi Electric synchronous reluctance motor **MELSUSMO**

• Efficiency improving technology

Our unique optimization technology achieves the design of the rotor that significantly improves the trade-off between high efficiency and rotor strength.



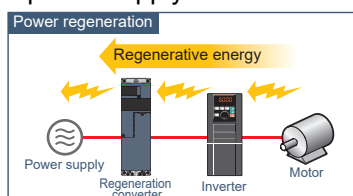
The commercial power supply operation is not available. Some inverters are not applicable. For details, refer to the Mitsubishi Electric FA Website.

4 ENERGY SAVING WITH INVERTERS

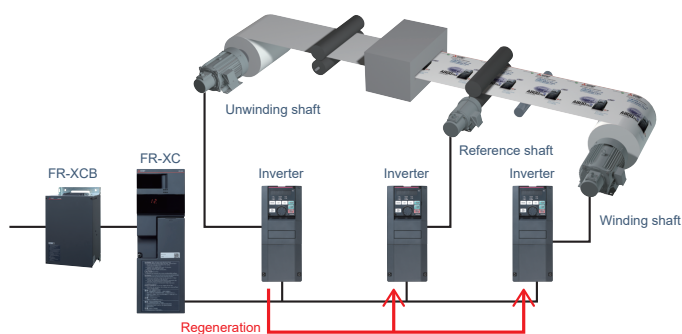
4.5 Energy saving with the regenerative option

Power regeneration function

While the motor rotates to drive the machine during power driving, the machine rotates the motor during regenerative driving, which results in energy saving since the motor serves as a generator which returns the power to the power supply.



By using the multifunction regeneration converter (FR-XC) as a common converter, the power returned from an inverter during regenerative drive can be supplied to another inverter, which in turn saves energy.



1

BASICS OF
INVERTERS

2

MOTOR
CHARACTERISTICS
AT INVERTER DRIVE

3

PRINCIPLE AND
FUNCTIONS OF
INVERTER

4

ENERGY SAVING
WITH INVERTERS

5

CAPACITY SELECTION
FOR MOTOR AND
INVERTER

APP

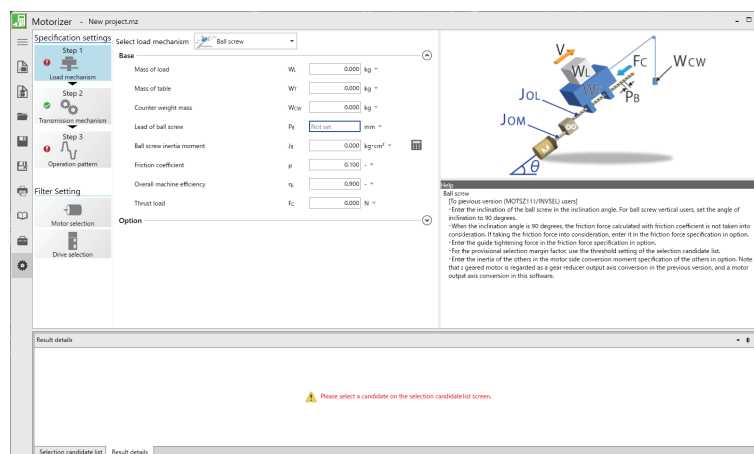
APPENDIX

Memo

CHAPTER 5 CAPACITY SELECTION FOR MOTOR AND INVERTER

5.1 Selection

Drive System Sizing Software Motorizer helps users select motors by entering data of mechanical configuration, specifications, and operating patterns. Applicable combinations include inverters, AC servo amplifiers, and sensorless servo drive units.



Features

- Flexibly supporting load mechanisms
A load mechanism can be selected from 12 typical types, and an inclination angle of the load mechanism can be set as desired.
In addition, transmission mechanisms such as coupling can be added.
- Supporting multi-axis system selection
Multi-axis servo amplifiers and converters are supported, and the operation patterns for multi-axis system can be set.
Regenerative options can be set for multi-axis system.
- Selecting multiple applicable models
Multiple applicable models are displayed in the list. The list shows motor models, driver types and capacities, and other relevant calculation result data such as the effective load ratio and moment of inertia as well.

Item	Description
Types of motor/drive	Servo, inverter, sensorless servo
Types of load mechanism	Ball screw, rack and pinion, roll feed, rotary table, cart, elevator/hoist, conveyor, fan, pump, crank, winding/unwinding, generic (rotary), generic (linear), linear servo
Types of transmission mechanism	Coupling, external gear reducer, v belt and pulley, toothed belt / roller chain
Operation pattern	Constant speed / pause, acceleration/deceleration, trapezoid, triangle, speed CSV file, MELSOFT GX LogViewer file
Types of input support of moment of inertia calculation function	Solid cylinder, hollow cylinder, disk, rectangular solid, truncated cone, sphere, generic

Item	Description
Sizing results	Result, motor type, power supply voltage, motor, motor capacity, drive, drive capacity, effective torque, torque effective load rate, peak torque, peak load rate, effective torque at stop, effective load rate at stop, motor output, motor output rate, maximum speed, maximum speed rate, maximum load inertia moment, inertia moment ratio, regenerative power, regenerative load ratio, regenerative option, maximally increased torque, rated speed, brake, oil seal, structure specification, graph of motor side speed / motor side torque / motor output
Printing of output of results	Prints load mechanism, transmission mechanism, operation pattern, and sizing results.
Data saving	Load mechanism, transmission mechanism, operation pattern, motor selection, drive selection, and sizing results are saved with a file name.

5.2 How to use Drive System Sizing Software

Drive System Sizing Software Motorizer can be downloaded for free at Mitsubishi Electric FA Website.

(1) Specifications settings

- (a) Load mechanism (Step 1)
 - 1) Select the load mechanism in "Select load mechanism". Machine structure will be displayed.
 - 2) Set the base information and options.
- (b) Transmission mechanism (Step 2)
 - 1) Select [Motor] and set Inverter to ON in "Motor display".
 - 2) Select [Transmission mechanism1] and set the moment of inertia in "Transmission mechanism1:Coupling".
 - 3) Select [Transmission mechanism2] and set "Transmission mechanism2:External gear reducer".
- (c) Operation pattern (Step 3)
 - 1) Click the [Add] button, select the operation pattern, and set the base information and acceleration/deceleration.

(2) Filtering setting

- (a) Motor selection
 - 1) Set Inverter to ON in "Motor display". (Set Servo and Sensorless servo to OFF.)
 - 2) Set "Motor common settings".
 - 3) Set "Transmission mechanism/motor common settings".
 - 4) Select the motor in "Motor selection candidate".
- (b) Drive selection
 - 1) Set Inverter to ON in "Drive display". (Set Servo and Sensorless servo to OFF.)
 - 2) Select the power supply voltage in "Common settings of the motor and drive".
 - 3) Set "Drive common settings".
 - 4) Select the drive in "Drive selection candidate".

(3) Selection result

The selection result is displayed in the selection candidate list. The green checkmark icon means "Match", indicating that the motor satisfies the selection requirements.

Clicking "Drive capacity" in the selection candidate list sorts the motor capacity in ascending order.

Select the display conditions.

☒ Match
☐ Warning
☐ Unmatch

Select only "Match" to list only the models that satisfy the selection requirements.

Clicking "Motor capacity" sorts the motor capacity in ascending order.

Motor	Motor capacity[kW]	Drive	Drive capacity[kW]	Torque effective load rate[%]	Peak load rate[%]	Effective load rate at stop[%]
SF-PR	0.750	FR-A820-0.75K(00077)(-E/GF)	0.750	-	17.5	-
SF-PR	0.750	FR-E820-0.75K(0050)(-EPA/EPB)	0.750	-	17.5	-
SF-JR	0.400	FR-A820-0.75K(00077)(-E/GF)	0.750	-	32.7	-

(4) Criteria for selection results

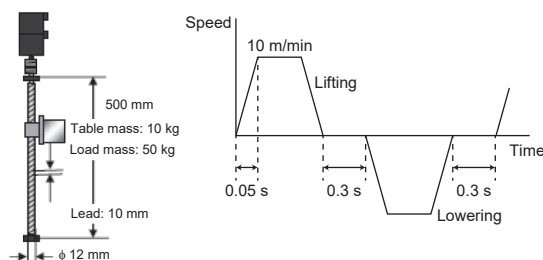
- Inertia moment ratio: Equal to or less than the recommended load inertia moment ratio described in the catalog. For a motor with reduction gear, equal to or less than the permissible load inertia moment ratio specified in the reduction gear equipped model specifications.
- Peak torque: Maximum torque or less
- Effective torque: Rated torque or less. For the vertical axis, 60% or less of the rated torque.
- Regenerative load rate: 80% or less

5.3 Selection example

Selection example: Vertical movement of a ball screw

The following conditions are assumed: Travel distance of 200 mm, speed of 10 m/min, acceleration/deceleration time of 0.05 s, stopping time of 0.3 s for both the upper and lower ends, efficiency of 90% at the driving section, and friction coefficient of 0.1.

(1) Selecting the ball screw



Select [Step 1 Load mechanism] and select the ball screw in "Select load mechanism".

Set the base information and options. Set "0" for the item whose actual value is unknown even if a value is pre-set.

The screenshot shows the 'Motorizer - New project.mz' window. The 'Specification settings' dialog box is open, showing the 'Base' and 'Option' tabs. The 'Base' tab is selected, and the 'Select load mechanism' dropdown is set to 'Ball screw'. The following parameters are set:

Parameter	Value
Mass of load (Wl)	50.000 kg
Mass of table (Wt)	10.000 kg
Counter weight mass (Wcw)	0.000 kg
Lead of ball screw (Ps)	10.000 mm
Ball screw inertia moment (Jb)	0.038 kg-cm ²
Friction coefficient (μ)	0.100
Overall machine efficiency (η)	0.900
Thrust load (Fc)	0.000 N
Frictional force (Ff)	0.000 N
Inertia moment of other motor side (Jom)	0.000 kg-cm ²
Inertia moment of other load side (Jol)	0.000 kg-cm ²
Inclination angle (θ)	90.000 degrees

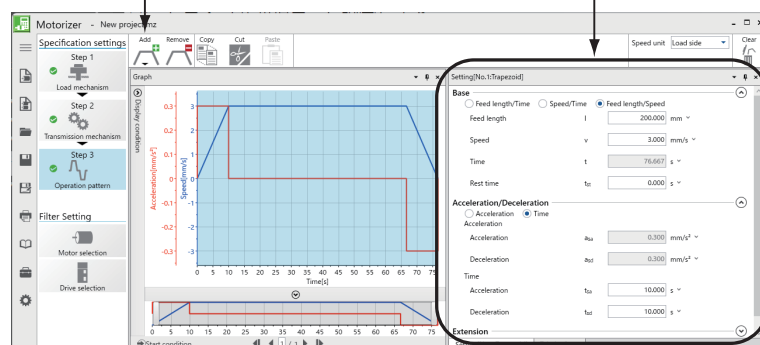
(2) Setting the operation pattern

Select [Step 3 Operation pattern], click the [Add] button, and select the operation pattern.

Set the operating conditions. (Feed length: 200 mm and -200 mm, speed: 10 m/min, rest time: 0.3 s, acceleration time: 0.05 s, deceleration time: 0.05 s)

Click [Add] to select the operation pattern.

Set the operating conditions.



5 CAPACITY SELECTION FOR MOTOR AND INVERTER

(3) Calculating the capacity

The selection result is displayed in the "Selection candidate list".

Motor	Drive	Regenerative option	Peak load rate[%]	Max frequency rate[%]	Minimum frequency rate[%]	Regenerative load rate[%]	Load rate of electronic thermal of converter[%]	Motor equivalent current rate[%]	Electronic thermal judgement time rate[%]	Load rate of the inverter rate current[%]
FR-A220-2.2K04M1P1-E/GF	FR-B20-3.7E + DR20200-14D 1/3 Serial		157.2	1.2	0.6	14.5	0.0	0.2	0.2	0.2
FR-E200-2.2K0110S-EP/EPB	MRS-100H4C		157.2	1.2	0.6	14.5	0.0	0.2	0.2	0.2
FR-A220-15K0377S-E/GF	FR-3C-22K/18.5K-PWM		157.2	1.2	0.6	14.5	0.0	0.2	0.2	0.2
FR-E200-7.5K0350S-EP/EPB	FR-3C-22K/18.5K-PWM		157.2	1.2	0.6	14.5	0.0	0.2	0.2	0.2
FR-A220-1.5K0105S-E/GF	FR-3C-7.5K		157.2	1.2	0.6	14.5	0.0	0.2	0.2	0.2
FR-E200-1.5K0105S-E/GF	FR-3C-22K/18.5K-PWM		157.2	1.2	0.6	14.5	0.0	0.2	0.2	0.2

(4) Criteria for selection results

The recommended models are the models with the green checkmark icon. Other models are available unless the red cross mark icon or the yellow exclamation mark icon is indicated.

Remark

For Drive System Sizing Software Motorizer ver.1.050C or later, the calculation process display screen can be accessed from the result details after a model is selected in the selection candidate list. (Not available for the crank and winding/unwinding load mechanisms.)

Memo

APPENDIX

Appendix 1 Power supply of inverter (harmonics and instantaneous power failure)

This chapter explains the influence of harmonics generated from the inverter on the power supply and its system to which an inverter is connected. Determine the level of influence on the peripheral devices according to the amount of harmonics generated from the inverter to consider concrete countermeasures against harmonics.

This section also explains the influence of voltage fluctuations such as an instantaneous power failure and voltage drop on the inverter is explained. It is important to understand the operation of the inverter and motor well.

POINT

1. Differences between harmonics and noise
2. Inflow path and the size of harmonic current
3. Harmonic suppression guidelines and handling methods
4. Operation of the inverter and motor at an instantaneous power failure (including an instantaneous voltage drop)

Appendix 1.1 Harmonics

A harmonic has a frequency that is an integral multiple of the fundamental wave (generally the power supply frequency). The composition of a single fundamental wave and multiple harmonics is called a distorted wave. (Refer to Fig. App 1.2.)

A distorted wave typically includes harmonics in a high-frequency range (kHz to MHz order). However, in a power distribution system, harmonics are usually up to 40th to 50th degrees (to 3 kHz). Harmonics have different problems from those of high-frequency that usually assume an irregular form. For example, noise and electromagnetic interference from the computer (refer to Appendix 2) are local problems which are closely related to hard devices, and the influences and measures are different from those of harmonics in electrical power network. This must be defined first.

$$i = i_o + \sum_{n=1}^{\infty} i_n \cdot \sin(2\pi f n t + \psi_n) \dots \dots \dots (\text{App 1.1})$$

$n = 1, 2, 3, \dots$
 $f = \text{Fundamental frequency}$

APPENDIX

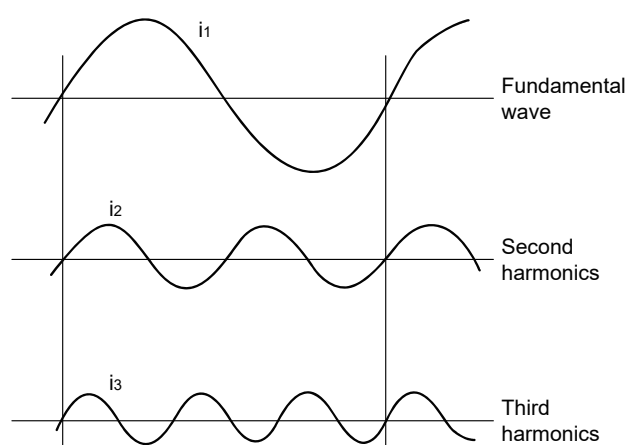


Fig. App 1.1 Fundamental wave and harmonics

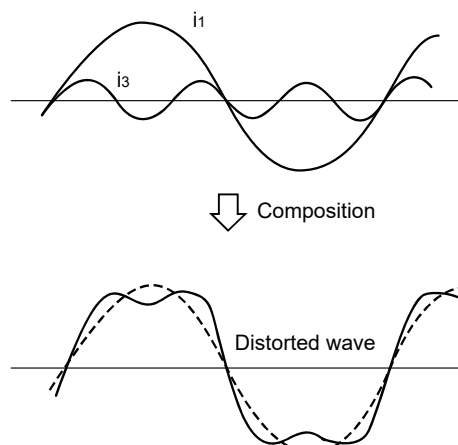


Fig. App 1.2 Distorted wave

Table App 1.1 Differences between harmonics and noise

Item	Harmonics	Noise
Frequency	Normally 40th to 50th degrees or less (3 kHz or less)	High frequency (several 10 kHz to MHz order)
Source	Converter section	Inverter section
Cause	Rectifier circuit commutation	Transistor switching
Environment	To-electric channel, power impedance	To-space, distance, wiring path
Quantitative understanding	Theoretical calculation possible.	Due to random occurrence, quantitative grasping is difficult.
Generated amount	Nearly proportional to the load capacity	Changes with the current variation ratio. (Gets larger as switching speed increases.)
Affected equipment immunity	Specified by standards per equipment.	Different depending on maker's equipment specifications.
Countermeasure	Provide a reactor (L).	Increase distance (ℓ).

Appendix 1.2 Characteristics of rectifier circuit and generated harmonics

Harmonics are generated by a rectifier, an AC power adjuster, etc. The converter circuit of a general-purpose inverter consists of a rectifier circuit, and generates a large amount of harmonic current. There are various types of rectifier circuits depending on the main circuit method. The three-phase bridge method is most widely adopted in the general-purpose inverter. (Refer to 3.2.) The ordinal number "n" of the generated harmonic current is theoretically equal to $PK \pm 1$ (P = number of pulses, $K = 1, 2, 3, \dots$). The general-purpose inverter using the three-phase bridge method ($P = 6$, as 6-pulse converter is used) generates $6K \pm 1$ st (5, 7, 11, 13th.....) harmonic current. The magnitude of the harmonic current (harmonic content) is $1/n$, and as the ordinal number of harmonic current increases, the generated amount decreases. The inverter using the single-phase power supply input generates $4K \pm 1$ st (3, 5, 7, 9th.....) harmonic current.

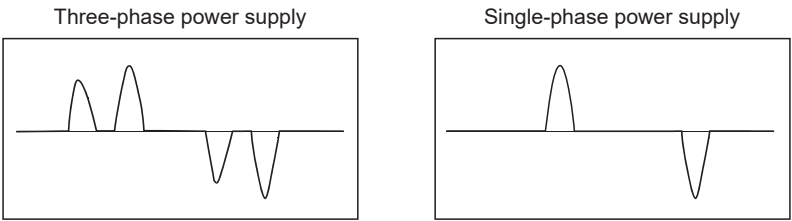


Fig. App 1.3 Inverter input current waveform (harmonic current)

Appendix 1.3 Split-flow path of harmonic current

When harmonic current is a problem in the power distribution system, the power supply of the harmonic current is not a general commercial power supply but the source of harmonics (the converter section for the general-purpose inverter). The commercial power supply (low and high voltage power transformer) becomes a load on harmonics. Therefore, as shown in the example of Fig. App 1.4, the harmonic current " I_n " generated from the inverter ($I_n = I_2 + I_3 + I_4 + \dots$ (n stands for the ordinal number)) splits and flows in proportion to the power transformer impedance ($\dot{Z}_L = R_L + j_nX_L$) and the devices connected in parallel with it (in the example of Fig. App 1.4, the motor B and the capacitor), in other words the reciprocal ratio $1/Z$ between the motor B impedance ($\dot{Z}_M = R_M + j_nX_M$) and the capacitor impedance ($\dot{Z}_C = j_nX_r - jX_c / n$). Since the frequency of harmonics is higher than that of the power supply, the impedance of the capacitor decreases and thus the harmonic current tends to flow into the capacitor. As a result, the capacitor may be overheated or damaged.

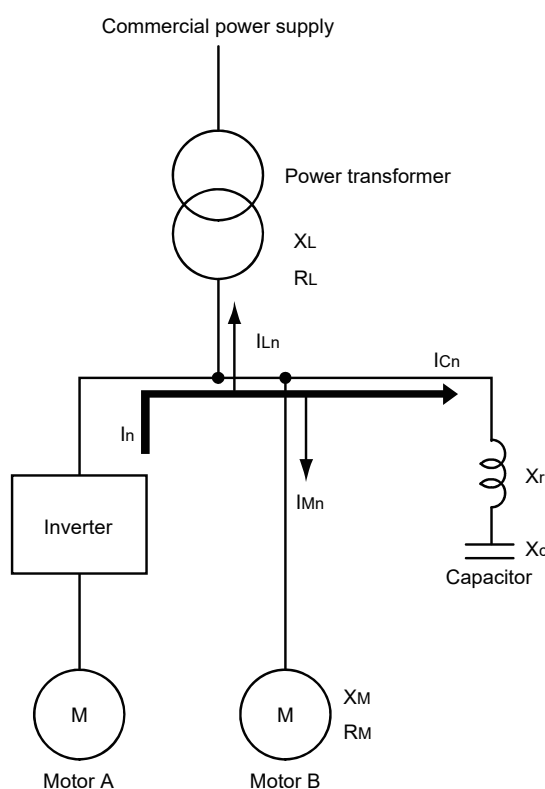


Fig. App 1.4 Power distribution system

☒ Good to know for checking an inverter

- Current tends to flow into the smaller impedance, and the harmonics may increase when there are capacitive impedance elements (such as a power factor correction capacitor).

Therefore, in harmonic problems, 1) Since the impedance at the power supply side $\dot{Z}_s$ is represented by the short-circuit capacity of the power supply system, the larger the power supply capacity is, the less the influence of other elements is. 2) Inductive loads can be ignored since they represent high impedance to harmonics. 3) Only capacitive loads such as a power factor correction capacitor should be considered.

Appendix 1.4 Harmonic suppression guidelines

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 200 V input specifications 3.7 kW or lower were previously covered by "the Harmonic Suppression Guidelines for Household Appliances and General-purpose Products" and other models were covered by "the Harmonic Suppression Guidelines for Consumers Who Receive High Voltage or Special High Voltage". However, the transistorized inverter has been excluded from the target products covered by "the Harmonic Suppression Guidelines for Household Appliances and General-purpose Products" in January 2004 and "the Harmonic Suppression Guideline for Household Appliances and General-purpose Products" was repealed on September 6, 2004. All capacities and all models of general-purpose inverters used by specific consumers (consumers who receive high voltage) are covered by the "Harmonic Suppression Guidelines for Consumers Who Receive High Voltage or Special High Voltage".

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

These guidelines set forth the maximum harmonic currents outgoing from a high-voltage or especially high-voltage receiving consumer who will install, add or renew harmonic generating equipment. If any of the maximum values is exceeded, certain measures must be taken.

However, we ask the users who are not covered by the guideline to connect a DC reactor or an AC reactor as usual.

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

Input power	Applicable capacity	Countermeasure
Three-phase 200 V	All capacities	Make a judgment based on the "Harmonic Suppression Guidelines for Consumers Who Receive High Voltage or Special High Voltage" issued by the Japanese Ministry of Economy, Trade and Industry (formerly Ministry of International Trade and Industry) in September 1994 and take countermeasures if necessary. For how to calculate the power supply harmonics, refer to the following.
Three-phase 400 V		<p>References</p> <ul style="list-style-type: none"> "Harmonic Suppression Measures of the General-purpose Inverter" January 2004 JEMA The Japan Electrical Manufacturers' Association "Calculation Method of Harmonic Current of the General-purpose Inverter Used by Specific Consumers" JEM-TR201 (Revised in December 2003): The Japan Electrical Manufacturers' Association

APPENDIX

For compliance with the "Harmonic Suppression Guideline of the General-purpose Inverter (Input Current of 20A or Less) for Consumers Other Than Specific Consumers" published by JEMA

Input power	Applicable capacity	Countermeasure
Three-phase 200 V	3.7 kW or lower	Connect the AC reactor or DC reactor recommended in the catalog or the Instruction Manual. References • "Harmonic Suppression Guideline of the General-purpose Inverter (Input Current of 20A or Less)" JEM-TR226 (Established in December 2003): The Japan Electrical Manufacturers' Association

Follow the procedure below to examine the necessity of the harmonic suppression techniques along the "Harmonic Suppression Guidelines for Consumers Who Receive High Voltage or Special High Voltage".

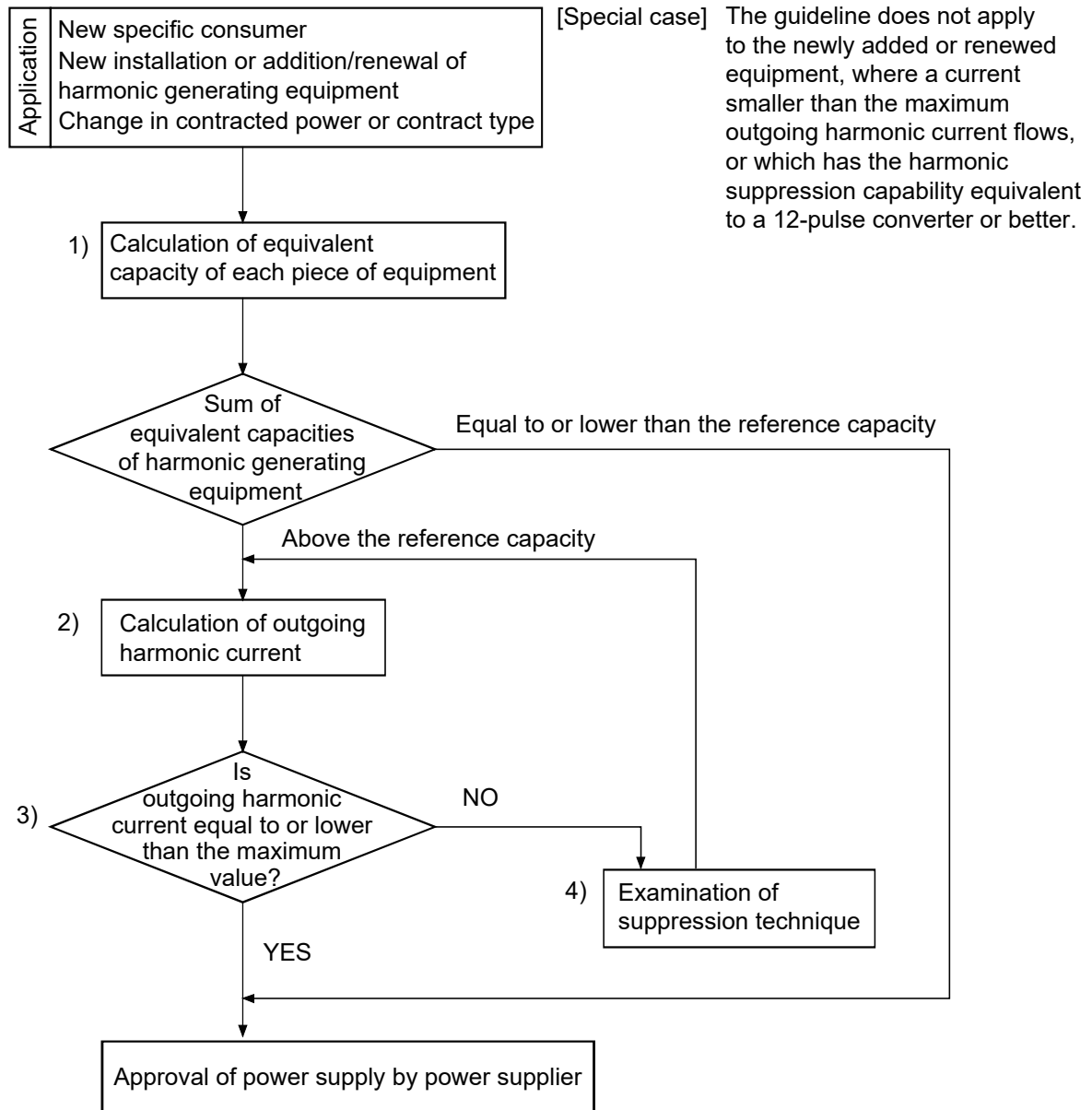


Fig. App 1.5 Harmonics examination flowchart

Appendix 1.5 Overview of harmonic suppression measures

The following table lists the basis and characteristics overview of the methods to suppress and absorb harmonics.

No.	Item	Description	Effects, etc.
1)	Reactor for inverter (FR-HAL, FR-HEL)	Connect an AC reactor on the power supply side of the inverter or/and a DC reactor on the DC side of the inverter to increase the circuit impedance and suppress the harmonic current.	Harmonic current is suppressed to approximately half.
2)	High power factor converter (FR-HC2)	The converter switches the converter section ON/OFF to reshape an input current waveform into a sine wave, greatly suppressing harmonics. Connect it to the DC area of an inverter.	Harmonic current is suppressed to almost zero.
3)	Installation of power factor improving capacitor	The power factor improving capacitor has a small impedance for high frequency components and can absorb the harmonic current when used with a reactor connected in series. This capacitor can be installed in either of the 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 combinations of Y to Δ and Δ to Δ will cause a timing shift that suppresses peak current, resulting in an effect equivalent to 12 pulses.	Even if the capacities of the combinations of Y to Δ and Δ to Δ are different, the effect equivalent to 12 pulses is expected for the smaller one. Thus, harmonic current can be suppressed to approximately half.
5)	AC filter	As in a power factor improving capacitor, a capacitor and reactor connected in series are used together to reduce the impedance for a specific frequency (ordinal number). The harmonic current is absorbed greatly.	Current is greatly suppressed. (The guideline requirements can be satisfied.)
6)	Active filter	This filter detects the current in 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 the harmonic current at the detection point.	Current is greatly suppressed. (The guideline requirements can be satisfied.) Since this filter corrects the whole waveform, a power factor can be improved.

* The countermeasures above are effective in the following order:

- For suppression effect: 6) or 2) → 5) → 4) → 3) → 1)
- For cost: 1) → 2) → 3) → 4) → 5) → 6)

For details on harmonics, refer to "Mitsubishi Electric Harmonics Suppression Devices" (K-K06-3-C9176). The catalog can be downloaded from the Mitsubishi Electric FA Website.

Appendix 1.6 Influence to inverter at instantaneous power failure

When an instantaneous power failure occurs, the power supply voltage of the control circuit for the inverter is shut off. To prevent malfunction of control due to this power failure, activate the instantaneous power failure protection to stop the inverter output and keep the output stopped. The protective operation differs depending on the instantaneous power failure time. The FR-A800 series is used as an example here.

(1) Inverter operation depending on the instantaneous power failure time

- (a) When the instantaneous power failure time is within 15 ms
Since the protective function is not activated, operation can continue normally.

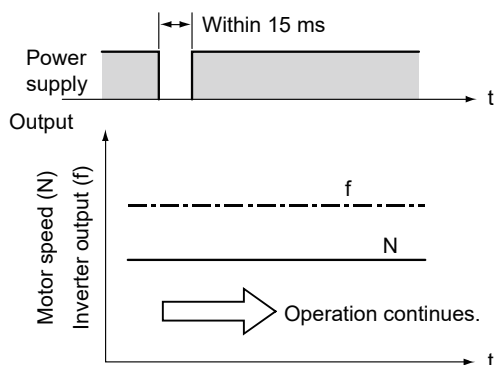


Fig. App 1.6 Instantaneous power failure for 15 ms or less

- (b) When the instantaneous power failure time is over 15 ms and under 100 ms
The protective function is activated and the inverter output is stopped. (The motor coasts to a stop.)

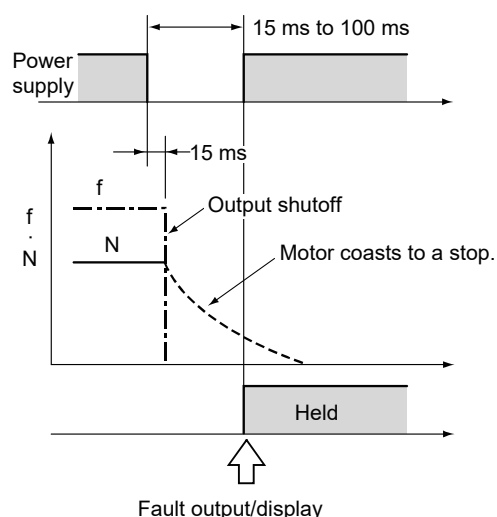
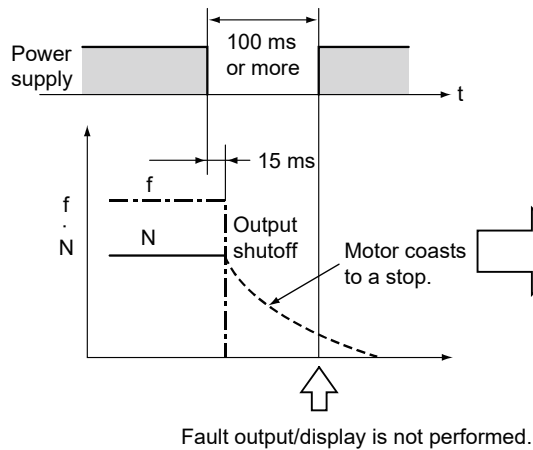


Fig. App 1.7 Instantaneous power failure for more than 15 ms and less than 100 ms

(c) Power failure for 100 ms or more

The protective function is reset automatically at the power restoration and the inverter can be restarted.



[Note]

When the start signal (STF, STR) is ON, the inverter restarts at the power restoration. If the motor is coasting at this time, the overvoltage or overcurrent protection may be activated, which may cause a trip. To restart automatically at power restoration, use the automatic restart after instantaneous power failure function.

(The FR-A800 series inverters have this function as standard. However, the function is not selected at the factory shipment. Thus, set the parameter A702 (Pr.57) to "0".)

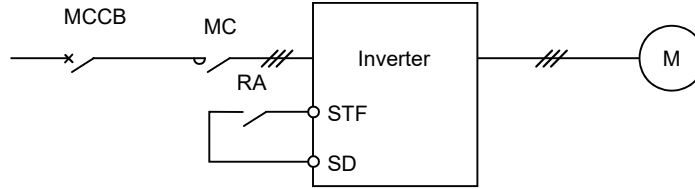
For details on the operation of automatic restart after instantaneous power failure, refer to Appendix 1.7.

Fig. App 1.8 Instantaneous power failure for 100 ms or more

* For the FR-E800 series, the inverter operation does not differ due to the difference in the instantaneous power failure time as described above. The output of the FR-E800 series will be shut off when the converter output voltage falls below a certain value due to an instantaneous power failure.

Appendix 1.7 Inverter peripheral circuit and inverter operation at instantaneous power failure

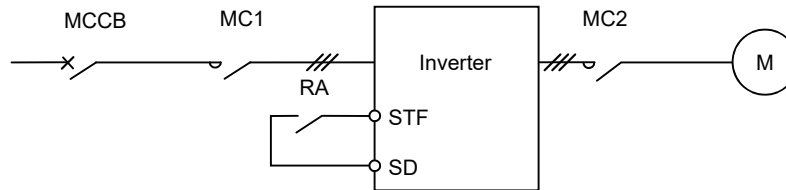
(1) For a magnetic contactor (MC) at the inverter's input line



When the instantaneous power failure time is short and both the magnetic contactor MC and relay RA do not trip (start signal STF remains ON), the operation is as described in Appendix 1.6.

When only the magnetic contactor MC trips, the motor coasts to a stop. Therefore, when restarting the inverter after a power restoration, turn on MC again or use the instantaneous power failure function after the motor coasts to a stop (coasting interlock timer is necessary).

(2) For magnetic contactors (MC) at both the inverter's input line and the output line



When the instantaneous power failure time is short and both the magnetic contactor MC1 and relay RA do not trip (start signal STF remains ON), the operation is as described in Appendix 1.6.

When only the magnetic contactor MC1 trips, the motor coasts to a stop. Therefore, when restarting the inverter after a power restoration, turn on MC1 again or use the instantaneous power failure function after the motor coasts to a stop (coasting interlock timer is necessary).

When only the magnetic contactor MC2 trips, the motor coasts to a stop. However, the inverter continues to output depending on the instantaneous power failure time, or only the inverter restarts after resetting at the power restoration. Therefore, when MC2 is turned on again, the motor starts directly with the inverter output frequency, and this may cause an inverter trip due to overcurrent.

☒ Good to know for checking an inverter

- 1) Even though an instantaneous power failure occurs at the receiving end, an instantaneous power failure is unlikely to occur (completely) at the low voltage side inverter input terminal (R, S, T) and voltage drops instantaneously. (Undervoltage protection operations)
- 2) An inverter has the instantaneous power failure protective function and the undervoltage protection. The protective function is activated when the DC circuit voltage of the inverter is under a certain value for a certain time. Therefore, when the power supply drops instantaneously, the protective function may be activated for an inverter whose load output (kW) is large, and the operation may continue for an inverter whose load output is small.

- 3) On the other hand, the magnetic contactors or relays may not trip due to an instantaneous voltage drop, if once it is turned on. In general, it trips when the voltage is equal to or lower than 30% to 50% of coil rating.

(3) Automatic restart after instantaneous power failure control

The inverter can be restarted without stopping the motor operation in the following situations:

- When an instantaneous power failure occurs during inverter operation
- When the motor is coasting at start

NOTE This function operates properly only when one motor is connected to the inverter. Using multiple motors disrupts proper operation of the function.

(a) Operation of automatic restart after instantaneous power failure

- 1) When an instantaneous power failure occurs during operation, the motor starts coasting.
- 2) After a power restoration, applying the DC voltage from the inverter to the coasting motor carries the DC to the motor. (Refer to Fig. App 1.9 ①.)
This DC includes the ripple cycle proportional to the motor speed.
- 3) Input the signal from the current detector to the CPU and count the ripple cycle to determine the motor speed.
- 4) The inverter outputs with the frequency according to the motor speed. (Refer to Fig. App 1.9 ②.) After that, restart the inverter operation while increasing the output voltage gradually to reduce the starting current of the motor.

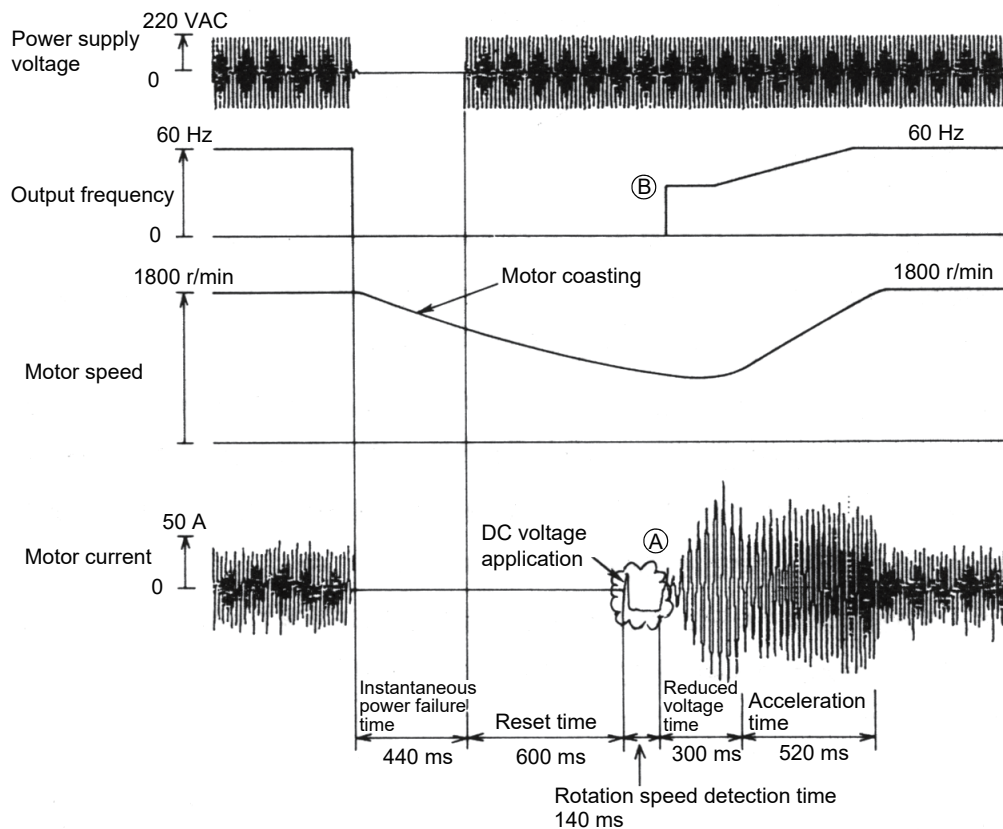


Fig. App 1.9 Example of automatic restart after instantaneous power failure operation

(b) Settings

- 1) Set A702 (Pr.57) = "0" (initial value: "9999") and A700 (Pr.162) = "0" (initial value)".
- 2) To use the automatic restart after instantaneous power failure function for the FR-A800 series, short across terminals CS and SD. (This step is not required for the FR-E800 series.)

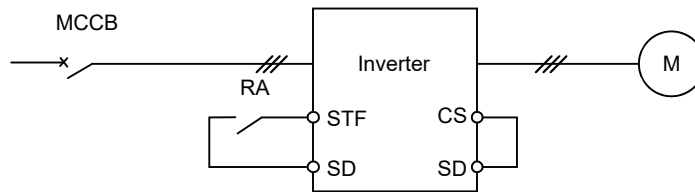
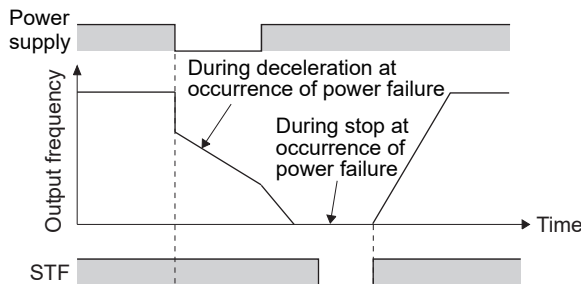


Fig. App 1.10 Wiring for automatic restart after instantaneous power failure operation

☒ Good to know for checking an inverter

Power failure time deceleration-to-stop function

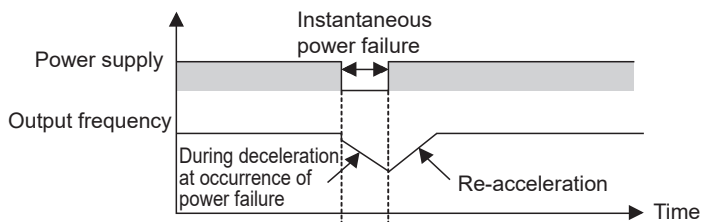
The motor normally coasts to a stop at a power failure. Using the power failure time deceleration-to-stop function enables the motor to decelerate to stop in a relatively short time using the regenerative power. The motor does not restart at the power restoration even when the start signal is ON. Re-acceleration can be selected when power is restored during power failure deceleration.



Continuous operation function at instantaneous power failure

When an instantaneous power failure is detected, the operation is continued by using the regenerative power generated by decelerating the motor. After the power restoration, the motor is accelerated until it reaches the command frequency and continues to operate. When the load inertia is small, a trip may occur due to an undervoltage since the regenerative power from the motor is not provided.

In this case, use the automatic restart after instantaneous power failure.



Appendix 2 Noise

Appendix 2.1 Processing speed improvement for main circuit elements

During development of inverters, PWM control has adopted to improve the control performance inexpensively. This has caused the problem of motor noise peculiar to inverter operation due to its switching frequency. To reduce the noise, high carrier frequency PWM control has been devised. However, this high carrier frequency increases noise and leakage current and becomes one of the factors to cause peripheral devices to malfunction in production sites.

This appendix explains malfunction prevention measures by reducing noise and leakage current caused by the inverter.

Appendix 2.2 Inverter operating principle

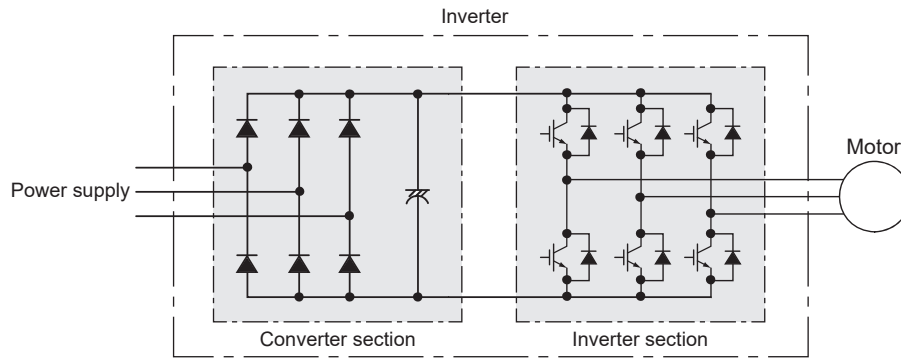


Fig. App 2.1 Configuration of inverter

(1) Configuration of inverter main circuit

The inverter main circuit consists of the converter section and the inverter section. The converter section converts the commercial power supply's current to DC and smooths the pulsating current. The inverter section converts DC to AC with variable frequency by switching three-phase bridge transistors.

(2) Control method of the inverter

For general-purpose inverters, PWM control is normally adopted. PWM control generates switching pulses multiple times in one output cycle and changes the pulse width to change the output voltage and frequency. The number of switching pulses generated in one second is called the carrier frequency.

Appendix 2.3 Noise and harmonics

Among the problems of the power supply and peripheral devices caused by an inverter, a problem whose cause cannot be identified, such as a malfunction of a peripheral device, tends to be confused with harmonics or noise. Due to this, countermeasures cannot often be performed smoothly. For example, the source and influences of problems such as noise and electromagnetic interference from the computer are obviously different from those of harmonics in electrical power network. Accordingly, the countermeasures to be performed are greatly different. The following describes the differences.

A harmonic has a frequency that is an integral multiple of the fundamental wave. It is distinguished from a high frequency *1. The composition of a single fundamental wave and multiple harmonics is called a distorted wave.

A distorted wave typically includes harmonics in a high-frequency range (kHz to MHz order).

However, in a power distribution system, harmonics are usually up to 40th to 50th degrees (to several kHz). Further higher frequency usually assume an irregular form and must be treated as noise.

*1 High frequency is just a frequency higher than the normal frequency. There is no concrete reference value.

For example, as general-purpose inverters can output a frequency of 0 to 400 Hz, inverters that can output a frequency higher than that is called high-frequency inverter. The inverter's carrier frequency is normally 1 to 2 kHz, and a frequency higher than that is called high carrier frequency.

Table App 2.1 Differences among noise, harmonics, and leakage current of the inverter

Item	Noise	Harmonics	Leakage current
Frequency band	High frequency (several 10 kHz to MHz order)	Normally 40th to 50th degrees or less (3 kHz or less)	(several Hz to MHz order)
Source	Inverter section	Converter section	Inverter section
Cause	Transistor switching	Rectifier circuit commutation	Transistor switching
Generated amount	Determined by the voltage change rate and switching frequency	Determined by the current capacity	Determined by the switching frequency and voltage
Path	Wire, air, induction	Wire	Insulator
Transmission amount	Distance, wiring path	Electric channel impedance	Static capacitance
Affected equipment and influences	Sensors, etc.: Incorrect detection Radio, wireless communications devices: Noise	Power factor correction capacitor: Heat Private electric generator: Heat	Earth leakage circuit breaker: Unnecessary operation Thermal relay: Unnecessary operation Devices on the output side (CT, meters, etc.): Heat
Major countermeasures	Changing the wiring route Installing a noise filter	Installing a reactor	Changing the detection sensitivity Changing the carrier frequency

For details on the harmonics influences and countermeasures, refer to the following.

- Mitsubishi Electric Inverter Technical Note No. 28
"Compliance of Inverters with Harmonic Suppression Guidelines"
- Mitsubishi Electric Inverter Technical Note No. 4
"Influence of Harmonic Current to Private Generators"

Appendix 2.4 Mechanism of noise generation

As described in Appendix 2.2, an inverter creates AC by switching of the main circuit elements, and can be considered as an essential source of the noise.

The following explains the generation mechanism.

Stray capacitance C exists in the wiring between the inverter and the motor and between the motor and the earth (ground).

Thus, the pulse-like leakage current flows from the stray capacitance C through the earth (ground) to the power supply at every timing of main circuit switching.

This change in leakage current generates noise and affects other devices connected to the same power system (such as programmable controllers and sensors).

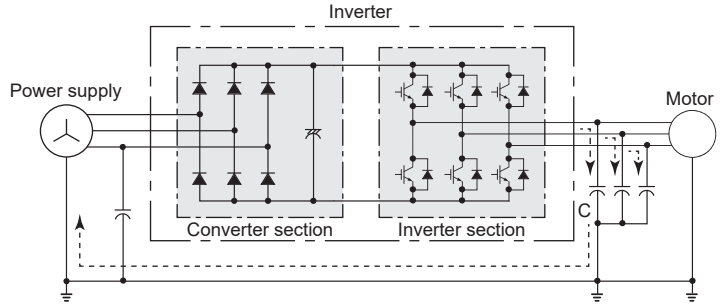


Fig. App 2.2 Leakage current path

C : Stray capacitance (F)
 dV : Variable voltage (V)
 dt : Switching time (seconds)

The magnitude of this leakage current i is calculated by the following formula.

$$i = C \times dV / dt$$

The magnitude of i is affected by the stray capacitance C and the switching speed (dV / dt).

In addition, the noise level is affected by the magnitude of carrier frequency as the leakage current varies at every timing of switching.

Specifically, note the following points.

- The noise level becomes higher when the carrier frequency is higher.
- Even at the same switching speed, a 400 V inverter generates a higher-level noise than a 200 V inverter as the variable voltage is higher.
- Even with the same carrier frequency, an inverter using fast switching elements (such as IGBTs) generates a higher-level noise.

Appendix 2.5 Influence of noise

(1) Devices susceptible to noise

Problems in the inverter's peripheral devices caused by noise depend on the device type, installation conditions, and wiring method, thus cannot always be identified.

The following lists the devices susceptible to noise and possible problems.

- 1) Sensors ... Photoelectric switch, proximity switch, rotary encoder (manual pulse generator), gear sensor, magnetic sensor, flow rate sensor, thermocouple used with converter, pressure transmitter used with converter, etc.
 - Malfunctions, incorrect detection
- 2) Indicators ... Rotation meter, speed meter, transit time meter, counter, ratio meter, circumferential speed meter, length measuring meter, etc.
 - Incorrect detection, variation in displayed data, etc.
- 3) Controllers ... Programmable controller, micro-computer board, etc.
 - Operation failure (CPU down), program runaway, etc.
- 4) Wireless communications devices ... Radio, marine radio, inductive radio, etc.
 - Noise, communication failure
- 5) Television receivers ... Monitoring TV, CRT, etc.
 - Image distortion, noise
- 6) Transmitter/receiver system ... Analog telephone, etc.
 - Noise
- 7) Others ... General devices using micro-electrical signals
 - Operation failure or malfunctions

(2) Noise immunity of sensors, indicators, etc.

Although the noise immunity of sensors and indicators has been improved by using inverters, they are not sufficiently capable of withstanding a high-level noise generated by IGBT elements. Sensors and indicators with high noise immunity are expected to be developed by the manufacturers in the future. Until then, consider installing a noise filter, or contacting sensor manufacturers and adopting models with higher noise immunity.

* Capacitive proximity switches generally have low noise immunity. Caution is required when using them.

Appendix 2.6 Noise propagation path

The inverter-generated noise is 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.

Fig. App 2.3 shows the types of noise, and Fig. App 2.4 shows the path of noise.

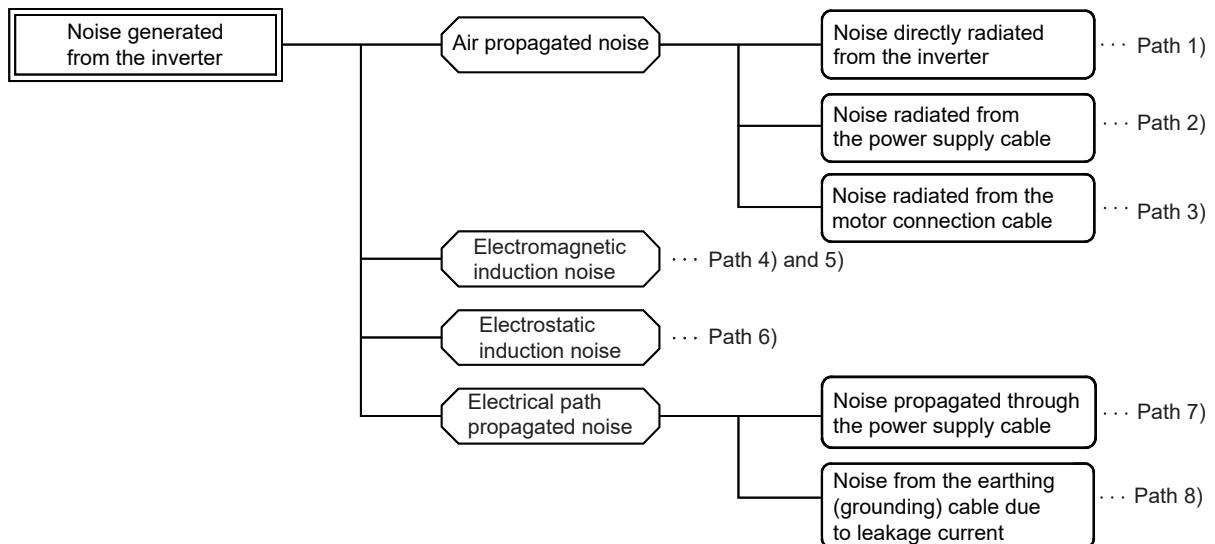


Fig. App 2.3 Types of noise

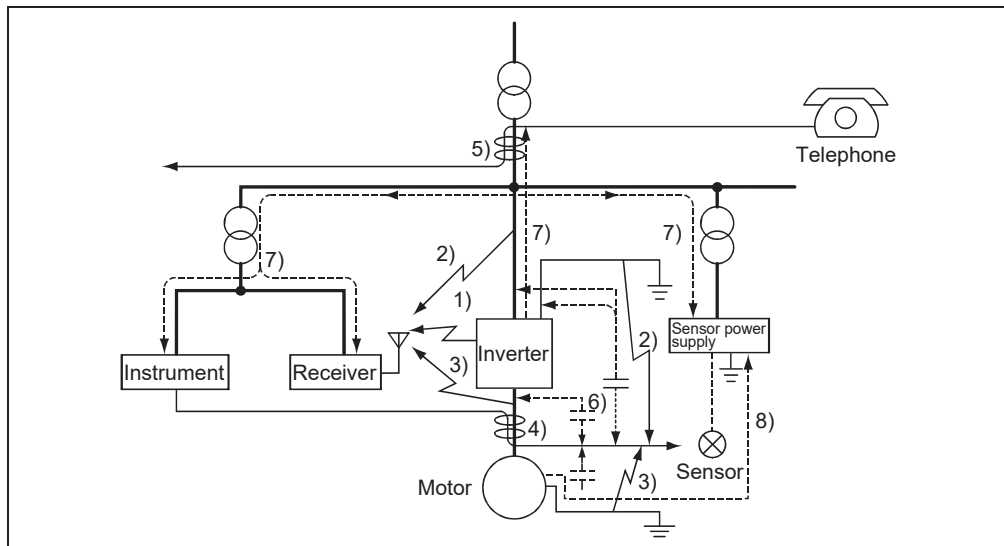


Fig. App 2.4 Path of noise

Each noise level tends to be decreased as the frequency band rises. In general, it does not matter in the frequency band of 30 MHz or more.

Therefore, it does not affect much the televisions or FM radios that use frequency of 30 MHz or more with some exceptions. However, it affects low frequency band (0.5 to 10 MHz) radios such as AM radios.

Accordingly, it is rational to consider the countermeasures with regard to the frequency band of the noise.

Appendix 2.7 Measures against noise

(1) Stance of countermeasures against noise

1) Basic of countermeasures against noise

Countermeasures against noise can be roughly classified as follows. In practice, combining these methods can effectively reduce noise.

- (a) Increasing the distance between the noise source and the affected device:
Reduce the influence of noise.
- (b) Installing a noise filter: Lower the noise level.
- (c) Shielding the inverter or cables: Contain the noise.
- (d) Insulating the circuit: Prevent noise from propagating.

2) Checkpoint for countermeasures

(a) Performing countermeasures suitable for the propagation path

The best way is to fully consider the noise propagation paths and combine individual countermeasures for each path according to the condition. For the effects of each countermeasure, refer to Table App 2.3.

- Installing a noise filter is not always the best way. In some cases, installing a noise filter without considering the propagation paths may not be effective. For example, bundling the inverter output cables and the sensor signal cables increases the influence of induction noise.

(b) Performing countermeasures in advance

The best way is to consider noise before installing the inverter or wiring the devices.

For example, the majority of noise-related problems can be prevented by measures such as running the signal circuit cables away from the power circuit cables, using shielded or twisted cables, and properly earthing (grounding).

The following explains specific countermeasures for each propagation path.

(2) Air propagated noise: Path 1) to 3)

The noise generated by an inverter is radiated and transmitted into the air. The strength is represented with the noise electric field strength. The paths are classified into three types shown in Fig. App 2.5. Installing the devices closely makes them more likely to be affected by noise. Specifically, it will result in noise for AM radios and wireless communications devices, or image distortion for CRTs.

1) Radiation from the inverter

2) Radiation from the input power supply cable and inverter earthing (grounding) cable

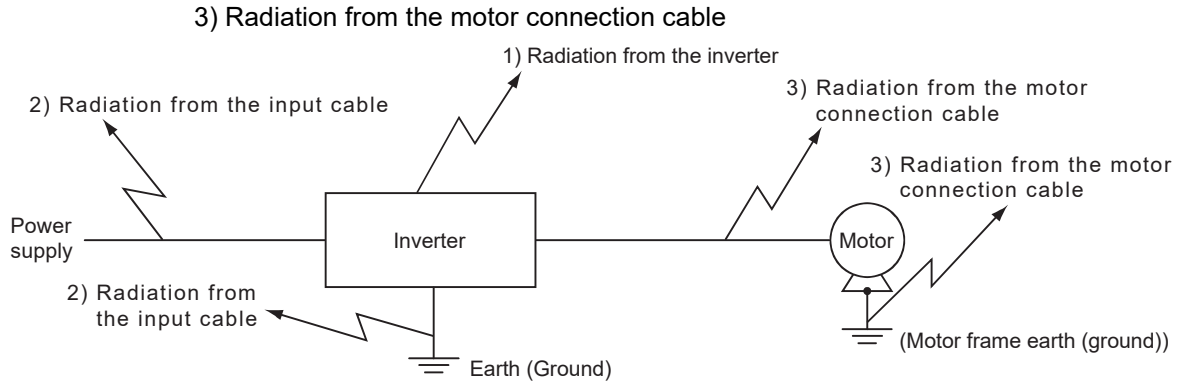


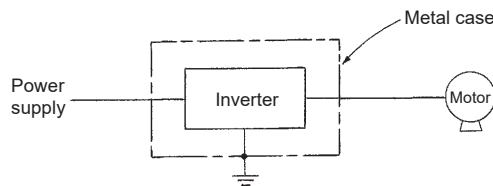
Fig. App 2.5 Air propagated noise

■ Countermeasures against air propagated (radiated) noise

1) Reducing the noise radiated from the inverter

Usually, the noise radiated from an inverter is relatively small and does not matter. However, when an inverter needs to be installed near a device susceptible to the noise described in Appendix 2.5, store the inverter in a metal case as shown in Fig. App 2.6 (*) and earth (ground) the case to shield noise.

When installing the inverter in an enclosure, it is more effective to use a different enclosure from the one used for other devices.



* When installing the inverter in a metal case, pay sufficient attention to the temperature rise of the inverter.

Fig. App 2.6 Reducing the noise radiated from the inverter

2) Reducing the noise radiated from the input power supply cable

Use a metallic pipe or shielded cable for the input power supply cable and earth (ground) the equipment to shield the noise radiated from the input power supply cable.

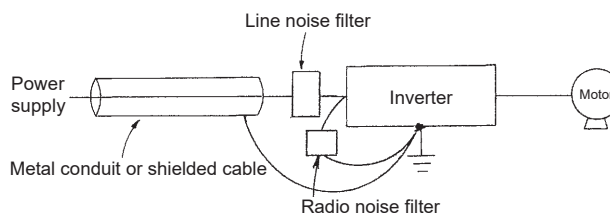


Fig. App 2.7 Reducing the noise radiated from the input power supply cable

The noise radiated from the input power supply cable can also be greatly reduced by reducing the electrical path propagated noise by installing a line noise filter, radio noise filter, or noise suppression transformer on the inverter's input side. These devices must be installed in locations where the wiring distance from the inverter is the shortest. (Refer to page APP - 23.)

3) Reducing the noise radiated from the motor connection cable

The radiated noise can be reduced by shielding the noise using a metallic pipe or shielded cable as shown in Fig. App 2.8. It is more effective to use a pipe whose thickness is 2 mm or more. Wiring inside the concrete pit or room surrounded by concrete has an effect similar to the metallic pipe.

For effective earthing (grounding) of the motor, connect one cable of the 4-core cable on the inverter side.

The noise radiated from the motor connection cable can also be greatly reduced by reducing the propagated noise by installing a line noise filter on the inverter's output side and increasing the impedance in the high-frequency range. (Refer to Fig. App 2.9.)

The more times the cable is wound to a line noise filter, the greater the impedance becomes, which is effective to reduce the noise. Therefore, wind the cable as many times as possible. However, the number of winding times must be within three times (four turns) when the line noise filter is installed on the inverter output side. Due to high-frequency switching, the line noise filter may generate heat if the cable is wound too many times.

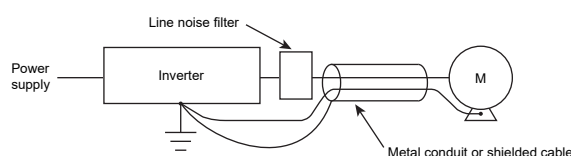


Fig. App 2.8 Countermeasures for the motor connection cable

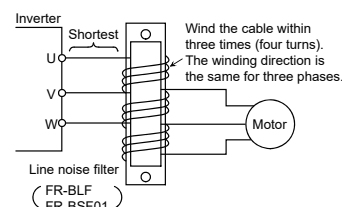


Fig. App 2.9 Installation of a line noise filter

(3) Electromagnetic induction noise: Path 4) and 5)

The noise is transmitted by the interlinkage of the power supply cables and signal cables for the peripheral devices in the magnetic field that is generated by the I/O side current of the inverter. When both cables are close and parallel, or when the loop of each cable is large, the induced noise increases. (Refer to Fig. App 2.10.)

* If the sensor signal cables and the motor power cables are bundled, the electromagnetic induction noise is superposed on the detection signals of the sensor. This causes a programmable controller and other devices to misrecognize the signals from the sensor.

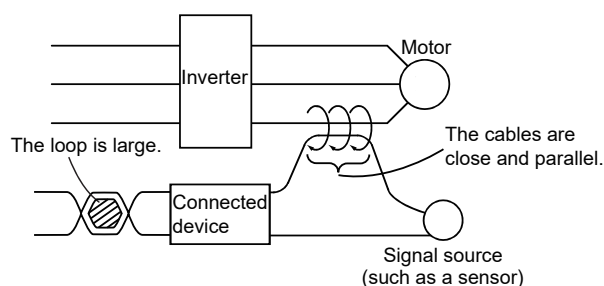


Fig. App 2.10 Example of increasing electromagnetic induction noise

■ Countermeasures against electromagnetic induction noise

- (a) Use 3-core cables for the I/O cables in the inverter main circuit.
(Separate the wiring of the motor earthing (grounding) cable.)

When using single-core cables, twist or tightly bundle three cables so that the electromagnetic induction noises cancel each other out.

- (b) To suppress the influence of the electromagnetic induction noise, separate the I/O cables in the inverter main circuit from the power supply cables and signal cables of the connected device.

The separation distance should be usually 30 cm or more (at least 10 cm). If there is not enough space, separation using shielding plates (steel plates) as shown in Fig. App 2.11 is possible.

- (c) Use twisted cables for the signal cables and power supply cables of the connected device. Shielded twisted pair cables are recommended in terms of countermeasures against electrostatic induction noise.
- (d) Install a line noise filter on the inverter output side to lower the induction noise level. For the installation method, refer to Fig. App 2.9.

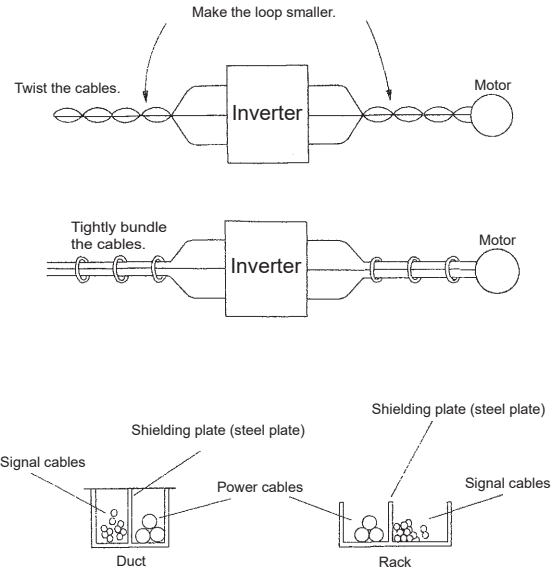


Fig. App 2.11 Countermeasures against electromagnetic induction noise

(4) Electrostatic induction noise: Path 6)

The noise is transmitted when the electric field that is generated by the I/O cables of the inverter is coupled with the signal cables through the stray capacitance. (Refer to Fig. App 2.12.)

* Devices such as capacitive proximity switches are affected by this electric field, which is likely to result in incorrect detection.

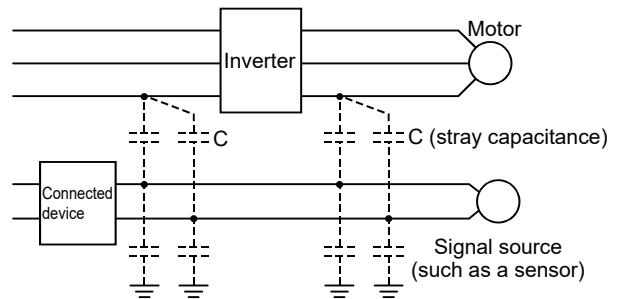


Fig. App 2.12 Electrostatic induction noise

Remark

The stray capacitance C can be estimated using the following formula.

$$C = \epsilon_0 \times \epsilon_s \times A/r \text{ (F)} \quad \text{(For details, refer to page APP - 40.)}$$

- r : Sheath thickness (m)
- A : Area of opposing electrodes (m^2)
- ϵ_0 : Permittivity in vacuum (8.84×10^{-12} (F/m))
- ϵ_s : Dielectric constant of the insulator

Use the result of the above formula as a reference as the static capacitance greatly depends on the wiring method.

■ Countermeasures against electrostatic induction noise

1) To suppress the influence of the electrostatic induction noise, decrease the static capacitance (A/r in the above formula) as much as possible by increasing the distance between the inverter I/O cables and signal cables and minimizing the distance that cables run in parallel.

2) Shield the electrostatic noise using a shield or metal conduit.

- (a) Use shielded 2-core cables for the signal cables, and always connect the shield of a shielded cable to only one point.
 - If the shield is connected to two or more points, circulating current flows in the shield due to the electric potential difference, and the shield becomes ineffective. This may have contrary effect depending on the electric potential difference, and caution is required. For example, when the shield is connected to the signal common cable of the signal source device, do not connect the shield to the connected device. (Refer to Fig. App 2.13.)
 - * Connecting the shield to the signal reference (common) cable is effective. Connecting to another shield may have contrary effect.

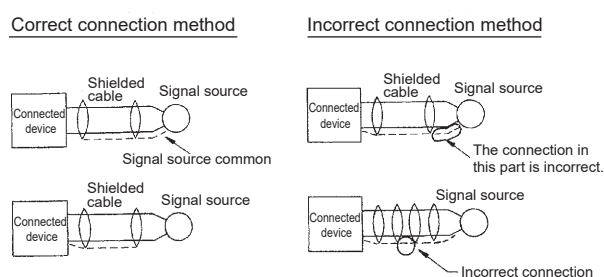


Fig. App 2.13 Shield connection method

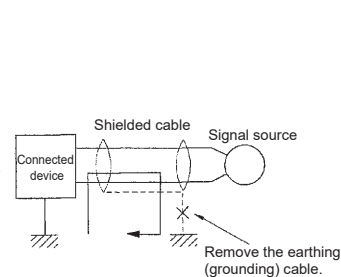


Fig. App 2.14 Removing the earthing (grounding) cable

- Do not connect the shield to the earth (ground), inverter, enclosure, and other modules. (Refer to Fig. App 2.14.)
Doing so may have contrary effect since the earth (ground) and modules are often connected to a dirty line and noise flows from the shield.
- (b) Besides shielded cables, a metallic pipe or shielding plate is also effective as is the case with countermeasures against electromagnetic induction noise. (Refer to Fig. App 2.11.)

(5) Electrical path propagated noise

1) Noise propagated through the power supply cable

The noise generated in the inverter is transmitted to the peripheral devices through the cables at the power supply side. The magnitude is represented with the noise terminal voltage.

Noise propagates to all devices connected to the same power system. (Refer to Fig. App 2.15.)

* Since a commercial power supply is connected to the inverter power supply side, the noise propagated through the power supply cable may affect unexpected devices such as a device far away from the inverter (for example, household appliances).

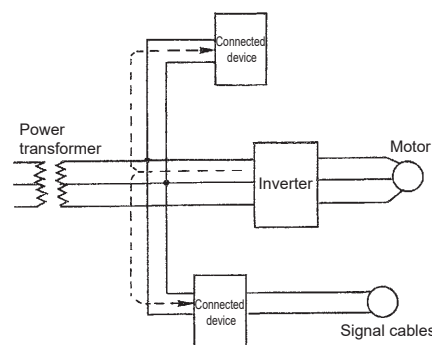


Fig. App 2.15 Electrical path propagated noise

■ Countermeasures against noise propagated to the power supply side

The following methods are available at the point closest to the inverter input side: A) installing a noise filter to reduce the propagated noise at the noise source, B) isolating the power supply side to prevent the noise from being transmitted to peripheral devices. The former is rational in terms of cost and space since the propagated noise is directly reduced and accordingly the noise radiated from the power supply cable is decreased.

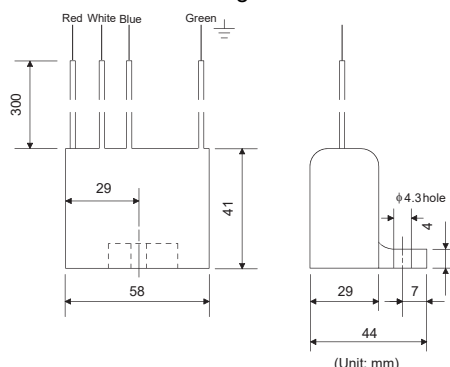
A) Installing a noise filter

Against high frequency components, use a noise filter on the inverter input side in the following ways.

- (a) Connect a capacitive filter with a small impedance in parallel to bypass the noise current.
..... Radio noise filter (Refer to Fig. App 2.16.)
- (b) Connect an inductive filter with a large impedance in series to decrease the noise current.
..... Line noise filter (Refer to Fig. App 2.17.)
- (c) Combine a capacitive filter and an inductive filter.
..... Using a radio noise filter and line noise filter together (Refer to Fig. App 2.18.)

As the effect of a noise filter will be insufficient if the wiring method is inappropriate, follow the precautions described in Fig. App 2.16 to Fig. App 2.18.

- Outline dimension drawings



- Connection method

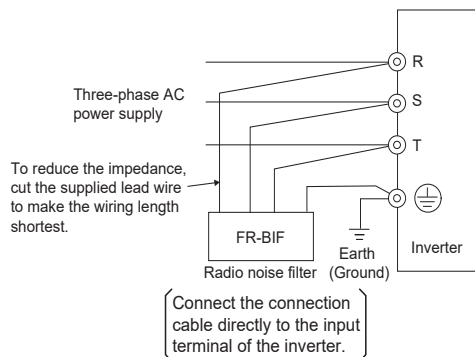
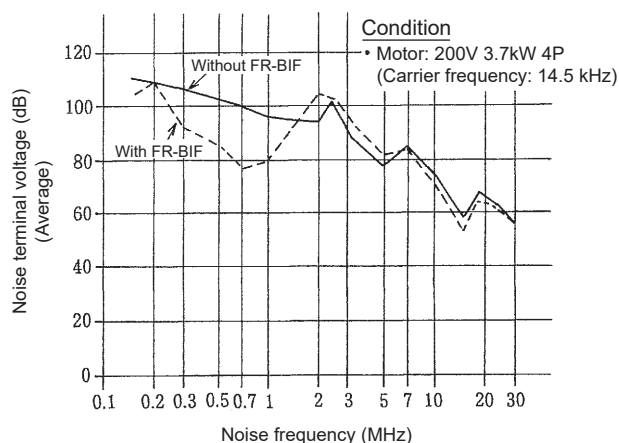


Fig. App 2.16 Radio noise filter (FR-BIF, FR-BIF-H)

- Noise reduction example



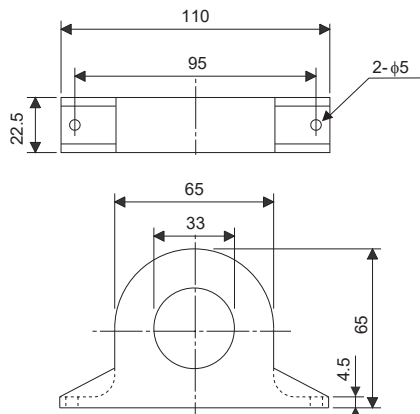
Note) The radio noise filter (FR-BIF, FR-BIF-H) cannot be used on the inverter output side.
If used, the radio noise filter will be damaged.
The leakage current will increase by approx. 4 mA.

APPENDIX

• Outline dimension drawings

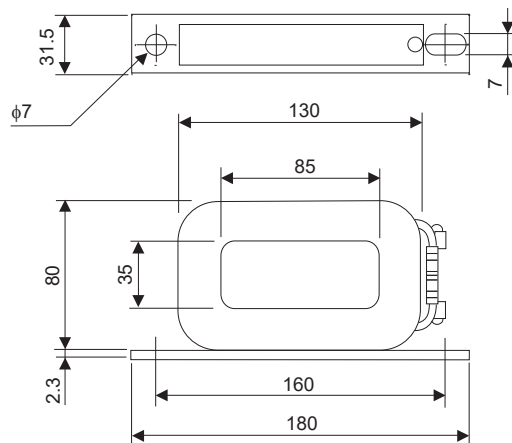
FR-BSF01 (small type)

- Common to 200 V and 400 V
- Reference of cable gauge: 3.5 mm² or less
(Inverter capacity: 3.7K or lower)



FR-BLF

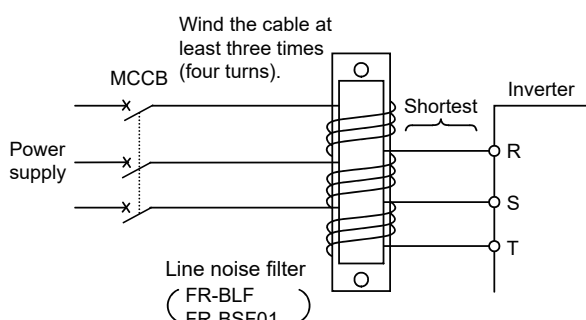
- Common to 200 V and 400 V
- Reference of cable gauge: 22 mm² or less



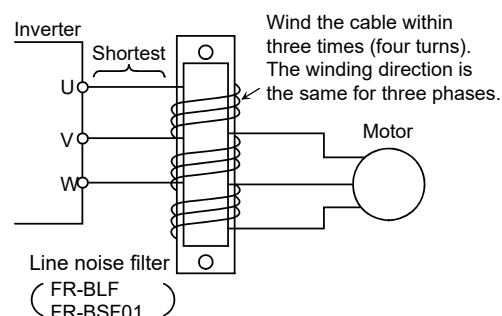
FR-BSF01 and FR-BLF provide almost the same noise reduction effect as long as the number of cable winding times (pass-through times) is the same. Use either depending on the used cable gauge.

• Connection method

<When connecting to the inverter input side>



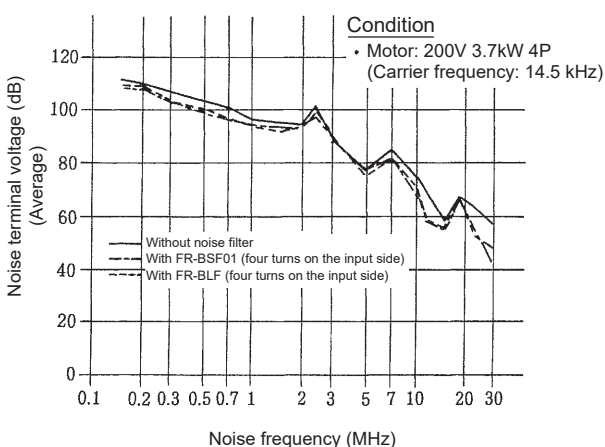
<When connecting to the inverter output side>



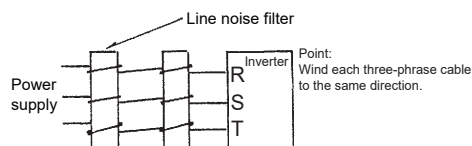
Note: The number of cable winding times must be within four turns on the inverter output side.

<When using multiple line noise filters to wind the cable four turns>

• Noise reduction effect example



• Correct method



• Incorrect method

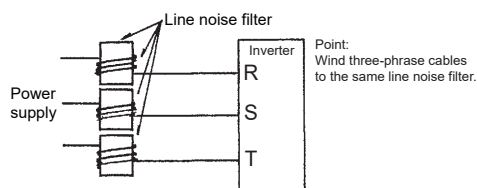
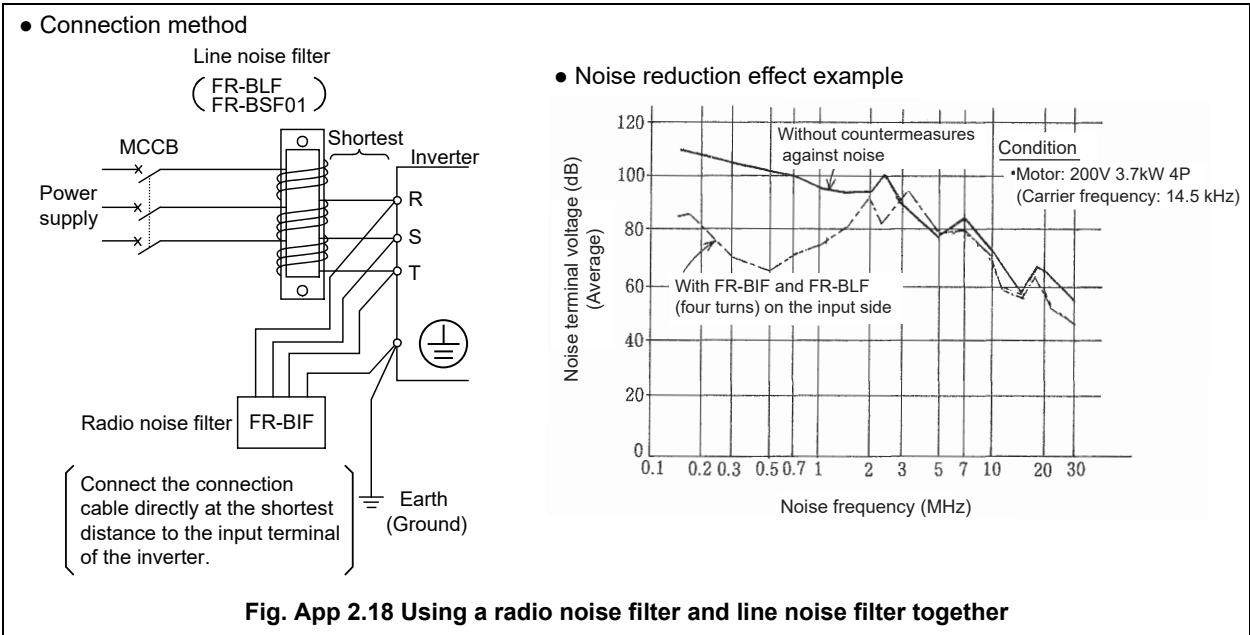


Fig. App 2.17 Line noise filter (FR-BSF01, FR-BLF)



APPENDIX

B) Isolating the power supply

- (a) Separate the power cable from the connected devices. (Refer to Fig. App 2.19.)
- (b) Install an isolation transformer on the inverter input side. (Refer to Fig. App 2.20.)

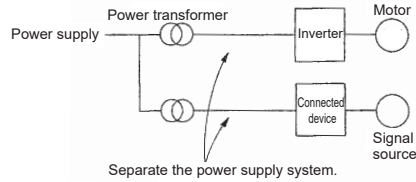


Fig. App 2.19 Separating power cables

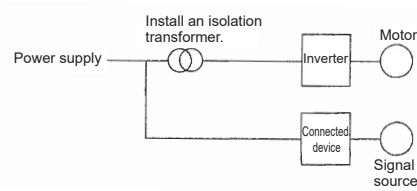


Fig. App 2.20 Installing an isolation transformer

- (c) Install an noise suppression transformer on the inverter input side.
Noise suppression transformers are transformers having extremely small magnetic and electrostatic coupling of the primary and secondary coils and greatly effective to reduce both noise emission and noise intrusion. (Refer to Table App 2.2.)
As earthing (grounding) is not required in principle, this is an ideal noise reduction method effective even when earthing (grounding) cannot be performed well or the earthing (grounding) cable is long. However, this method is expensive and requires sufficient space. A transformer with the necessary capacity is needed in the main circuit, and three single-phase transformers are required for the three-phase power supply. In addition, caution is required of a large voltage drop due to a large internal impedance.

Table App 2.2 Example of noise reduction by a noise suppression transformer (noise terminal voltage)

Measured frequency [Hz]	5K	7.5K	10K	25K	50K	75K	100K	250K	500K	750K	1M	2.5M	5M	7.5M	10M	25M	50M	75M	100M
Reduction ratio - [dB]	100 or less							85 or less	74 or less	77 or less	72 or less	54 or less	45 or less	37 or less	32 or less	22 or less	28 or less	42 or less	46 or less

(Note) Decay ratio = $20 \log_{10} \frac{\text{Voltage after decay}}{\text{Voltage before decay}}$ [dB]

2) Noise from earthing (grounding) cable due to leakage current

Leakage current flows from the earthing (grounding) cable through the stray capacitance of the inverter output cables to the connected device.

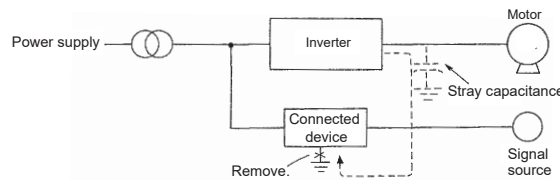


Fig. App 2.21 Noise from earthing (grounding) cable due to leakage current

- It is effective to remove a circuit in which undesirable current is generated due to leakage current.

It is effective to remove the earthing (grounding) cable of the connected device and remove a circuit in which undesirable current is generated. However, the earthing (grounding) cable of the connected device may not be able to be removed in terms of electric shock prevention in a high-voltage circuit.

It is also effective to earth (ground) the connected device using a capacitor. (Refer to page APP - 31.)

Appendix 2.8 Specific examples of countermeasures

(1) Countermeasures and effects

The following table lists the promising effects (estimation) for each item of countermeasure examples (refer to page APP - 31). When taking actual countermeasures, refer to the list to determine the priorities.

Meaning of signs

⊙: Greatly effective, ○: Effective, Δ: Slightly effective, —: Not effective

Table App 2.3 Effects of countermeasures against noise

Location	Symbol	Countermeasures	Propagation method of noise						
			Air propagated noise			Electromagnetic induction noise	Electrostatic induction noise	Electrical path propagated noise	
			Radiation from inverter	Radiation from power supply cables	Radiation from motor cables			Power supply cable	Undesirable current of earthing (grounding) cable
Inverter	A	Decrease the carrier frequency in E600 (Pr.72).	⊙	⊙	⊙	⊙	⊙	⊙	⊙
	B	Increase the input filter time constant in T002 (Pr.74).	Δ	Δ	Δ	○	Δ	—	—
Input side	C	Install the radio noise filter FR-BIF(-H).	—	⊙	—	—	—	⊙	—
	D	Install the line noise filter FR-BSF01 or FR-BLF.	—	⊙	—	—	—	⊙	Δ
	E	Wire the power supply cable with a metal conduit or shielded cable.	—	⊙	—	—	—	⊙	—
	F	Install an isolation transformer or noise suppression transformer.	—	Δ	—	—	—	⊙	—
	G	Separate the power supply system.	—	—	—	—	—	⊙	⊙

Table App 2.3 Effects of countermeasures against noise

Location	Symbol	Countermeasures	Propagation method of noise						
			Air propagated noise			Electromagnetic induction noise	Electrostatic induction noise	Electrical path propagated noise	
			Radiation from inverter	Radiation from power supply cables	Radiation from motor cables			Power supply cable	Undesirable current of earthing (grounding) cable
Output side	H	Install the line noise filter FR-BSF01 or FR-BLF.	—	—	⊙	Δ	Δ	—	⊙
	I	Wire the output cable with a metal conduit or shielded cable.	—	—	⊙	○	○	—	—
	J	Use 4-core cable for motor power cable and use one cable as earthing (grounding) cable.	—	—	Δ	Δ	Δ	—	⊙
Connected device	K	Use a shielded twisted pair cable for the signals from the sensor.	○	○	○	⊙	⊙	—	—
	L	Connect the shield to the sensor signal common cable.	—	—	—	⊙	⊙	—	⊙
	M	Do not earth (ground) the sensor power supply unit directly to the enclosure, etc.	—	—	—	—	—	Δ	⊙
	N	Earth (ground) the sensor power supply unit using a capacitor.	—	—	—	—	—	Δ	○
	O	Use a shielded cable for input signals and connect the shield to common (input terminal) SD.	Δ	Δ	Δ	○	⊙	—	Δ
	P	Use a shielded twisted pair cable for the speed input and connect the shield to terminal 5.	○	○	○	⊙	⊙	—	Δ

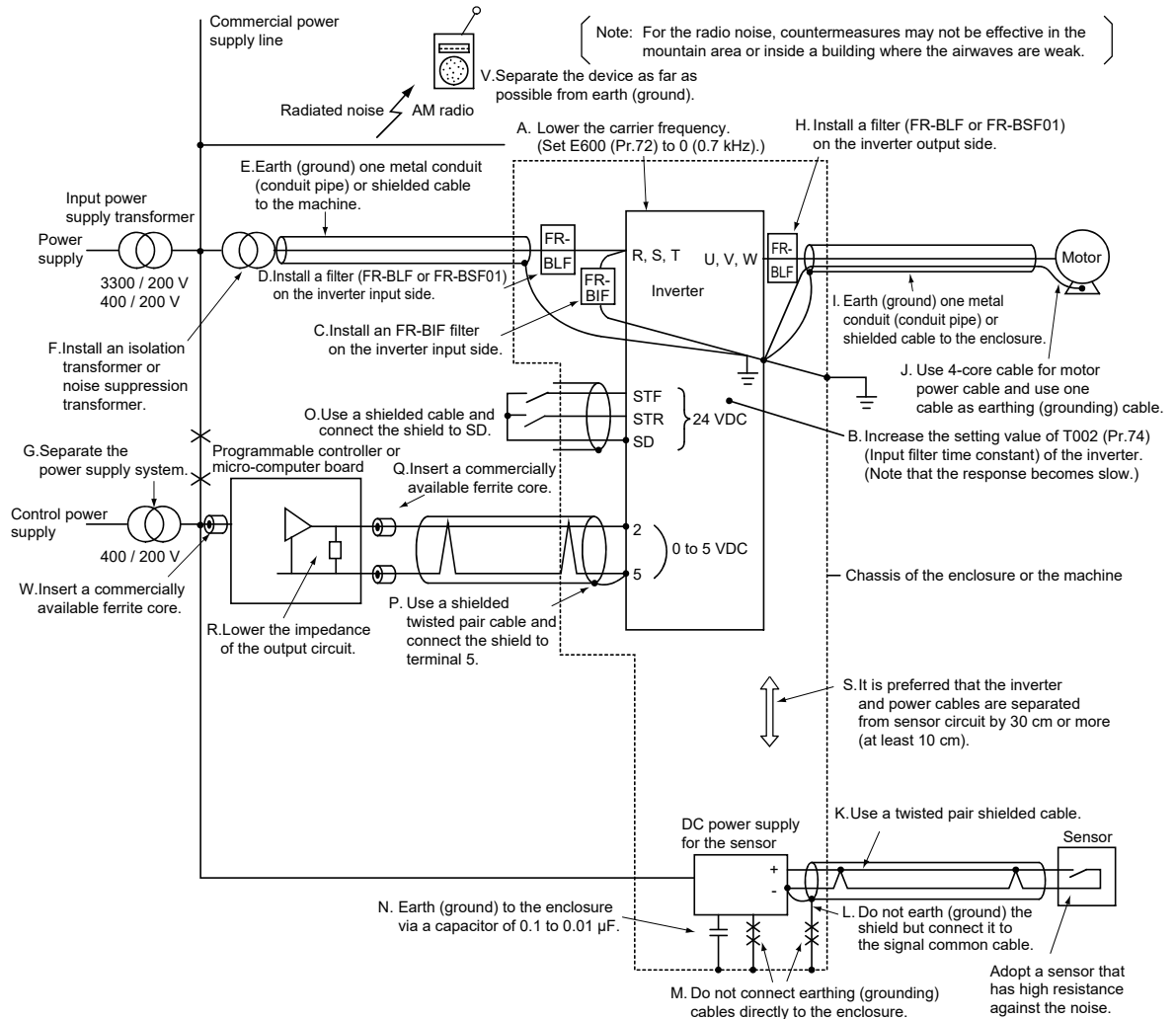
APPENDIX

Table App 2.3 Effects of countermeasures against noise

Location	Symbol	Countermeasures	Propagation method of noise						
			Air propagated noise			Electromagnetic induction noise	Electrostatic induction noise	Electrical path propagated noise	
			Radiation from inverter	Radiation from power supply cables	Radiation from motor cables			Power supply cable	Undesirable current of earthing (grounding) cable
Connected device	Q	Attach a commercially available ferrite core to the speed input cable (at the output side of the connected device).	Δ	Δ	Δ	○	—	—	—
	R	Reduce the output circuit impedance of the connected device.	Δ	Δ	Δ	○	—	—	—
	S	Keep a distance of 30 cm or more between the sensor circuit and the inverter or its power cable.	⊙	⊙	⊙	⊙	⊙	—	—
	T	Do not run cables in parallel with each other and do not bundle them.	Δ	Δ	Δ	⊙	⊙	—	—
	U	Install the shielding plate.	○	Δ	Δ	Δ	Δ	—	—
	V	Keep the device away from earth.	Δ	○	○	Δ	Δ	—	—
	W	Attach a commercially available ferrite core to the input side of the connected device.	—	—	—	—	—	○	Δ

(2) Countermeasure examples

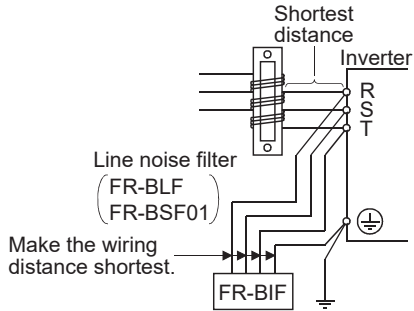
The following figure shows promising countermeasures against the inverter noise.



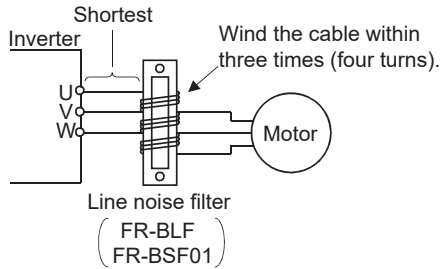
APPENDIX

Precautions for installing a noise filter

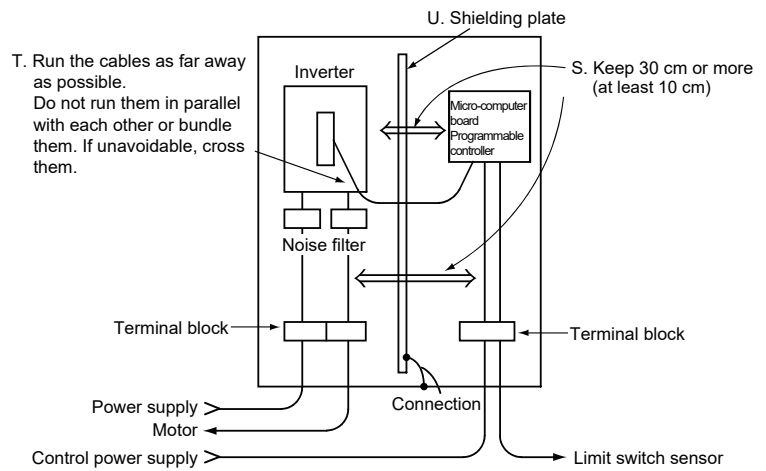
<Inverter input side>



<Inverter output side>



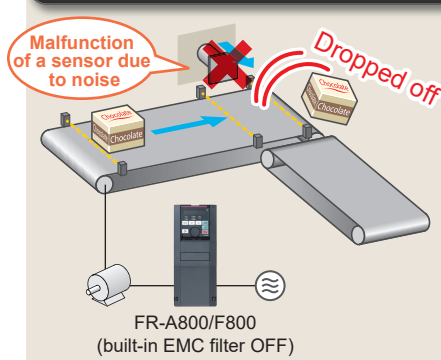
Wiring inside the enclosure



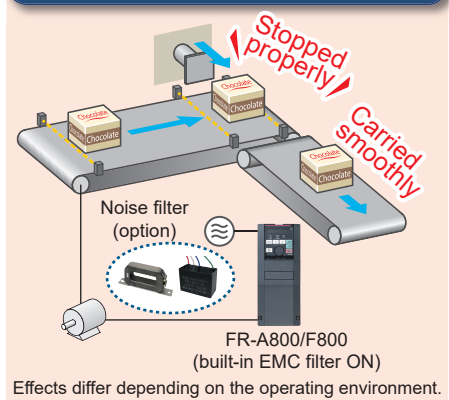
Remark

Illustrative examples

Countermeasures not taken



Countermeasures taken



Appendix 2.9 Regulations regarding the inverter noise and supplemental information

(1) Regulations

The following are the current main regulations regarding electromagnetic noise.

1) International standards:

- EU EMC Directive
- VDE (Verband der Elektrotechnik) standards
- CISPR (Comité International Spécial des Perturbations Radioélectriques) standards
- FCC (Federal Communications Commission) standards

2) Standards in Japan:

- VCCI (Voluntary Control Council for Interference by Information Technology Equipment) standards

Applications: Office automation equipment, medical equipment

The above regulations have not been applied to general-purpose inverters in Japan currently, but are expected to be strengthened in the future to prevent malfunction of peripheral devices.

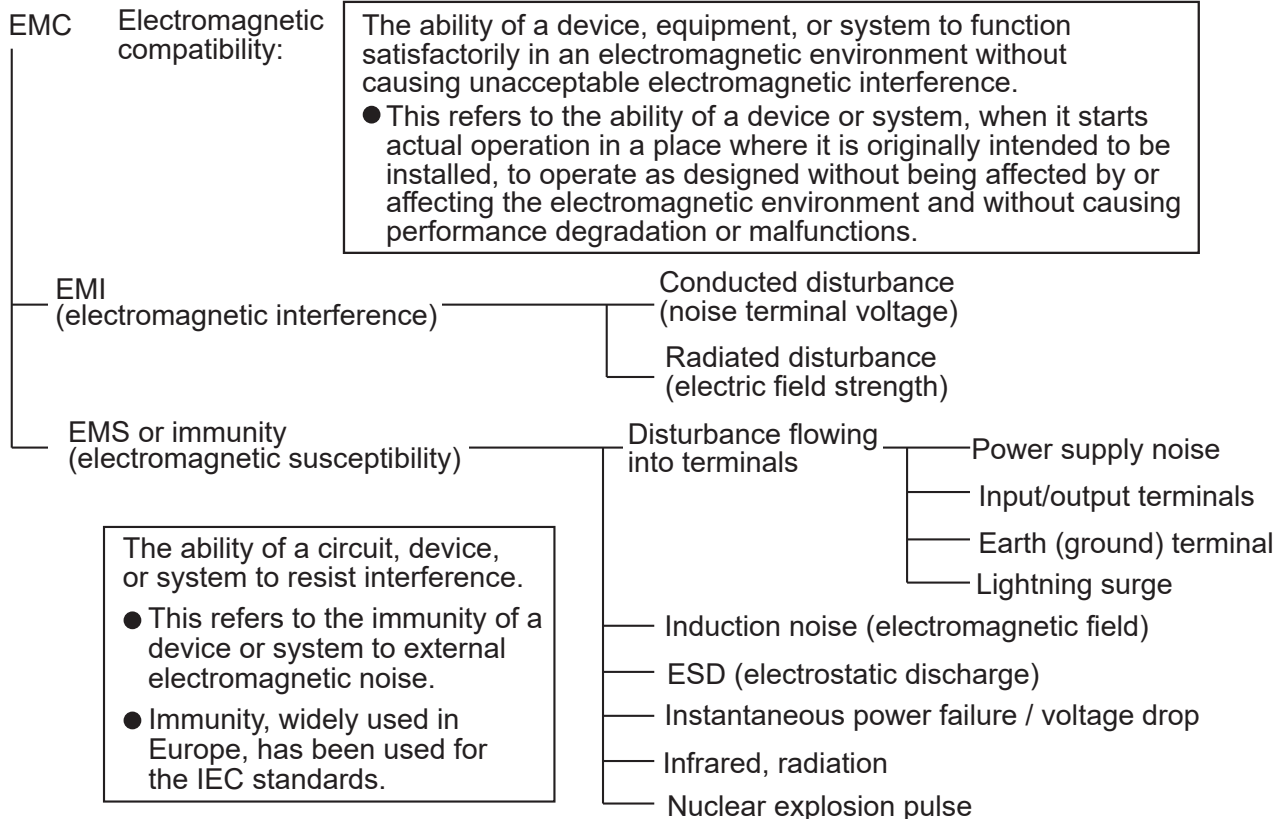
(2) How to comply with regulations

As an inverter alone cannot comply with the above regulations, filters compliant with the standards must be installed.

However, compliance with the above regulations does not necessarily directly prevent malfunction of peripheral device due to inverter noise. For specific countermeasures to prevent malfunctions, refer to the inverter noise countermeasures.

1) EU EMC Directive compliant noise filter

- EMC classification



APPENDIX

Note) EMC: Electromagnetic Compatibility

EMI: Electromagnetic Interference

EMS: Electromagnetic Susceptibility

ESD: Electrostatic Discharge

IEC: International Electrotechnical Commission

- SF□

FR-E5NF-H□K,

FR-S5NFSA-□K

Noise filters compliant with the EU EMC Directive, mainly designed to reduce conducted noise.

Fig. App 2.22 shows its effect example.

These products can be mounted on the rear of an inverter, saving space.

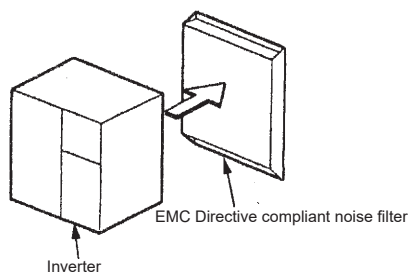


Fig. App 2.23 EMC Directive compliant noise filter installation

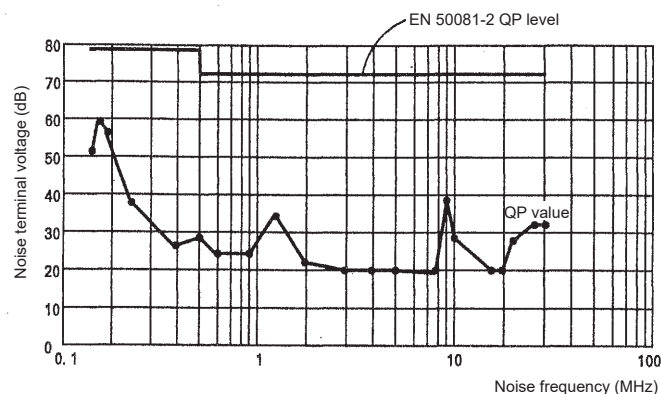


Fig. App 2.22 Effect of the filter (when using SF1174B and 5.5 kW motor)

To make the user's equipment (enclosure) comply with the EMC Directive, the following are important as well as installation of a noise filter: proper enclosure preparation, correct installation, shield wiring between an inverter and a motor, etc.

Refer to the EMC Installation Guidelines (BCN-A21041-202/204).

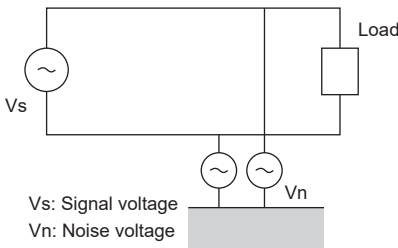
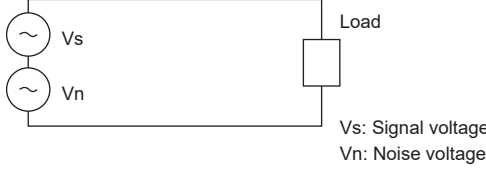
2) Introducing main noise filter manufacturers

Various noise suppression filters are provided by filter manufacturers. The following shows some of them.

- Soshin Electric Co., Ltd.: HF, NF, and TF series, etc.
- TOKIN: LF series, etc.

(3) Supplemental information

- 1) Definition of noise
Among electrical signals in a transmission circuit, signals other than the intended signals are treated as "noise".
- Types of noise
Noise are classified into two types, common mode noise and normal mode noise, depending on what is applied to the signal cable of the electrical equipment.

Common mode noise	Normal mode noise
Noise that applies voltage and current to both of two signal cables	Noise that applies signal voltage and noise voltage in series to a load
	

Appendix 3 Leakage current

Appendix 3.1 Mechanism of leakage current generation

As described in Appendix 2.2, an inverter creates AC by switching of the main circuit elements. Therefore, it is inevitable in principle that a leakage current is generated due to the switching frequency and the leakage capacitance among the cables, a motor and the earth (ground).

The following explains the generation mechanism.

Stray capacitance C exists in the wiring between the inverter and the motor and between the motor and the earth (ground).

Thus, the leakage current flows from the stray capacitance C through the earth (ground) to the power supply due to high-speed switching in the main circuit.

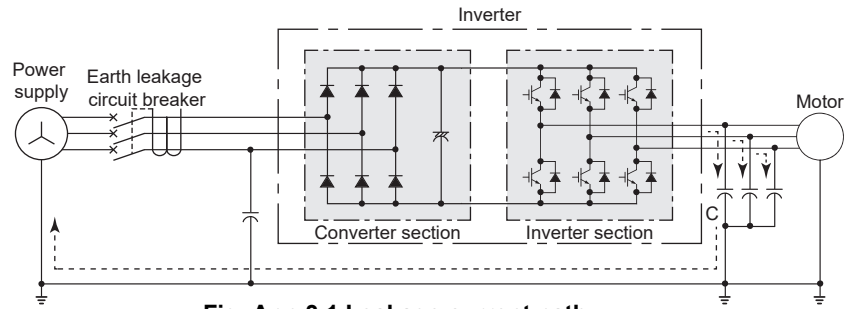


Fig. App 3.1 Leakage current path

The magnitude of this transient leakage current i is calculated by the following formula.

C : Stray capacitance (F)
 dV : Variable voltage (V)
 dt : Switching time (s)

$$i = C \times dV / dt$$

The magnitude of i is affected by the stray capacitance C and the switching speed (dV / dt). In addition, high-frequency switching in the main circuit decreases the to-earth (ground) impedance, which increases constant leakage current. The constant leakage current I (effective value) can be calculated by the following formula.

$$I = V/Z$$

$$= V / (1 / 2 \pi f_c C)$$

$$= 2 \pi f_c C \times V \text{ (A)}$$

Z : To-earth (ground) impedance (Ω)

V : To-earth (ground) voltage (circuit voltage) (V)

f_c : Carrier frequency (Hz)

The above formula indicates that the leakage current depends on the carrier frequency and to-earth (ground) voltage. Therefore, note the following points.

- The leakage current becomes larger when the carrier frequency is higher.
- Even when the carrier frequency is the same, a 400 V inverter generates a larger leakage current than a 200 V inverter as the variable voltage is higher.

[Summary] The leakage current is increased by driving the motor by an inverter compared with the commercial power supply operation, and further increased by increasing the carrier frequency.

Appendix 3.2 Effect of the leakage current

(1) The to-earth (ground) leakage current causes operation of an earth leakage circuit breaker or earth leakage relay.

The leakage current of an inverter contains many high frequency components that have a relatively small impact on the human body.

However, general earth leakage circuit breakers, except for breakers designed for harmonics and surge suppression, detect leakage currents from low to high frequency levels regardless of the frequency band. Therefore, an earth leakage circuit breaker operates when the high-frequency leakage current of an inverter exceeds the breaker's operation current level.

Unnecessary operation of an earth leakage circuit breaker can occur in the circuit to which an inverter is connected or in other circuits that are not directly related to an inverter. The following explains the undesirable current paths, referring to Fig. App 3.2.

(a) Unnecessary operation of an earth leakage circuit breaker (NVI) in the same system of the inverter

A leakage current flows through the to-earth (ground) stray capacitance C then along the paths indicated with the dotted lines A) and B). When its magnitude exceeds the setting value for the earth leakage circuit breaker NVI, the breaker may operate.

- Path A): Flowing affected by the stray capacitance between the wiring on the output side and the earth (ground)
- Path B): Flowing affected by the stray capacitance between the inverter and the earth (ground)

(b) Unnecessary operation of an earth leakage circuit breaker (NV2) in a system separated from the inverter

A leakage current flows through the earth (ground). When its magnitude exceeds the operation current level of the earth leakage circuit breaker NV2, the breaker may operate.

- Path C): Flowing from the stray capacitance between the wirings on the output side
- Path D): Flowing through the stray capacitance between the motor coil and the chassis
- Path E): Flowing through the to-earth (ground) stray capacitance in the separated system

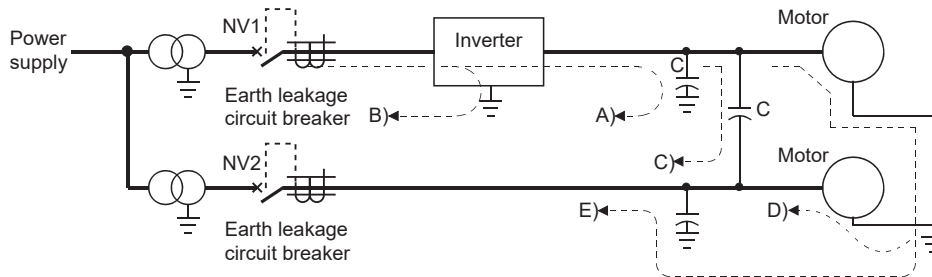


Fig. App 3.2 Undesirable current paths of to-earth (ground) leakage currents

(2) The line-to-line leakage current causes operation of an external thermal relay.

When a thermal relay connected externally is used for motor protection and the wiring distance is long (50 m or more) on the inverter output side, the effective value of the current flowing into the thermal relay may be increased due to line-to-line leakage current A) (shown in Fig. App 3.3), which may activate the thermal relay.

The lower the rated motor current is (several A or less), the greater the effect of leakage current becomes. Therefore, this problem remarkably occurs with the 400 V class, small-capacity (7.5 kW or lower) models.

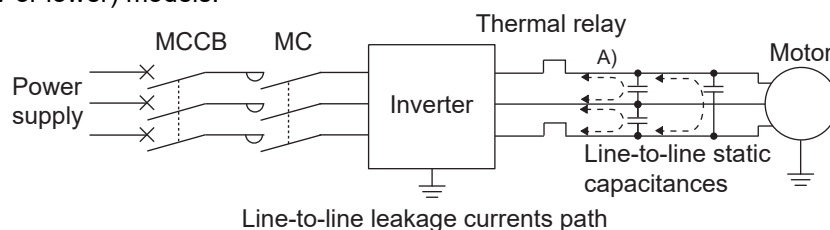


Fig. App 3.3 Line-to-line leakage current path

Remark

The equipment connected on the inverter output side (such as CTs and ammeters) may generate heat due to line-to-line leakage current. Therefore, choose the equipment which has enough capacity for the current rating.

Appendix 3.3 Leakage current data and measurement method

Example of leakage current data

1) To-earth (ground) leakage current

Table App 3.1 To-earth (ground) leakage current (actual measurement example of the composite value less than 100 kHz using an FFT)

Condition	Carrier frequency	Leakage current value (mA)
400 V class inverter	2 kHz	90
	14.5 kHz	210

(Running frequency: 60 Hz, wiring length: 20 m)

(Motor capacity: 3.7 kW 4P)

* For commercial power supply operation, leakage current is approx. 1 mA.

2) Line-to-line leakage current

Table App 3.2 Line-to-line leakage current (actual measurement example of the composite value less than 100 kHz using an FFT) (Carrier frequency of 14.5 kHz)

200 V class			
Motor capacity (kW)	Rated current (A)	Leakage current value (A)	
		Wiring length 50 m	Wiring length 100 m
0.4	1.8	0.31	0.50
0.75	3.2	0.34	0.53
1.5	5.8	0.37	0.56
2.2	8.2	0.40	0.59

*The leakage current value varies depending on the cable insulation type, motor capacity, wiring length, circuit voltage, etc.

(The value is not much affected by the inverter capacity and cable gauge.)
The line-to-line leakage current of the 400 V class is about twice of that of the 200 V class.

(Cable: 2 mm², 4-core cabtyre cable)

Appendix 3.4 Countermeasures against unnecessary operations due to leakage current

The following are countermeasures against the problems caused by leakage currents.

(1) Countermeasures against unnecessary operation of an earth leakage circuit breaker

- (a) Use an earth leakage circuit breaker with a weak sensitivity in a high frequency range.
The output current of the inverter contains a high-frequency leakage current component, which gives relatively low impacts to human bodies. The detection level for this high-frequency leakage current component can be set weaker to prevent unnecessary operations. It does not have much effect on human bodies. For details, refer to Appendix 3.1.

* Specifically, select an earth leakage circuit breaker designed for harmonics and surge suppression such as Mitsubishi Electric New Super NV series. (When using an earth leakage circuit breaker or earth leakage relay not designed for harmonics and surge suppression, increase the sensitivity current.)

- (d) Lower the inverter carrier frequency.

Since the constant leakage current is dependent on the carrier frequency (refer to Appendix 3.1), setting the inverter carrier frequency lower using parameters will certainly reduce the leakage current.

However, as the noise during motor driving is increased by lowering the carrier frequency, this method can be used only when low noise operation is not required.

* The leakage current i_g when the carrier frequency f_c is lowered from f_1 to f_2 can be estimated using the following formula.

$$i_g = i_{g1} \times \sqrt{f_2 / f_1} \quad (\text{Approximate formula}) \quad i_{g1}:$$

Leakage current when the carrier frequency is f_1 (A)

If f_c is lowered from 14.5 kHz to 2 kHz, the leakage current is reduced to approx. one-third.

$$\sqrt{2 / 14.5} \approx 0.37$$

- (e) Decrease the to-earth (ground) stray capacitance.

Use the cables insulated with a low dielectric constant (ϵ_s) material (refer to Table App 3.3), and perform wiring to make the wiring length between the inverter and the motor to be as short as possible.

* The to-earth (ground) or line-to-line stray capacitance C can be estimated using the following formula.

$$C = \epsilon_o \times \epsilon_s \times A/r \text{ (F)}$$

- r : Sheath thickness (m)
- A : Area of opposing electrodes (m²)
(obtained by multiplying the cable length by the outer diameter of the core wire)
- ϵ_o : Permittivity in vacuum (8.84×10^{-12} (F/m))

Use the result of the above formula as a reference as the stray capacitance greatly depends on the wiring method.

Table App 3.3 Dielectric constant of the insulating material of cables

Insulating material	Dielectric constant ϵ_s	Cable name	Insulating material	Dielectric constant ϵ_s	Cable name
Air	1	—	Cross-linked polyethylene	2.2 to 2.4	CV, CE
Water	80	—	Butyl rubber	3 to 5	BN, BV, BE
Epoxy resin	3.3 to 5	—	Chloroprene rubber	4 to 10	CT, RNCT
PVC	3.5 to 9	HIV (PVC insulated wire)	Ethylene propylene rubber	3 to 5	PN, PV, PE
Chlorosulfonated polyethylene	2 to 6	LHH (Chlorosulfonated polyethylene insulated lead wire)	Natural rubber	3 to 5	RN, RV, RE

The to-earth (ground) and line-to-line stray capacitance is smaller when using a CV cable insulated with low dielectric constant, cross-linked polyethylene than when using a PVC insulated (HIV) cable. Even with the same cable gauge and wiring length, the leakage current is reduced to approx. one to two thirds.

<Calculation example>

- When a 14 mm² CV cable (core outer diameter: 4.8 mm, sheath thickness: 1.0 mm) is connected with a length of 100 m, the to-earth (ground) stray capacitance can be estimated as follows.

$$C = \overset{\epsilon_o}{8.84 \times 10^{-12}} \times \overset{\epsilon_s}{2.3} \times \overset{A}{100 \times 0.0048} / \overset{r}{0.001} = 9760 \times 10^{-12} \text{ (F)}$$

- The constant leakage current in the above case can be estimated as follows.
 $I_g = 27 \pi f c \times C \times V = 2 \times 3.14 \times 14.5 \times 10^3 \times 9760 \times 10^{-12} \times 300 = 0.266 \text{ (A)}$

Remark

Noise filters (FR-BIF, FR-BSF01, FR-BLF) are not effective as a countermeasure against leakage current. When a noise filter (FR-BIF) is connected, the to-earth (ground) leakage current increases by several mA.

(2) Countermeasures against malfunction of an external thermal relay

- (b) Use the electronic thermal O/L relay built in the inverter.

The electronic thermal O/L relay in the inverter detects currents excluding harmonics, which prevents the current detection value from being increased due to leakage currents so that the influence becomes smaller. To ensure that the motor is protected, it is recommended to use together a temperature sensor to directly detect motor temperature.

- (c) Increase the external thermal relay setting by the amount of the leakage current.

Increase the setting value by the amount of the leakage current (refer to Table App 3.2) to prevent unnecessary activation of the thermal relay.

Note that the protective characteristics will deviate and the motor with enough capacity is required. To ensure that the motor is protected, use a device such as a temperature sensor to directly detect motor temperature.

*Malfunction rarely occurs with a 11 kW or higher motor or 200 V class motor since the rated current is large and the effect of leakage current is a few percent.

- (d) Lower the inverter carrier frequency.

Since the constant leakage current is dependent on the carrier frequency (refer to Appendix 3.1), setting the inverter carrier frequency lower using parameters will certainly reduce the leakage current.

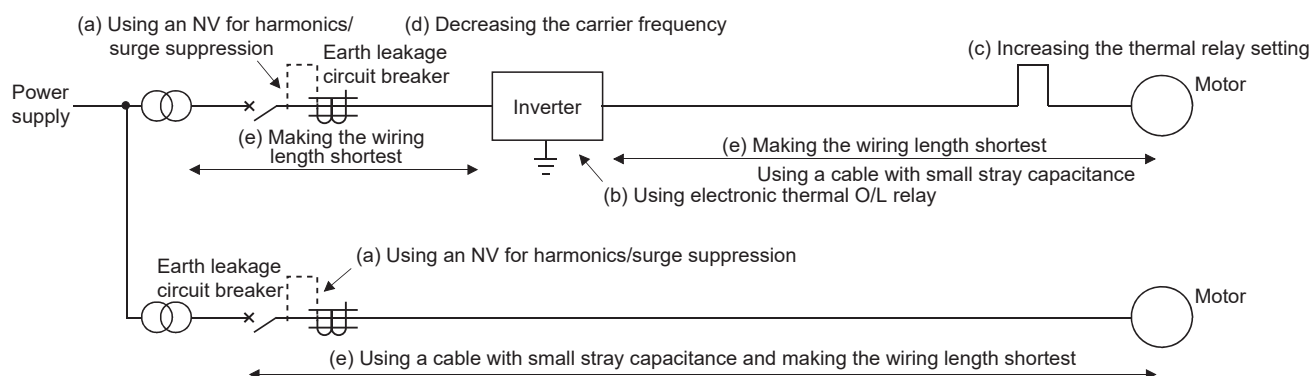
However, as the noise during motor driving is increased by lowering the carrier frequency, this method can be used only when low noise operation is not required.

- (e) Decrease the line-to-line stray capacitance.

Use the cables insulated with a low dielectric constant (ϵ_s) material (refer to Table App 3.3), and perform wiring to make the wiring length between the inverter and the motor to be as short as possible.

(3) Countermeasures

Countermeasure examples against unnecessary operation



APPENDIX

Effects of countermeasures

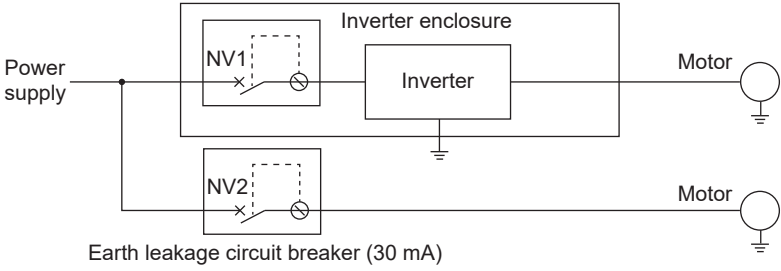
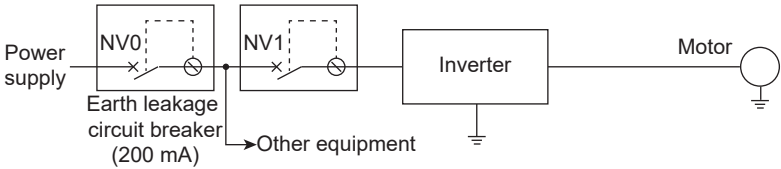
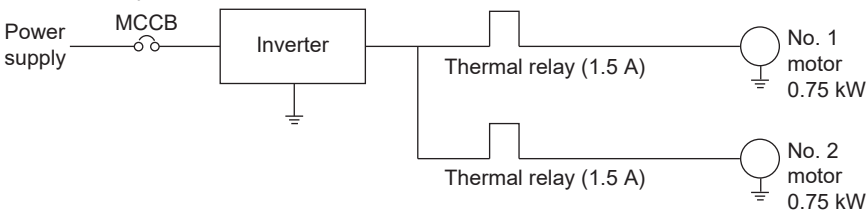
It is recommended to take the countermeasures indicated with ◎ in the following table against the problems due to the effect of leakage current.

No.	Problem	(a) NV for harmonics/ surge suppression	(b) Using electronic thermal O/L relay	(c) Changing thermal relay setting	(d) Changing carrier frequency	(e) Reducing stray capacitance
1)	(a) A breaker in the same system operates.	◎	×	×	◎	○
	(b) A breaker in a separated system operates.	◎	×	×	◎	○
2)	Thermal relay operates.	×	○	○	◎	○

◎ : Effective enough, ○ : Effective, × : Not effective

Appendix 3.5 Specific examples of countermeasures

The following table shows the problems that could be caused by leakage current and their specific countermeasures and results.

No.	Condition	Countermeasures and results
1)	<p>Unnecessary operation of an earth leakage circuit breaker</p> <ul style="list-style-type: none"> After an inverter enclosure was newly installed, the existing earth leakage circuit breaker (NV2) in a separated system operated unnecessarily. (NVI was the breaker designed for harmonics and surge suppression.) 	<ul style="list-style-type: none"> Replaced the existing earth leakage circuit breaker with a breaker designed for harmonics and surge suppression. This solved the problem.
2)	<p>Unnecessary operation of an earth leakage circuit breaker</p> <ul style="list-style-type: none"> After an inverter was installed, the earth leakage circuit breaker (NVO) in the existing power system operated unnecessarily. 	<ul style="list-style-type: none"> Changed the inverter carrier frequency (E600 (Pr.72)) to 0.7 kHz. This solved the problem.
3)	<p>Unnecessary operation of an earth leakage fire alarm</p> <ul style="list-style-type: none"> After an inverter was started, the existing earth leakage fire alarm (200 mA) operated unnecessarily. 	<ul style="list-style-type: none"> Changed the inverter carrier frequency (E600 (Pr.72)) to 0.7 kHz. This solved the problem.
4)	<p>Unnecessary operation of the existing earth leakage relay</p> <ul style="list-style-type: none"> After an inverter was started, the existing earth leakage relay (30 mA) operated unnecessarily. 	<ul style="list-style-type: none"> Changed the inverter carrier frequency (E600 (Pr.72)) to 0.7 kHz. This solved the problem.
5)	<p>Unnecessary operation of an external thermal relay</p> <ul style="list-style-type: none"> Although the current value monitored by the inverter was approx. 5.5 A, the thermal relay whose operation level was set to 7.2 A operated unnecessarily. The rated motor current was 7.5 A. The wiring length between the inverter and the motor was 150 to 180 m. 	<ul style="list-style-type: none"> Removed the thermal relay and used the electronic thermal O/L relay built in the inverter for protection. With the electronic thermal O/L relay set to 7.5 A, unnecessary operation was eliminated.
6)	<p>Unnecessary operation of an external thermal relay</p> <ul style="list-style-type: none"> Although the current value monitored by the inverter was approx. 2.5 A in total of two motors, the thermal relay whose operation level was set to 1.5 A operated unnecessarily. 	<ul style="list-style-type: none"> Increased the thermal relay setting by the amount of the line-to-line leakage current (refer to Table App 3.2), thus to 2.5 A. Unnecessary operation was eliminated. (Since two motors were used, protection by an electronic thermal O/L relay was unavailable.)

Appendix 3.6 Impacts of the leakage current on human bodies and related laws and regulations

To prevent unnecessary operation of an earth leakage circuit breaker, the following countermeasures are possible on the breaker side: (a) increasing the sensitivity current setting, (b) decreasing the detection sensitivity in a high frequency range, etc. The following explains the impacts on human bodies when these countermeasures are applied to inverter operation, and laws and regulations regarding leakage currents.

(1) Impacts of the leakage current on human bodies

1) Human body resistance and contact voltage

Human body resistance is different with each person and affected by humidity and the amount of contact voltage. In general, the resistance is estimated to be decreased to approx. 500 Ω in the worst case as shown in Fig. App 3.4.

In addition, the current flowing through the human body is determined by contact voltage (to-earth (ground) voltage) and human body resistance, and it is important to decrease the contact voltage. Therefore, the equipment must be earthed (grounded). Earthing (grounding) must conform to the requirements of national and local safety regulations and electrical code (NEC section 250, IEC 61140 class 1 and other applicable standards).

2) Current splitting into the earth (ground) resistance and human body resistance

Out of the leakage currents generated by inverter operation, the current flowing into the human body is determined by the split ratio between the earth (ground) resistance and human body resistance.

Specifically, when the motor is earthed (grounded) as mentioned in 1), the earth (ground) resistance is 100 Ω or less. Assuming that the human body resistance is 500 Ω and the total leakage current is 400 mA, the current flowing into the human body is calculated as follows.

$$400\text{mA} \times \frac{100\Omega}{500\Omega + 100\Omega} = 67\text{mA}$$

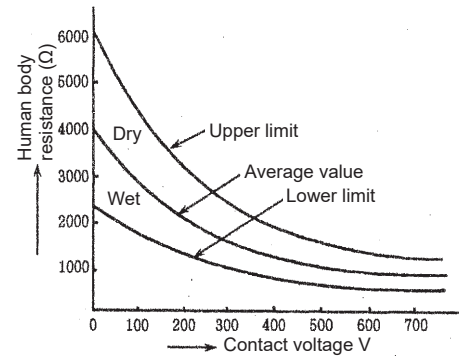


Fig. App 3.4 Relationship between contact voltage and human body resistance

3) Current flowing through human body and current causing ventricular fibrillation

Fig. App 3.5 shows the current to cause ventricular fibrillation in the human body when using a commercial power supply (50/60 Hz). It is important to keep the current flowing through human body to 30 mA or less.

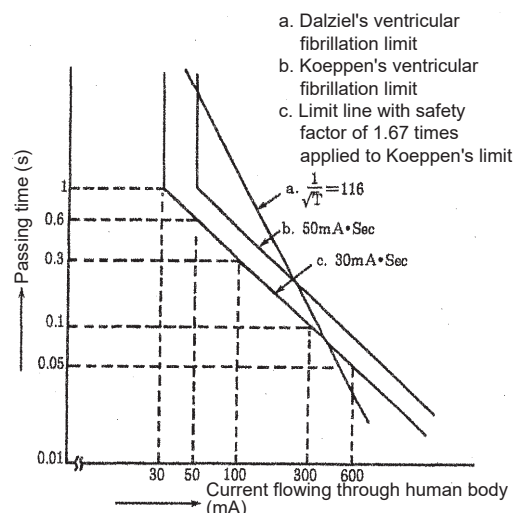


Fig. App 3.5 Ventricular fibrillation current passing time limit

4) Impacts of high frequency

The main component of the leakage current generated by inverter operation is high frequency of 10 kHz or more, and such current hardly flows into the human body, just passing through the skin due to the skin effect.

Therefore, the current to cause ventricular fibrillation in 1 kHz or higher frequency range is 14 times or more larger than during commercial frequency operation. (Refer to Fig. App 3.6.)

In other words, a current of up to 14 times is allowed in high-frequency current operation compared with commercial frequency operation.

(For example, if the above-mentioned case is converted to commercial frequency operation, the flowing current is approx. 5 mA, obtained by dividing 67 by 14. With earthing (grounding) mentioned in 1), the current does not have much effect on the human body as shown in Fig. App 3.6.)

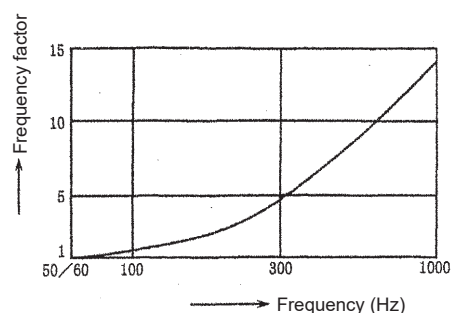


Fig. App 3.6 Current value to cause ventricular fibrillation due to current flowing through human body (IEC 479-2)

5) Sensitivity of an earth leakage circuit breaker

Since the leakage current component in inverter operation is high frequency, using a breaker with a weaker detection sensitivity to a high frequency is an effective countermeasure with little impact on the human body against unnecessary operation of an earth leakage circuit breaker.

(2) **Measures against leakage currents**

To protect against leakage currents and electric shock, consider implementing measures such as installing an earth leakage circuit breaker in accordance with the standards of each country.

Remark

For electric shock protection with an earth leakage circuit breaker, refer to the "MCCB ELCB Technical Note".

1	BASICS OF INVERTERS
2	MOTOR CHARACTERISTICS AT INVERTER DRIVE
3	PRINCIPLE AND FUNCTIONS OF INVERTER
4	ENERGY SAVING WITH INVERTERS
5	CAPACITY SELECTION FOR MOTOR AND INVERTER

Appendix 4 Earth (ground)

Appendix 4.1 Earth (ground) and leakage current

(1) Purpose of earthing (grounding)

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 actually, a slight current flows into the case.

The original purpose of the earth (ground) terminal is earthing (grounding) the case of an electrical apparatus to prevent operators from getting an electric shock from this leakage current when they touch it.

In addition, to avoid the influence of external noises, earthing (grounding) is important to machines that handle low-level signals or operate very fast such as audio equipment, sensors, and computers.

(2) Notes for earthing (grounding)

As described above, earthing (grounding) has two completely different types, and a problem occurs when these are earthed (grounded) together. Therefore, consider a dirty earth (ground) for electric shock prevention and a clean earth (ground) for noise prevention separately.

When an inverter is used, its output voltage has not a sine waveform but a precipitous pulse waveform. Therefore, the charging/discharging current to the static capacitance in the isolated section flows as the leakage current.

Furthermore, the same charging/discharging leakage current flows into the motor where the output voltage of the inverter is applied. The leakage current contains more high frequency components and the current value is larger compared to the operation with a commercial power supply as shown in Fig. App 4.1. The higher the carrier frequency of the inverter is, the stronger this tendency is.

Therefore, when earthing (grounding) of the inverter, motor driven by the inverter, and devices such as audio devices, sensors, and computers are connected together, the leakage current becomes the noise source and the noise that affects the devices.

To resolve this problem, separate the dirty earth (ground) for the inverter or motor and the clean earth (ground) for devices such as audios, sensors, and computers.

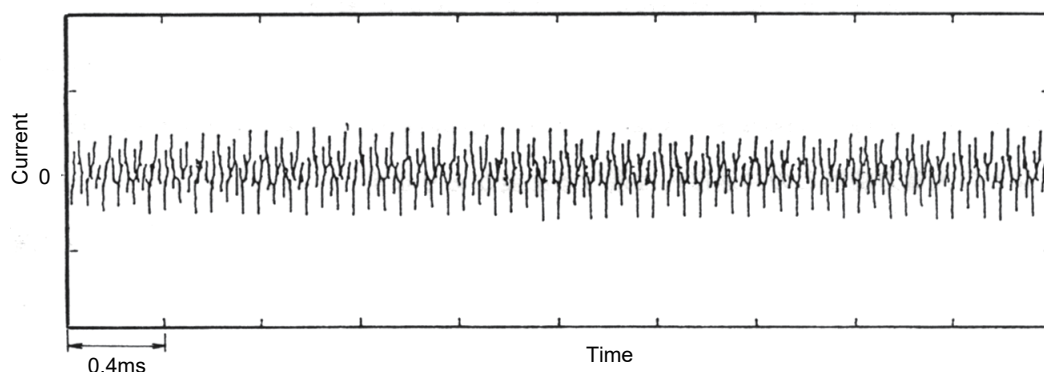


Fig. App 4.1Example of the earthing (grounding) current of the inverter-driven motor
(Inverter: 200 V class 0.75 K, Motor: 0.75 kW 4 P)

Appendix 4.2 Earthing (grounding) system to be established

As described previously, the purpose of earthing (grounding) is roughly classified into the electrical shock prevention and the prevention of malfunction due to the influence of electromagnetic noise. These two purposes should be clearly distinguished, and the appropriate earth (ground) system must be established to prevent the leakage current having high frequency components from reversing through another earth (ground) point for malfunction prevention by following these instructions:

- (a) Make the separate earth (ground) connection (I) for the inverter from any other devices wherever possible. (Refer to Fig. App 4.2.)

Establishing adequate common (single-point) earth (ground) system ((II) in the figure) is allowed if the separate earth (ground) system ((I) in the figure) is not feasible.

Do not use the other equipment's earthing (grounding) cable to earth (ground) the inverter as shown in ((III) in the figure).

Especially, the common earthing (grounding) with the high-power devices such as motors or transformers must be avoided.

As leakage currents containing many high frequency components flows into the earthing (grounding) cables of the inverter and the motor driven by the inverter, the inverter must also be earthed (grounded) separately from EMI-sensitive devices described above.

In a high building, it may be effective to use its iron structure frames as earthing (grounding) electrode for EMI prevention in order to separate from the earth (ground) system for electric shock prevention.

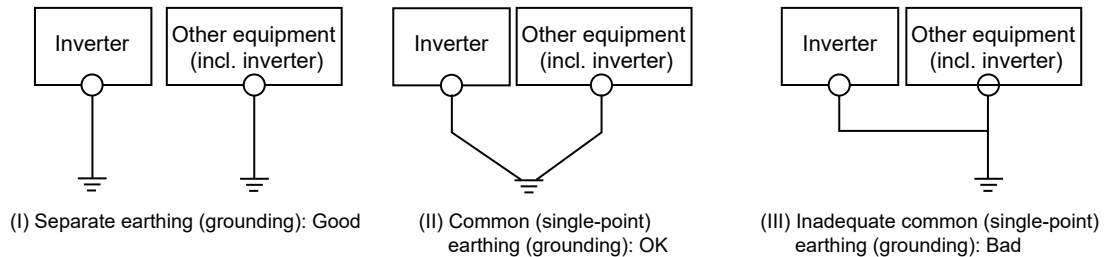
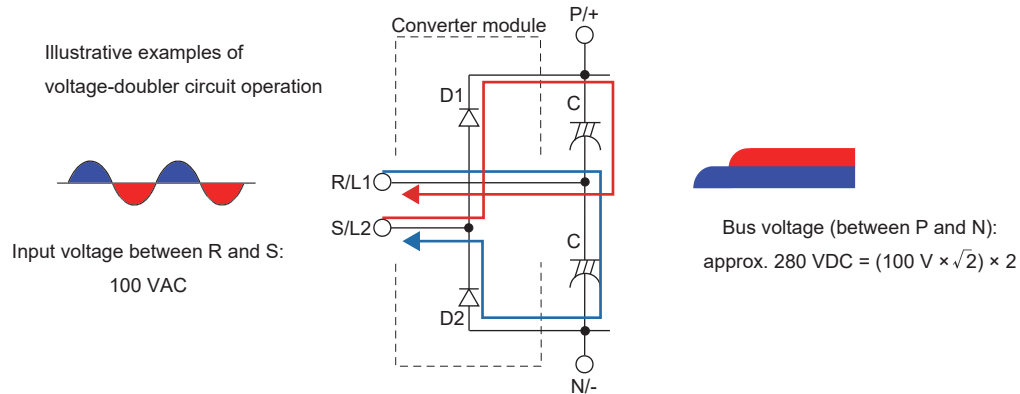


Fig. App 4.2 Earthing (grounding) methods

- (b) Earthing (grounding) must conform to the requirements of national and local safety regulations and electrical codes. (NEC section 250, IEC 61140 class 1 and other applicable standards).
- (c) Use the thickest possible earthing (grounding) cable. The size of the earthing (grounding) cable should be the same or larger than the one indicated in the Instruction Manual of the inverter.
- (d) The earthing (grounding) point should be as close as possible to the inverter, and the earth (ground) wire length should be as short as possible.
- (e) Run the earthing (grounding) cable as far away as possible from the I/O wiring of the EMI-sensitive devices and run them in parallel in the minimum distance.
- (f) For the earth (ground) terminal of the motor, use one cable of the 4-core cable and earth (ground) at the inverter side.

Appendix 5 Voltage-doubler circuit

The converter section of the single-phase 100 V power input model is equipped with a voltage-doubler circuit. The following outlines its basic operation.

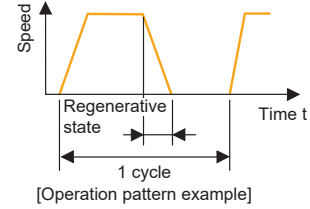


- 1) In the positive (+) section, the lower capacitor is charged. (Half-wave rectification)
- 2) In the negative (-) section, the upper capacitor is charged. (Half-wave rectification)
- 3) At bus voltage P/+ and N/-, the ends of the series connected capacitors, doubled voltage (approx. 280 VDC) can be obtained.

Appendix 6 Glossary

· %ED

Ratio of the regenerative driving time to the operation time per cycle of repeated operation. With the regenerative driving time is 10 s and one cycle is 100 s, for example in the figure on the right, 10%ED is obtained.



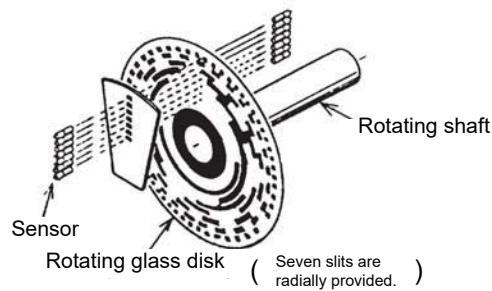
· Absolute (absolute position) encoder <Antonym: Incremental encoder>

An encoder that can output the angle data within one rotation of the encoder to an external device. Generally, an encoder that can output 360° with 8 to 12-bit data is used.

By using the encoder as a servo motor encoder, the position within one rotation of the motor can be identified. Therefore, the encoder is used together with a rotation amount counter to configure an absolute position system.

The encoder 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

Change of the motor speed expressed with ratio to the acceleration time, in other words, slope to the time of motor speed change.

· Acceleration time

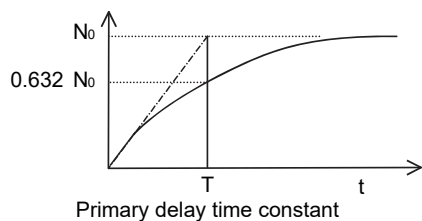
Time taken to change the motor speed from the current speed to the commanded speed.

APPENDIX

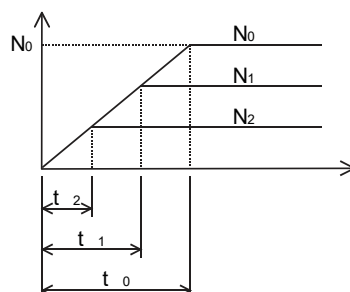
· Acceleration time constant

Time taken from start to end of the acceleration when the motor is accelerated from the stop status to the certain speed (rated speed, parameter limit speed, etc.).

For the acceleration pattern of the primary delay function, it indicates the time until the actual speed reaches 63.2% of the target speed.



Acceleration pattern with primary delay time constant
Acceleration time and acceleration time constant



t_0 : Acceleration time to reach the reference speed = Acceleration time constant
 t_1 : Acceleration time to reach the motor speed N_1
 t_2 : Acceleration time to reach the motor speed N_2

· All digital control (Digital control)

Control that is performed by a micro computer or a circuit configured with the peripheral LSI and logic IC.

· Analog control <Antonym: Digital control>

Control method that is performed by a circuit configured with analog devices, such as an operational amplifier.

· Angular frequency (ω)

Term to express the continuous sine wave. While the number of cycles per second is measured in Hz (hertz), angular frequency refers to the frequency expressed in angles (radians). The frequency f [Hz] is converted to $2\pi f$ [rad/s].

· Auto tuning (Offline auto tuning / Online auto tuning)

The offline auto tuning is a function with which an inverter 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. High-accuracy operation without being affected by motor temperature is achieved. Also high torque can be provided at very low speed and stable operation is possible.

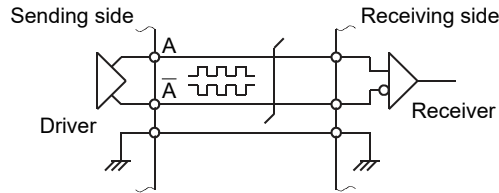
· Capacitor regeneration

Method to perform regenerative driving by charging the regenerative energy to 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 to be charged to the capacitor. However, this method is only applied to small-capacity models since the energy that can be charged to the capacitor is small.

· Differential transmission system

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>

Control method that is performed by a circuit configured with digital devices. In recent times, a system, in which an operation is processed with software using a micro computer or micro processor, has become common due to increase of the calculation amount.

The advantages of the digital control system are stable performance and high-repeatability without offset and temperature drift.

· Earth (ground) fault

This is a state where any of the motor power cables (U, V, and W) is shorted with the earth (ground).

· Electronic gear

Adjustment method for the ratio of feedback pulse to a command pulse. However, the position resolution is not changed since it is determined by an encoder. The ratio can be changed with fraction using parameters. Unlike a mechanical gear, the motor torque is not increased even if the ratio is increased.

· Feedback control

Control to detect a gap between a command and the actual speed with a closed loop and compensate the command value to reduce this gap.

· Frequency response (characteristic)

Speed response expressed quantitatively. This indicates the frequency to which the actual motor can respond, expressed with ω_c [rad/s] or f_c [Hz], when the speed command is changed into a sine wave pattern as an extremely low-speed command of approximately 10 r/min. This frequency response can be enhanced by increasing the speed loop gain. However, if it is increased too much, a vibration may occur or operation may become unstable due to the rigidity of a mechanical system, etc.

· IGBT (Insulated Gate Bipolar Transistor)

Compared to the conventional transistors, IGBTs enable high-speed switching and can better tolerate current, pressure, etc.

· Impact drop

Value indicating the fluctuation range of the output to an input command under feedback control. Its temporal response characteristic is indicated with the amount and duration time of the temporary fluctuation when the load is changed in step-like manner.

This will be especially effective when an integral operation is included.

APPENDIX

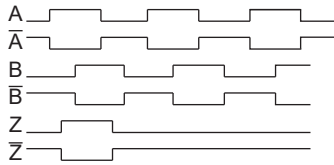
· Incremental encoder <Antonym: Absolute encoder>

Pulses are output in accordance with the number of rotations 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.

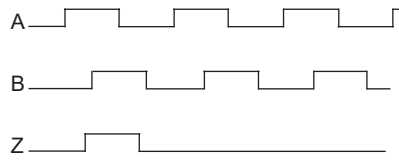
- Differential line driver

A/ $\bar{A}$ -phase signal 1000 to 4096 pulses/rev
B/ $\bar{B}$ -phase signal 1000 to 4096 pulses/rev
Z/ $\bar{Z}$ -phase signal 1 pulses/rev



- Complementary, open collector

A-phase signal 1000 to 4096 pulses/rev
B-phase signal 1000 to 4096 pulses/rev
Z-phase signal 1 pulses/rev



Output pulse specification example

· Inertia (Moment of inertia)

Refer to "Moment of inertia" on page APP - 54.

· Instantaneous power failure

The inverter continues the operation when the power failure time is very short (normally, 15 ms or less). However, if the power failure time is longer than 15 ms, an instantaneous power failure error is activated and the operation is stopped.

If the power failure continues (normally, several 100 ms or more), as in the case of powering OFF, the operation is recovered to the power-ON state by power restoration. The power failure from 15 ms to several 100 ms is normally called instantaneous power failure, and the instantaneous power failure error will be held.

· Machine analyzer

This automatically vibrates a vector motor to analyze the frequency characteristic of the machine. This analysis is influenced by the computer's capability.

· Model adaptive speed control

The trackability for speed commands and the response level to the motor disturbance torque can be adjusted individually.

· Moment of inertia (Inertia)

Amount indicating the rotational gravity of a rotor. This is equivalent to the mass for the linear operation.

Definitional equation $J = m \times r^2$

where	J	:	Moment of inertia [kg·m ²]
	m	:	Mass [kg]
	r	:	Rotation radius [cm]

GD² is usually used as the amount indicating the moment of inertia. The r (radius) of the equation above is expressed in 2r (diameter), and there is the following relationship.

$$GD^2 = m \times (2r)^2 = 4J$$

· Motor electromagnetic brake

The brake of an electromagnetic brake equipped motor is a non-excitation type brake to be used during vertical movement to prevent drop of the workpiece at a power failure or an inverter fault occurrence or hold the workpiece during stop.

· Motor frame number

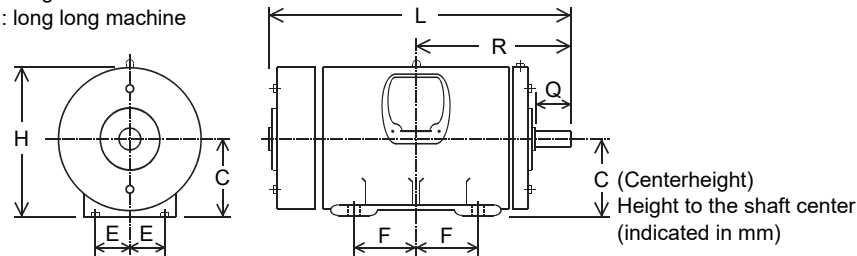
The specifications such as the installation dimensions, shaft diameter, and shaft length of a standard motor are specified by the JIS standards as follows.

The motor size can be checked with the frame number.

For the frame number, the shaft center height (dimension C) is indicated in mm, followed by the size indication of the frame length.

The size is indicated by an additional letter such as S, M, L, and LL.

S : short machine
M : medium machine
L : long machine
LL : long long machine



Example: 315 S
Represents the shortest frame of the 315 frame (L dimension)
Center height 315mm

· Open loop

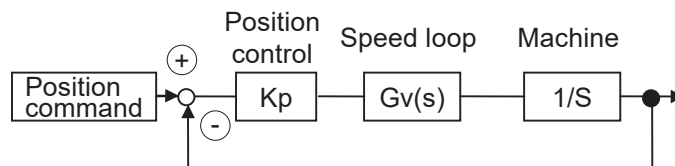
Since this system does not use an encoder, the control system is simple and economical. Therefore, this system is often used for a relatively rough positioning or small-capacity applications that do not need much torque at high speed. Most inverters use this system.

· Position loop gain

This indicates the response to a command during position control. The following shows the block diagram of the position control indicating the speed control system as $G_v(s)$.

Here, the position loop gain is expressed as follows.

$$\begin{aligned} \text{Position loop gain} &= K_p \times G_v(s) \\ &= K_p \end{aligned}$$



$G_v(s)$ is assumed to be nearly equal to 1 since the response of speed control is enough compared with position control.

Here, the position loop gain is expressed as the position response: $K_p = \omega_p$ [rad/s].

APPENDIX

· Power regeneration

System in which the regenerative energy is returned to the power supply side via the DC bus. Although a dedicated module for returning the energy to the power supply side is required, this has advantages such as less heat generation than resistor regeneration and smaller installation dimensions for large regenerative energy. Therefore, this system is mainly used for applications requiring continuous regeneration such as large-capacity models and lift axes.

· Primary delay time constant

Time constant of exponential function, which indicates a time required to reach 63% of the final value. (Refer to the figure of "Acceleration time constant" on page APP - 52.)

· Regeneration

The state 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 by the motor. This state is called power driving. On the contrary, the rotation energy of the motor and load flows to the inverter when the load speed is decelerated, for example, at motor deceleration or descent load drive. This state is called regeneration.

The inverter obtains the regenerative brake torque by consuming the regenerative energy with a capacitor and resistor.

The regenerative brake torque is automatically adjusted depending on the deceleration pattern. However, use a regenerative option when the regenerative driving is performed frequently.

· Regenerative overvoltage

The state that the DC bus voltage exceeds the permissible value due to the regenerative energy that flows to the inverter during regenerative driving. In this case, since devices such as capacitors may be damaged, the regenerative overvoltage error is activated to stop control functions.

This state may occur when the regenerative energy is extremely large or the capability of regenerative resistor is low.

· Resistor regeneration

System in which braking torque is obtained by applying the regenerative energy to the resistor connected to the bus and consuming it as heat.

· Response

This indicates the trackability for commands and generally refers to the speed response.

· Speed feed forward control

This improves the motor trackability for speed command changes.

· Speed fluctuation ratio

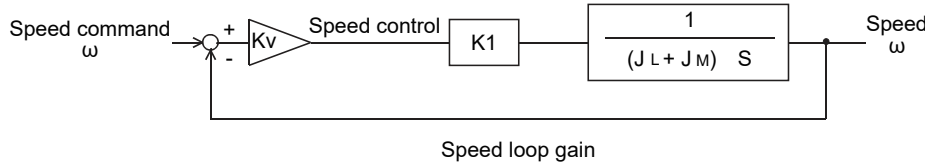
Fluctuation ratio of the motor speed, expressing the ratio of fluctuating speed to the rated speed as a percentage.

The ratio of speed fluctuation due to load fluctuation is calculated by the following formula.

$$\text{Speed fluctuation ratio} = \frac{\text{Speed with rated load} - \text{Speed with no load}}{\text{Rated speed}} \times 100 \quad [\%]$$

· Speed loop gain

This indicates the response to a command during speed control. When the constant to be determined by a motor is assumed as K_1 , the speed loop gain is calculated as follows.



$$\text{Speed loop gain} = \frac{K_1 \times K_v}{J_M + J_L}$$

K_v : Speed amplifier gain

J_L : Load inertia

J_M : Motor inertia

· Undervoltage

If the power supply voltage to the inverter falls below the specified value, the operation is stopped and the fault signal is output to protect the equipment. This specified value is usually 150 VAC for the 200 VAC class inverters, and a voltage lower than this value is called undervoltage level.

· Uneven rotation

Instantaneous fluctuation of motor speed to a command. The unevenness generally increases at low speed and decreases at high speed.

· V/F control

Control method in which the ratio of frequency to the output voltage is kept constant when the frequency is changed.

In this control method, 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.) Therefore, the amount of the voltage drop is estimated and added to the output voltage (torque boost) to compensate the torque shortage at low speed.

· Vector control

Motor speed is detected with an encoder and a motor slip is calculated to identify the load magnitude.

Under this control, vector calculation is performed based on the obtained load magnitude, and the inverter output current is divided into the excitation current (required to generate magnetic flux) and the torque current (proportional to load torque), then the frequency and the voltage are controlled optimally to output the required currents.

REVISIONS

* The school text number is given on the bottom left of the back cover.

Print date	* School text number	Revision
Jun. 2017	SH(NA)-060026ENG-A	First edition
Mar. 2026	SH(NA)-060026ENG-B	Added <ul style="list-style-type: none">•FR-F800 (FR-F700P → FR-F800)•FR-E800 (FR-E700 → FR-E800)•FR-D800 Deleted <ul style="list-style-type: none">•FR-V500

Trademarks

Microsoft®, Windows®, Windows®95, Windows NT®, Windows98, Windows®2000, Windows®ME, Windows®XP, Windows Vista®, Windows®7, Windows®8, Windows®8.1, Windows®10, Internet Explorer, Excel, and Visual Basic are registered trademarks or trademarks of Microsoft Corporation in the United States and/or other countries.

The other company names and product names mentioned in this inverter school text are either registered trademarks or trademarks of their respective companies.

INVERTER SCHOOL TEXT
INVERTER BASIC COURSE (FR-E800)

mitsubishi electric corporation
HEAD OFFICE: TOKYO BUILDING 2-7-3, MARUNOUCHI, CHIYODA-KU, TOKYO 100-8310, JAPAN

When exported from Japan, this manual does not require application to the
Ministry of Economy, Trade and Industry for service transaction permission.