MITSUBISHI ELECTRIC
Changes for the Better

Practical Guide

Inverters

Guide to Investment Planning

Watermanagement

Overview

Tried and tested and results oriented

Foto: HAMBURG WASSER

Helpful guide for practical applications

Practical solutions achieved quickly and efficiently – this is the motto for this practical primer from Mitsubishi Electric. It is a helpful guide for anyone involved in designing drives with inverter. For design and engineering offices, for system builders and project engineers, the primer is intended to show everyone which of the many possible paths leads to an optimum result.

Good planning is indispensable when designing a speed-controlled drive system. This is where the quality of the drive system regarding its operating and maintenance costs and its trouble-free and safe operation is defined. A careful approach is therefore vitally important, particularly at this stage.

At the same time, the practical primer will help you to take into account all aspects necessary for the design. As well as increased design safety, this will reduce the risk of overlooking important details.

The main points relating to system planning are presented briefly and to the point. Lengthy explanations of technical relationships have been deliberately avoided in order to come specifically to a result.

The selection guide

To assist you in your planning, you will find a line at the end of each subject where you can briefly record the results of your deliberations. You can then enter further detailed information and the components selected for the purpose in the selection guide at the end of the primer. When you have worked through all the points in this practical primer, you will have a reasoned basis for implementing your system.

Item	What do you need or what is available?	
1	☐ XXXX	☐ XXXXXXX

Why use an Inverter?

The use of speed controlled motors in the water industry leads to significant energy and cost savings. The strengths of the inverter are particularly evident in the control of flow and pressure of electromagnetic pumps. Let us consider this by taking the supply of drinking water as an example.

When measured over a period of time, water consumption varies considerably. These variations occur both seasonally and daily:

- Annual variations as a function of the climatic conditions (hot or cold summer)
- Monthly variations as a function of the season
- Daily variations as a function of weekends and public holidays
- Hourly consumption variations as a function of the particular time of day

Because of these variations, pumps usually run at partial load. By controlling pumps using an inverter, they always work at maximum efficiency, even under different flow conditions. And if we look at the cubic relationship between speed and power (see page 10), it can quickly be seen that a pump which is running at half speed only consumes about one-eighth of the power that it would at full speed.

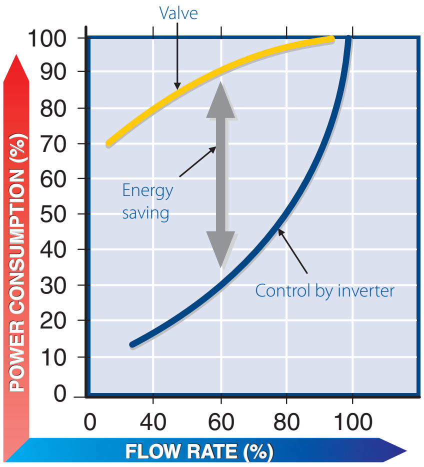
The advantages at a glance

Effective energy saving

Drastic energy savings of up to 60 % can be achieved, particularly with pumps and fans

Limitation of starting current

The inverter limits the starting current to the motor rated current.



Energy saving when using an inverter

Conversion

Existing systems can be easily retrofitted with inverters.

Reduced system wear

All components coupled to the motor, such as gearbox, coupling etc, are subject to reduce load thanks to soft starting and stopping.

Optimum operating point

Inverters enable a system to be operated at the optimum operating point and therefore increase the efficiency.

Extended control range

The inverter enables the motor to be operated over a larger speed range.

Long service life

Operating the drive system at part load causes less wear, as a result of which the service life of individual components is significantly increased.

Reduced noise

Less noise is produced when a system is not running at full load.

Special demands on the inverter

Networking capability

The networking of the drives using a fieldbus system must enable the drives to be controlled and monitored centrally by an external PLC.

Remote monitoring

One of the main requirements in the water industry is the remote monitoring from a central control room of the stations, which are distributed over a wide area.

High starting torque

The production of additional torque in order to move a load from standstill is referred to as overload capability.

Protection class

Depending on the place of use, special attention must be paid to the protection class and the protective varnishing of the printed circuit boards, particularly in the water industry.

Cascading of pumps

The cascading of pumps enables effective motor management (e.g. in the case of a sudden increase in water demand).

Safeguarding against failure

High reliability of the components, which are often spatially far apart, is just as important as their service-friendliness.

Special software solutions

Software solutions specially tailored for the water industry assist in the planning, development and commissioning of the system.

Save costs over time

Life cycle costs (LCC)

The focus of attention should not only be on the procurement and installation costs when selecting a pump system. Only a full consideration of all costs which arise from the use of pump systems during their working life will provide a solid basis for a purchase decision. The individual items are recorded in the life cycle cost equation.

The elements of life cycle analysis

C_{ic} = Procurement costs (invested capital)

Costs which are incurred before commissioning, i.e. purchase costs for the individual components etc.

C_{in} = Installation/commissioning costs (installation)

Costs for the installation and commissioning of the entire system

C_e = Energy costs (energy)

Costs for the energy required by the individual components

C_o = Operating costs (operation)

Costs such as personnel costs or costs which are incurred as a result of control by a superimposed system

C_m = Maintenance costs (maintenance)

Costs for normal maintenance, i.e. cleaning and lubrication of components or replacement of cooling fans.

C_s = Downtime costs (standstill)

Costs due to lost revenue

C_{env} = Environmental costs (environment)

Costs which are incurred due to demands on the environment and safety at work such as the disposal of lubricants.

C_d = Decommissioning/disposal costs (decommissioning)

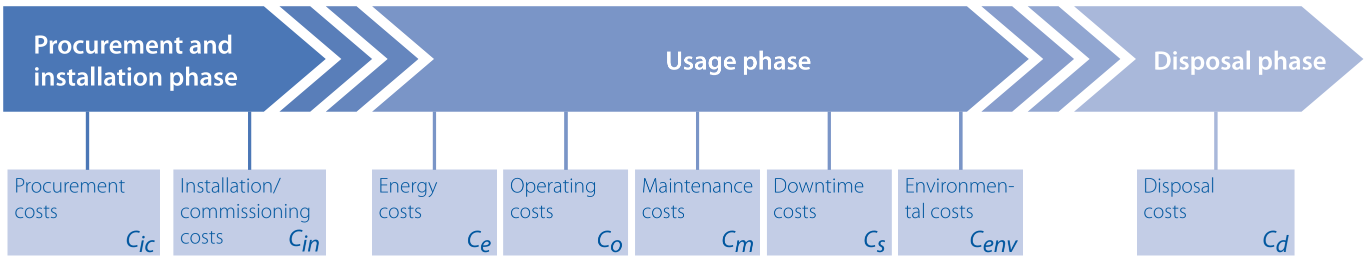
Costs for decommissioning and disposal of the system at the end of its life.

Cost reduction factors

Two parameters, energy costs and maintenance costs, have a major influence on the magnitude of the life cycle costs. It has already been explained on the previous page that tremendous energy savings can be made particularly by using inverter in pump control systems.

In addition, Mitsubishi Electric inverter have long-life and easily accessible components, such as the fans for example, as a result of which the cost of maintenance is significantly reduced.

The maintenance timer, which monitors the life of various components, enables wearing parts to be replaced before the machine fails or comes to a stop. This leads to an enormous reduction in the downtime costs.



$$LCC = C_{ic} + C_{in} + C_e + C_o + C_m + C_s + C_{env} + C_d$$

Inverters in the water industry

Inverters enable flow to be controlled efficiently and cost effectively. In the water industry, they are therefore used in the following areas amongst others:

Water supply:

- Drinking water treatment
- Water booster systems
- Surface water (weirs, dams, irrigation)
- Seawater desalination systems
- Swimming pools
- Industrial water
- Pumped storage power stations
- Marine & Offshore industry

Wastewater treatment:

- Effluent treatment
- Sludge treatment
- Biogas recovery

By way of example, the following applications can be realised in practice with the following measures:

Pumps in the water treatment industry

Every day, large quantities of rainwater and effluent flow from domestic properties to wastewater treatment systems. About 20 hours later, this water can be redispensed with excellent quality. Hundreds of drives are used in the process. In addition to the transportation of water and effluent sludge by means of pumps, oxygen must be introduced into the water in order to promote the cleaning process. Further drives set screens and scrapers in motion.

The use of inverter enables the deployment of optimally controlled variable speed drives which guarantee that the cleaned water is of consistently high quality. At the same time, energy costs can be significantly reduced.

Sluice gate control

Another challenge is the safe movement of heavy loads, such as those which occur with sluice gates. Here, inverter with a high overload capability which can respond to changing water levels and counteract high breakaway torques must be used.

Similar criteria also apply to the control of floodgates which are used to control the water flow by diverting it via dams or discharge channels.

Swimming pools

According to law, the water in a swimming pool must be continuously circulated and filtered. However, the volume flow can be reduced to half outside the opening times. Here, a frequency converter can be used to control the pump. The fact that the pump only runs at a fraction of the maximum power during this time results in high energy savings.

Also, the pump does not have to be operated at maximum power during the opening times. Only the backwashing of the filter should be carried out at high speed.

In this case, the frequency converter can be automatically switched off using the "Switch motor to mains operation" function and the motor operated directly on the mains.

Important norms and standards

Compliance with EC Directives

Within the member states of the EU, the Machinery Directive, the EMC Directive and the Low-Voltage Directive are the constituent parts of the EC Directives which govern the assurance of fundamental safety requirements and the carrying of the "CE" mark. All Mitsubishi Electric inverters bear the CE mark.

Compliance with the EC directives is indicated by the submission of a Declaration of Conformity and by applying the "CE" mark to the product.

Machinery Directive

A machine must be designed so that, when it is correctly installed and appropriately maintained, it does not cause a hazard when used as intended. Since 29th December 2009, the application of Directive 2006/42/EC has been mandatory.

Individual components, such as inverters, are not subject to the Machinery Directive. The system builder who fits a frequency converter in a machine must guarantee compliance with all relevant norms and safety regulations.

EMC Directive

The EMC Directive 2004/108/EC defines the electromagnetic compatibility of electrical equipment. Its application has been mandatory since 20.07.2007. Inverters are not devices which can be operated independently. Compliance with the EMC Directive therefore cannot be achieved either by a CE mark or by an EC Declaration of Conformity (see Page 14).

Low-Voltage Directive

Along with the EMC Directive, the Low-Voltage Directive is the most important regulatory instrument for the safety of electrically operated equipment. Electrical equipment with a rated voltage between 50–1000 V AC and between 75–1500 V DC must be designed so that, when it is correctly installed and appropriately maintained, it does not cause a hazard when used as intended. Frequency converters are items of electrical equipment within the specified voltage range and are therefore subject to the Low-Voltage Directive.

Further norms and standards

The following norms and standards are also applied in the water industry:

- **DNP3**

(Distributed Network Protocol 3)
Special communications protocol for telemetry. It is used for the general transmission of data between control systems and substations.

- **IEC 60870**

General open communication standard for the control and monitoring of industrial systems for infrastructure automation (substation automation, telemetry, power system management)

- **IEC 61131-3**

PLC programming standard. Enables standardised, reusable PLC programs and function blocks to be created.

- **NAMUR**

(Automation Systems Interest Group of the Process Industry)
One of the central requirements of NAMUR recommendation NE 124 is for manufacturers to provide standardised solutions in order to ensure a high degree of interoperability and interchangeability regardless of manufacturer.

- **HART**

(Highway Addressable Remote Transducer)
Global standardised protocol for transmitting and receiving digital information between devices and systems for control and monitoring via analogue cables.

Compliance with global norms and standards

Mitsubishi Electric inverters are designed so that they can be used throughout the world without additional expense or acceptance testing. This means: Compliance with the global standards CE, UL, cUL, Gost, CCC, ISO 9001 and ISO 14001. The inverters FR-F700 and FR-A700 also comply with the DNV standard.

Approval marks of national and international standards

System planning

Basic principles

Meticulous attention must be paid to all parameters when sizing a drive system. For this reason, important factors such as the power supply, the ambient conditions and many others are considered in this part of the primer. This chapter discusses the procedure for the basic selection of the inverter.

The inverter should be selected with the utmost caution, as careful sizing is the key to a cost-saving drive solution. In doing so, the inverter must not be rated exclusively on the basis of the power in kilowatts. More accurately, the rated motor current at the maximum load must be used as a basis, as the motor power refers not to the connected electrical power, but to the mechanical shaft power.

At the same time, it must be borne in mind that the power is only achieved when the full output voltage of the inverter is applied to the motor. This must therefore not be reduced by voltage drops across filters, chokes or the motor cable, as the motor would then require a higher current to achieve the power. The resulting additional heat losses reduce the life of the motor and send the costs spiralling.

Selection steps

The motor and inverter can be rated using the following method:

- Check the connection conditions
  Check the mains voltage range (200 V–690 V) and the mains frequency (50 Hz–60 Hz)
- Check the process requirements
  What is the starting torque? What is the working speed range? What is the type of load? (The types of load are explained on the following pages.)
- Select the motor
  Select the motor so that the motor torque corresponds to the rated torque of the machine. The thermal overload capability of the motor must not be exceeded.
- Select the inverter
  Select the inverter to suit the connection conditions, the process requirements and the motor. Check the power range with regard to the required current and the power output. Can you use the overload capability of the inverter for a cyclic overload? For example, Mitsubishi Electric inverters have an overload capability of up to 250 %. Does this allow a smaller inverter to be chosen? Should the inverter have special characteristics for your drive (e.g. cascading of pumps, integral PID regulator, regeneration avoidance function)?

Load characteristics in the water industry

The load profile

Most drive systems in the water industry have a characteristic with a torque which increases quadratically with speed ($M \sim k \times n^2$; k: drive constant).

A breakaway torque seldom occurs with these drives. The drive power is highly dependent on the speed. It varies with the cube of the speed ($P \sim n^3$).

An example is used to illustrate the relationship:

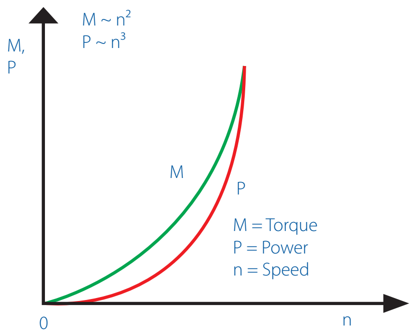
If the pump power is reduced from 100 to 90 % for example, then the drive power reduces to $0.9^3 \times Pn$, i.e. approximately 70 %.

There are also applications in the water industry which can demand a high torque from the motor over the whole working range, that is to say even at low speeds (reciprocating pumps).

As well as the quadratically increasing or constant torque which frequently occurs in the water industry, in practice we also find other characteristics:

- linearly increasing torque
- constant power throughout the speed range

Mixed forms of these loads also occur and are more difficult to describe in a general presentation. Among others, these include various symmetrical and asymmetrical loads. However, the four basic types are usually sufficient for approximate sizing.



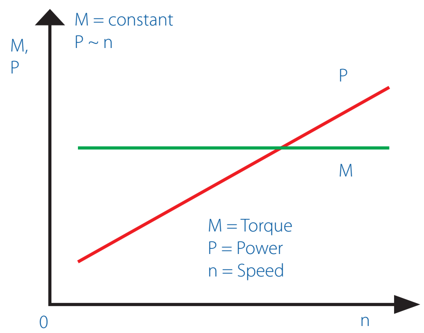
Quadratically increasing torque

A torque which increases quadratically with speed usually occurs in the case of gas or liquid friction. The cubic relationship between power and speed means that if the speed is halved, only one-eighth of the power is required.

This relationship gives rise to one of the main arguments for the use of inverters in pump and fan drives - the enormous saving in energy when the flow rate is controlled by the speed of the motor instead of throttle valves or slide valves.

Typical applications with quadratic torque characteristic are:

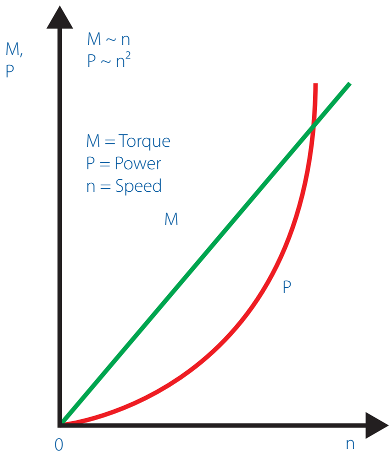
- Booster pumps
- Filter feed pumps
- Groundwater pumps
- Heating pumps (primary & secondary circulation)
- Ducted-impeller pumps
- Circulating pumps
- Cold water pumps (primary & secondary circulation)
- Storm water tank drainage pumps
- Sludge pumps
- Submersible pumps
  - Wet rotor submersible pumps (use of a sinusoidal filter is recommended.)
- Turbo compressors
- Fans



Constant torque

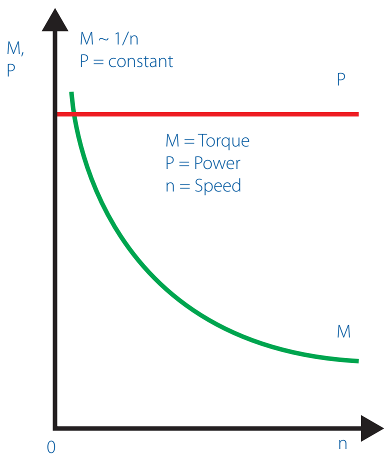
A constant load torque which is independent of speed (M = constant) is usually found in metering pumps, piston blowers and compressors. Under certain circumstances - for example when raising a sluice gate or starting a pump in which sludge has collected - it is necessary to overcome a breakaway torque of considerable magnitude. In such a case, the short-term overload capability of the inverter and motor must be checked to ensure that it is adequate to overcome the breakaway torque or whether a larger drive unit will have to be selected.

With a constant load, the power increases in proportion to the speed. If large torques are continuously encountered at low speeds, separate ventilation of the motor must be provided in order to dissipate the heat losses. In the case of self-ventilated motors, it is necessary to reduce the continuously permissible torque. There is a risk of thermal overload, particularly when the motor is operated at low speeds and high torque for long periods. The use of PTC resistors in the motor prevents a critical temperature from being exceeded.



Linearly increasing torque

A load torque which increases linearly with speed (M ~ k × n; k: drive constant) is therefore found in calenders with viscous friction which is proportional to speed, paper processing machines and eddy current brakes. Breakaway torques rarely occur with these applications. The power increases quadratically with speed, i.e. double the speed requires four times the power.



Constant power throughout the operating range

This load characteristic (P = constant, M ~ 1/n) is a particular feature of all winders. The described behaviour occurs when material is wound at constant speed and tension, and also with chip removal in the machine-tool field, for example in facing lathes and rotary peeling machines. Coarse chips are removed at lower speeds (roughing), whereas finishing, i.e. the removal of very fine chips, is carried out at the highest speed (high surface quality).

Determining the load characteristic

The objective when designing a drive system is to design the components so that the load can be operated over the required range.

In order to move the load, the drive torque must be greater than that of the load. If it is smaller, the load cannot be moved or the load moves the drive. When both torques are in equilibrium, the system is at its operating point.

In practice, it can be very complicated to accurately calculate the load torques. The procedure is described briefly below:

- The process forces can be calculated using mathematical models, graphical evaluations, estimates and comparisons with similar applications which already exist.
- The forces and movements can be measured using force and torque measuring instruments, an analysis of the movement with video cameras, etc.
- However, the measurement can also be carried out using a motor which drives the existing machine. After calibration by measuring the torque, a back calculation to the load data can be carried out by recording the current which produces the torque.

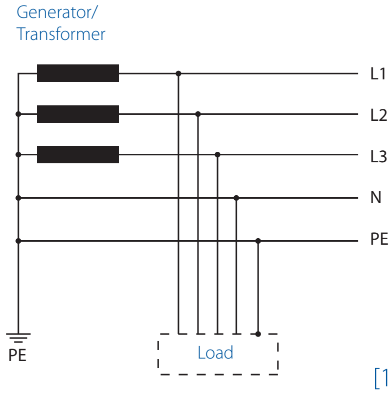
As well as the load torque discussed above, an additional torque must be applied to overcome the moment of inertia when accelerating the load and to produce a possible breakaway torque.

Selection guide

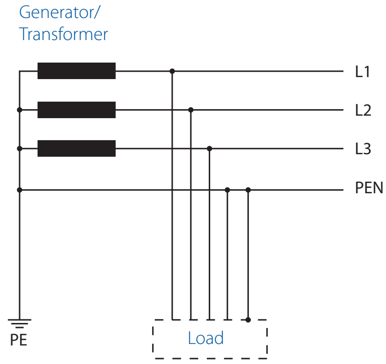
Characteristics with quadratically increasing or constant torque are those most commonly encountered with drive systems in the water industry. If necessary, ask your pump/motor manufacturer for the torque characteristic. Make a note of the load characteristic for your drive system in the line below and transfer it to Item 1 in the selection guide.

Item	What do you need or what is available?							
1	☐	Constant torque	☐	Linearly increasing torque	☐	Quadratically increasing torque	☐	Constant power over the operating range

Types of supply network



[1]



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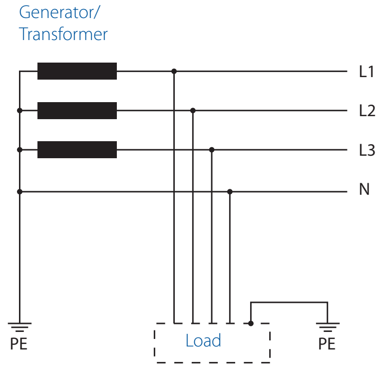


[3]

Industrial systems are usually supplied via transformers and dedicated distribution networks. Each network has its own EMC behaviour. The correct connection of an inverter therefore requires a knowledge of the existing network. The TN-S 5-conductor network provides the best situation, and the isolated IT network the worst.

TN networks

In a three-phase power supply system with a TN network, the star point (neutral conductor) is earthed. Earth faults in the TN network cause the upstream overcurrent protection devices, such as fuses, circuit breakers etc., to trip. Here, discrimination is made between the TN-S and TN-C network.

TN-S network [1]

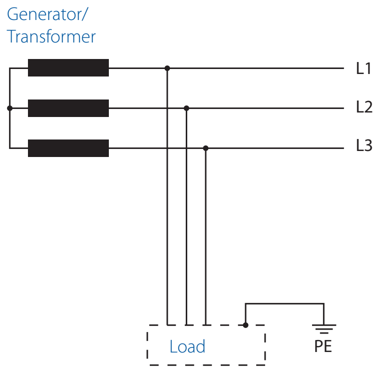
In a TN-S network, the neutral conductor and the protective conductor are fed separately from the supply point to the load. This network is a 5-conductor network. The separation of neutral and protective conductor gives rise to excellent EMC characteristics.

TN-C network [2]

In a TN-C network, the neutral conductor and the protective conductor are connected to one another. By combining the neutral and protective conductor, compensating currents, which contribute to the poor EMC characteristics of the TN-C network, flow via the protective conductor. The TN-C network is also described as a 4-conductor network.

TT network [3]

The TT network is similar in design to the TN network. The star point of the supply is earthed separately from the load. A low-resistance connection between these separate earth points can only be achieved with difficulty. Low earthing resistances are required for protective earthing, however, as high currents are required to trip the overcurrent protection device. The TT network is a 4-conductor system. The network has good EMC characteristics when the earthing is implemented well.



[4]

IT network [4]

The IT network is an isolated network with three conductors. The load is earthed separately. In three-phase networks, it is possible to use the neutral conductor as a fourth conductor. The neutral conductor can be unearthed or earthed via an impedance on the supply side. No EMC measures, such as filtering etc., can be used in an IT network

Abbreviations used in the network names

T: Earthed (terra)

I: Isolated

N: Body of the equipment is connected to the neutral conductor

S: PE and PEN conductors are separate

C: PE and N conductors are laid together as a PEN conductor (common)

The first letter of the above abbreviations always relates to the network and the second to the equipment. The connection of the neutral conductor is described by the third letter S or C.

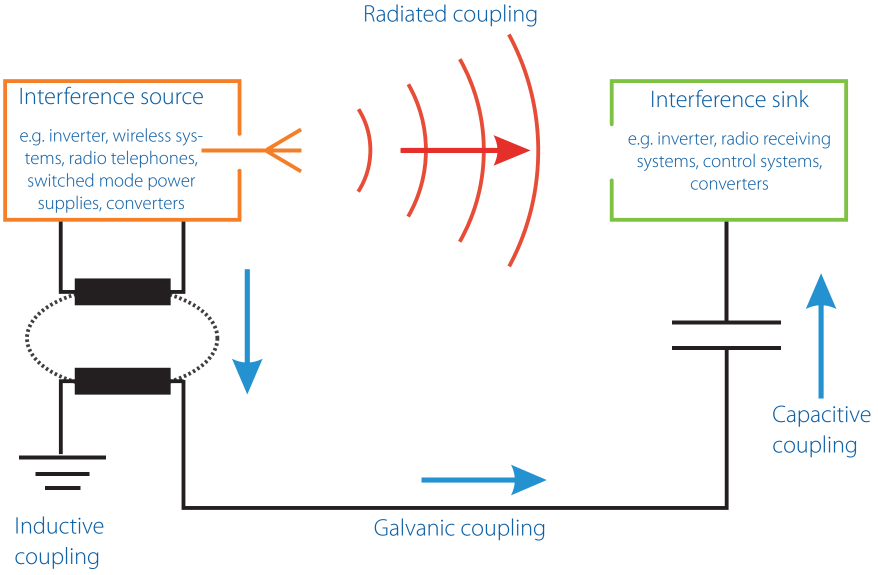
Type of network	Meaning of letters	Protective device
TN-S network	Network earthed Housing to operational earth via PE	Circuit breakers and if necessary fault current protective devices (RCD)
TN-C network	Network earthed Housing to operational earth via PE PE and N connected	
TT network	Network earthed Housing earthedt	
IT network	Network isolated Housing earthed	Earth leakage circuit breaker (ELCB) or insulation monitor.

Selection guide

Check which type of network exists at the place where your inverteris to be installed and whether it is suitable for your application.
If necessary, contact the responsible energy provider for advice. Then make a note of the network type in the line below and transfer it to Item 3 in the selection guide.

Item	What do you need or what is available?			
2	☐ TN-S network	☐ TN-C network	☐ TT network	☐ IT network

Electromagnetic compatibility (EMC)



The different types of coupling

Interference coupling can take place in the following ways:

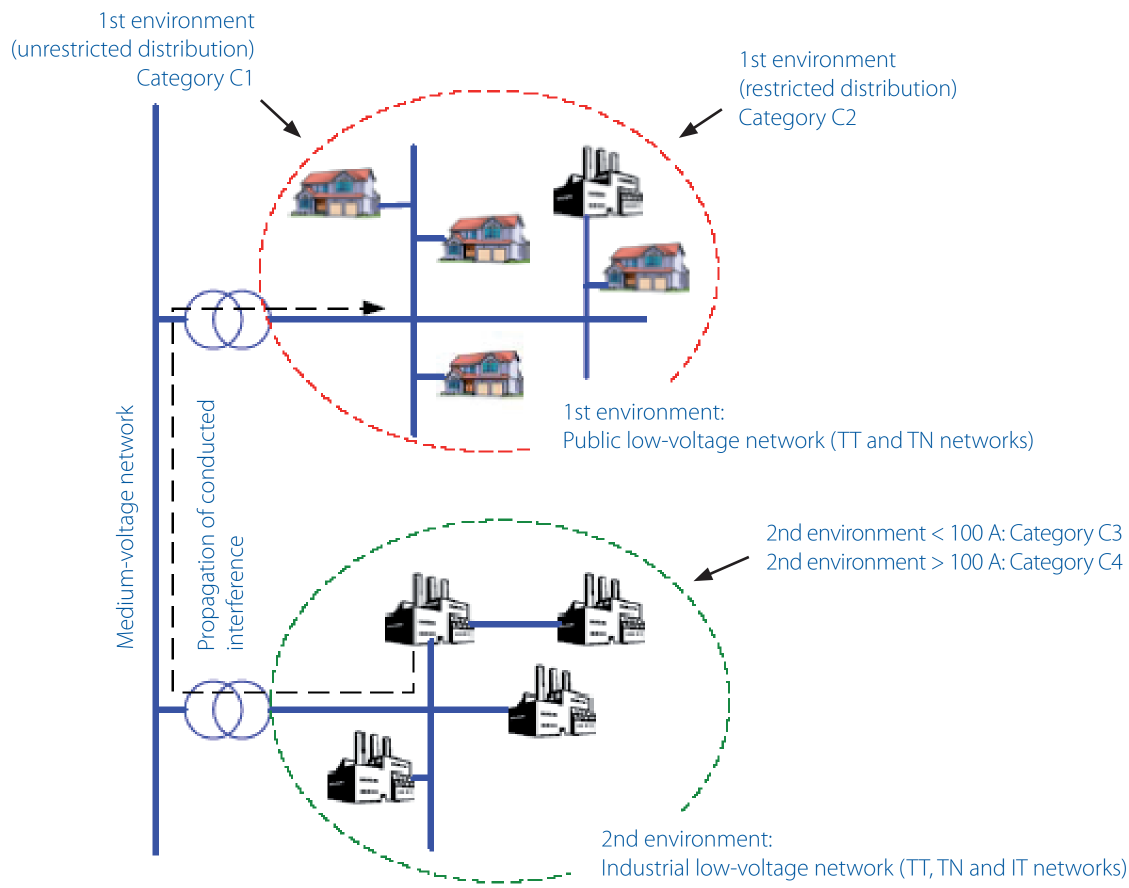
- Galvanic coupling
  Galvanic coupling occurs when two circuits are conductively connected to one another.
- Capacitive coupling
  Capacitive coupling describes the coupling between conductors which lie closely together via an electric field.
- Inductive coupling
  Inductive coupling occurs as a result of an alternating magnetic field produced by a current flowing through a conductor.
- Radiated coupling
  The interference sink receives an electromagnetic wave radiated in free space by the transmitter.

Like all electrical equipment, an inverter must also work faultlessly at its place of use and withstand externally acting electromagnetic influences. On the other hand, the inverter itself generates electromagnetic interference when in operation, and this can affect other consumers. Fundamentally, a device can be a source of interference and itself also be susceptible to interference from other equipment (interference sink). This aspect of the behaviour of inverters is referred to as electromagnetic compatibility, EMC for short.

Conducted and radiated interference

Interference can be differentiated by the way in which it is propagated. Discrimination is made between conducted and non-conducted interference.

Conducted interference is mainly propagated via the cables which feed the supply to the inverter. Non-conducted interference is high-frequency interference which propagates in the form of electromagnetic waves.



1st and 2nd environment

Different interference levels are permissible depending on the place of use. Differentiation is made between 1st and 2nd environment. The first environment includes residential and business areas which are connected directly to the low-voltage network, i.e. which are not supplied via dedicated high-voltage or medium-voltage transformers.
In contrast, the second environment is not connected directly to the public low-voltage network. The second environment is also referred to as the industrial environment.

Norms and directives

The limits for the respective environments are specified in norms. The environmental norm EN 55011 defines the limits of the basic environments in the industrial area with Classes A1 and A2 and in the residential area with Class B. In addition, the product norm EN 61800-3 for electrical drive systems, which defines the new categories C1 to C4, has been in force since June 2007.

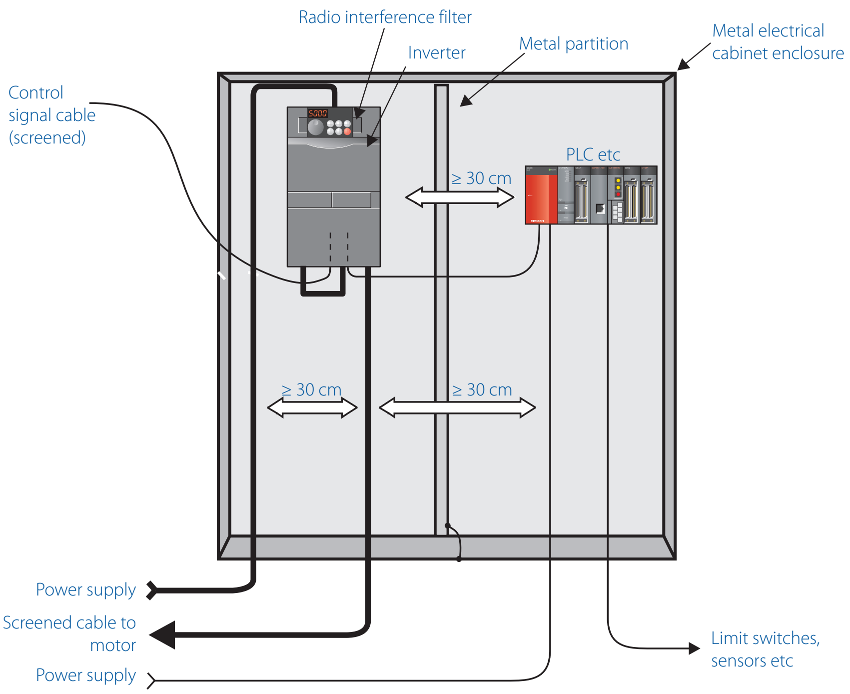
The user of the system is responsible

These days, the operator or user of the system is responsible for complying with the statutory directives and norms. With the help of solutions provided by the manufacturer, he must ensure that any interference which occurs is eliminated. Mitsubishi Electric offers a wide range of EMC filters, chokes, harmonic filters and much more, which are optimised for use with the appropriate inverter. To ensure that all units are capable of fulfilling their function without interference, the user of the system must also take into account the connection requirements of the local power supply company.

The user of the system has to take responsibility for complying with the environmental norm EN 55011, the product norm EN 61800-3 has to be fulfilled by the manufacturer of the frequency inverter.

Product norm EN 61800-3 (2005-07) for electrical drive systems

Assignment by category	C1	C2	C3	C4
Environment	1st environment	1st or 2nd environment (user's decision)		2nd environment
Voltage/Current	< 1000 V			> 1000 V; In > 400 A, connection to IT network
EMC expertise	No requirements	Installation and commissioning by an EMC specialist		EMC plan required
Limits according to EN 55011	Class B	Class A1 (+ warning notice)	Class A1 (+ warning notice)	Values exceed Class A2



EMC-compliant installation of inverter

EMC and Inverter

An inverter produces electromagnetic interference which is essentially caused by the fast switching processes in the power stage or by the clocking of the processor. The steep flanks of the voltage pulses contain high-frequency signal elements which are radiated by the motor cable and the inverter, and are also fed back into the network.

In the case of inverters with pulse width modulation, the clock frequency therefore determines the magnitude of the emitted interference.

Reduction measures

There are two possible ways for the system builder to reduce or prevent interference:

- Increase the resistance of the unit to interference
- Suppress interference at source

As a basic principle, an EMC-compliant design of the installation and connection must be taken into account right at the planning stage. Examples of this include the low-resistance design of all earth connections, the use of screened motor feed cables and the use of filters.

Screened cables and EMC-compliant routing

Signal and motor cables must be screened. On the one hand, the screen prevents the radiation of interference and, on the other, improves the resistance of the unit to interference.

The screen must be connected to earth using an all-round connection which covers a large area. Power cables and signal cables should be laid at a distance of at least 20 cm from one another. Avoid running cables parallel to one another. If necessary, use earthed cable trunking or metal conduit to separate the cables.

You will find further information on EMC-compliant installation, screening and cabling on Page 27.

Use of filters

Many of the inverters provided by Mitsubishi Electric already have an inbuilt EMC filter and comply with the European Community requirements for the second environment with regard to their electromagnetic compatibility (EMC Directive EN 61800-3). They can be adapted for use in the first environment by means of an optional filter.

Specially matched radio interference filters for mounting under the unit have been developed for all power classes of inverterin order to comply with the specified limits.

Inverter which do not comply with Category C1 must be provided with a warning notice.

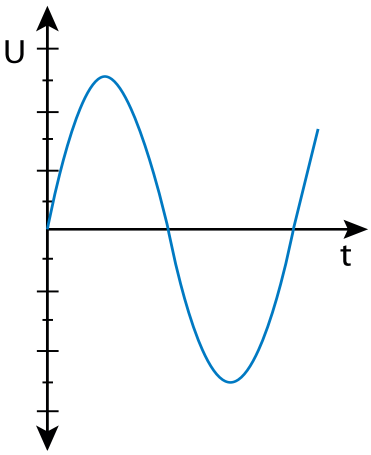
Mitsubishi Electric has its own accredited EMC laboratory: The International Approval Centre in Dusseldorf already supports many well known brand manufacturers during the development of their products.

Selection guide

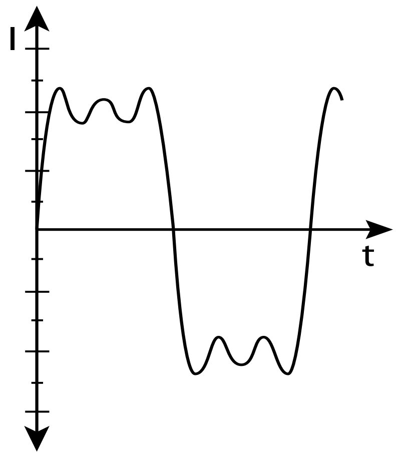
If an EMC check of your system shows that you need an optional filter in order to comply with the norms and specifications, choose a suitable filter from the technical catalogue for the inverter. You will find the technical data and dimensions of the individual filters in the supplementary filter sheets on the Mitsubishi website. Make a note of the environment for your place of use and your results for electromagnetic compatibility in the line below and transfer the result to Item 3 in the selection guide.

Item	What do you need or what is available?				
3	☐ EMC filter	☐ C1	☐ C2	☐ C3	☐ C4

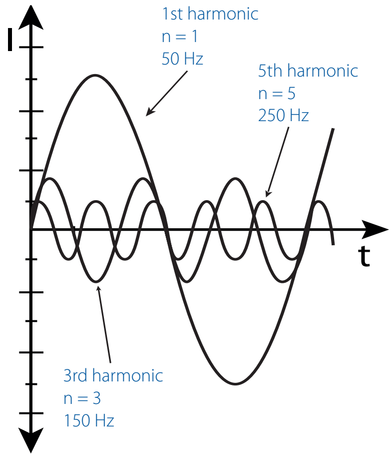
Low-frequency mains disturbances



[1] Mains voltage



[2] Input current for a non-linear load



[3] Resulting sinusoidal oscillations (harmonics) of different frequency

In the ideal case, the mains voltage provided by the electrical supply company should be sinusoidal and have constant amplitude and frequency. [1]

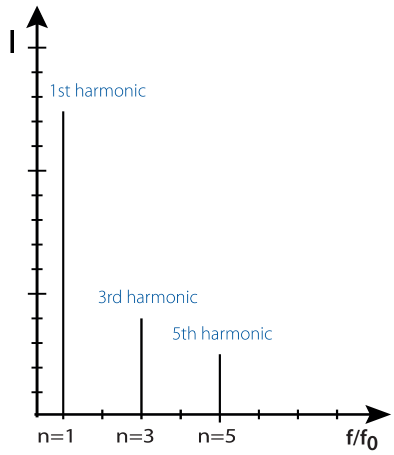
The quality of the supply voltage is steadily deteriorating. The reason for this is the continuously increasing number of loads - starting with the use of controlled and uncontrolled semiconductor rectifiers in computer power supplies, via energy-saving lamps to the use of modern drive equipment.

The justification for this is the non-sinusoidal input current of these so-called non-linear loads. [2]

Fourier analysis

The severity of these mains disturbances can be determined by means of Fourier analysis. Joseph Fourier (1768-1830) discovered that any periodic oscillation can be described with the help of sinusoidal oscillations of different frequency. [3]

The third and fifth harmonics are particularly pronounced in the case of a single-phase inverter, while in the case of a three-phase inverter it is the fifth and seventh.



Common representation of magnitude in the form of a bar diagram

Mains disturbances due to inverters

Limits are defined for the maximum degree of mains disturbance. If these limits are exceeded, the electricity supply company is entitled to switch off the system.

However, it should be noted that the limits only have to be maintained at the point of common coupling with the network (busbar).

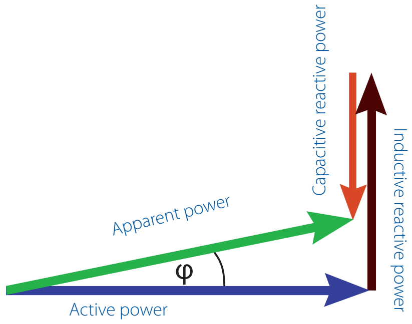
This is because the degree of mains disturbance is significantly affected by the ratio of the number of non-linear loads to linear loads and the supply network conditions.

Mains disturbances and their consequences

As well as the increased power demand, harmonics also place a burden on other installed components such as transformers and cables. Their life can be shortened as a result of additional heating due to resonances. Care should therefore be taken to comply with the maximum limits at the point of common coupling. This avoids high cable losses, elevated transformer temperatures and excessive noise. On the other hand, the consequence can be malfunctions, including damage to electrical and mechanical components.

In addition to the active power, the network is also loaded with reactive power due to the harmonics. These occur due to the phase shift between current and voltage caused by connecting inductive loads (e.g. motors, transformers or ballast units).

As a result, resonance is possible in reactive power compensation systems and can lead to their destruction. For this reason, reactive power compensation systems should be fitted with chokes.



In power engineering, differentiation is made between apparent, active and reactive variables when assessing mains disturbances, electrical currents, powers and electrical energy. The active current is the "working" current. This causes active power to be converted into other forms of energy, e.g. heat, movement, light etc.

The reactive current is an oscillating current which is required, among other things, to build up fields (magnetic + electric) and generates only losses and reactive power.

The apparent current is the current which is most easy to measure. It is the geometric sum of active and reactive current (see diagram). The apparent power is the product $S = U \times I$.

A major part of the total electrical energy consumed in the EU is converted to movement. This usually takes place in electric motors, such as three-phase asynchronous and synchronous motors. In doing so, however, not only active power, but also reactive power is taken from the electrical supply. This is divided into capacitive and inductive reactive power. Capacitive reactive power is mostly used to build up an electric field, and inductive reactive power to build up a magnetic field. The two quantities oppose one another in direction (phase shifted).

As the reactive portion of power also loads the electricity providers' networks, its maximum value is specified. Attention in private households is not directed towards this form of energy. However, with large customers, the reactive content is often measured and also passed to account.

Norms and directives

The following norms, directives and specifications govern the limits to be maintained in public and industrial networks:

G5/4-1

Identifies consumers by their point of common coupling (PCC) to the supply, and applies limits at that point. G5/4-1 therefore applies to every consumer connected to the Public Electricity Supply (PES), including:

- Domestic
- Commercial, shop and office consumers
- Industrial users.

EMVG

Law relating to the electromagnetic compatibility of equipment

EN 61000-2-2

Electromagnetic compatibility (EMC) – Environment - Compatibility levels for low-frequency conducted disturbances and signalling in public low-voltage power supply systems

EN 61000-2-4

Electromagnetic compatibility (EMC) – Environment - Compatibility levels for low-frequency conducted disturbances in industrial systems

EN 61000-2-12

Electromagnetic compatibility (EMC) – Environment – Compatibility levels for low-frequency conducted disturbances and signalling in public medium-voltage power supply systems

EN 61000-3-2

Limits for harmonic current emissions (equipment input current 16 A per phase)

61000-3-12

Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current > 16 A and ≤ 75 A per phase.

EN 50160

Upper limits of harmonics in public electricity networks

EN 50178

Electronic equipment for use in power installations

As a basic principle, the connection requirements of the local electricity supply company must also be taken into account.

Measurement of harmonics

Before taking action to reduce mains disturbances, it is sensible to verify these by measurement. Such measurements are carried out by specialised service providers. In order to attain a meaningful analysis of the mains quality, these measurements should be carried out over an extended period (at least 24 h). If you want to undertake these measurements yourself, we recommend a so-called mains analyser.

Reducing mains disturbances

In general, harmonics can be reduced by limiting the amplitude of the pulse current. With inverters, this can be achieved by means of chokes in the input or in the DC link circuit. The following curves show the measurements of the total current distortion (THDI = Total Harmonic Distortion of current) when using different chokes for reducing mains disturbances.

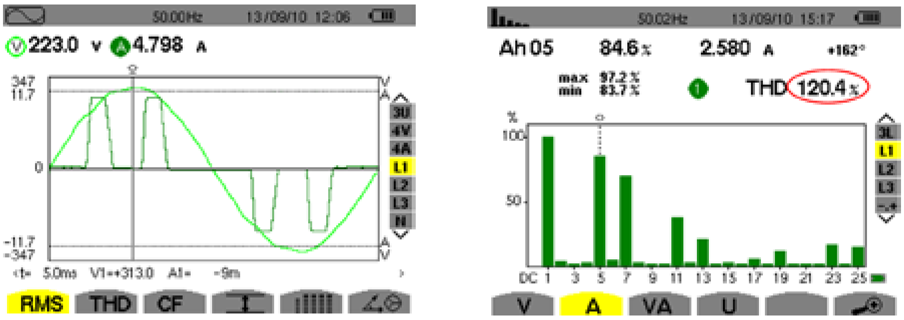
The adjacent curves and harmonic measurements show that the total harmonic distortion can be reduced from 120 % to 32 % by the use of a DC link choke.

The effect of an additional mains input choke is very small and also results in an additional voltage drop at the input to the inverter. For this reason, we only recommend the use of DC link chokes, which are already included with some of our units.

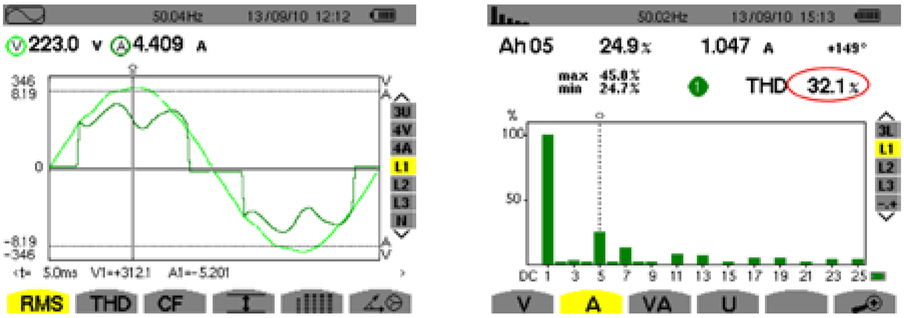
With the help of a so-called passive filter, the values of the harmonics can be reduced to less than 5 % when simultaneously using a DC link choke.

Active filters are used when the harmonic distortion has to be reduced to significantly below 5 %.

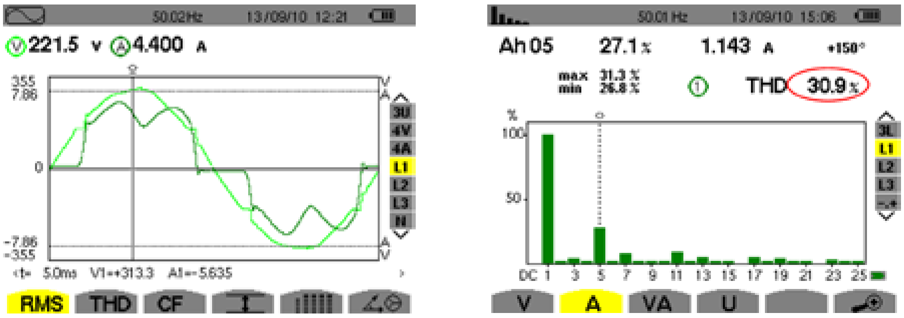
The FR-A741 regenerative inverter has an integral mains choke and inherently generates only very low mains distortion. This enables an external circuit with chokes to be dispensed with. At 100 % load, the value of the total harmonic distortion in driving mode is about 52 %, and in regenerative mode about 37 %.



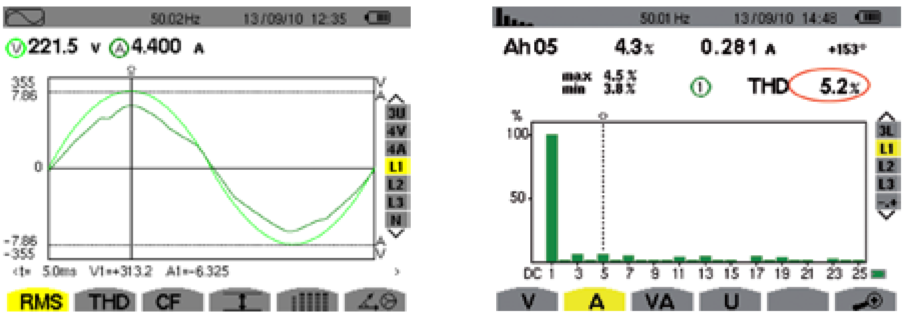
Input voltage and current of the inverter without the use of a harmonic-reducing input or DC link choke



Input voltage and current when using a DC link choke

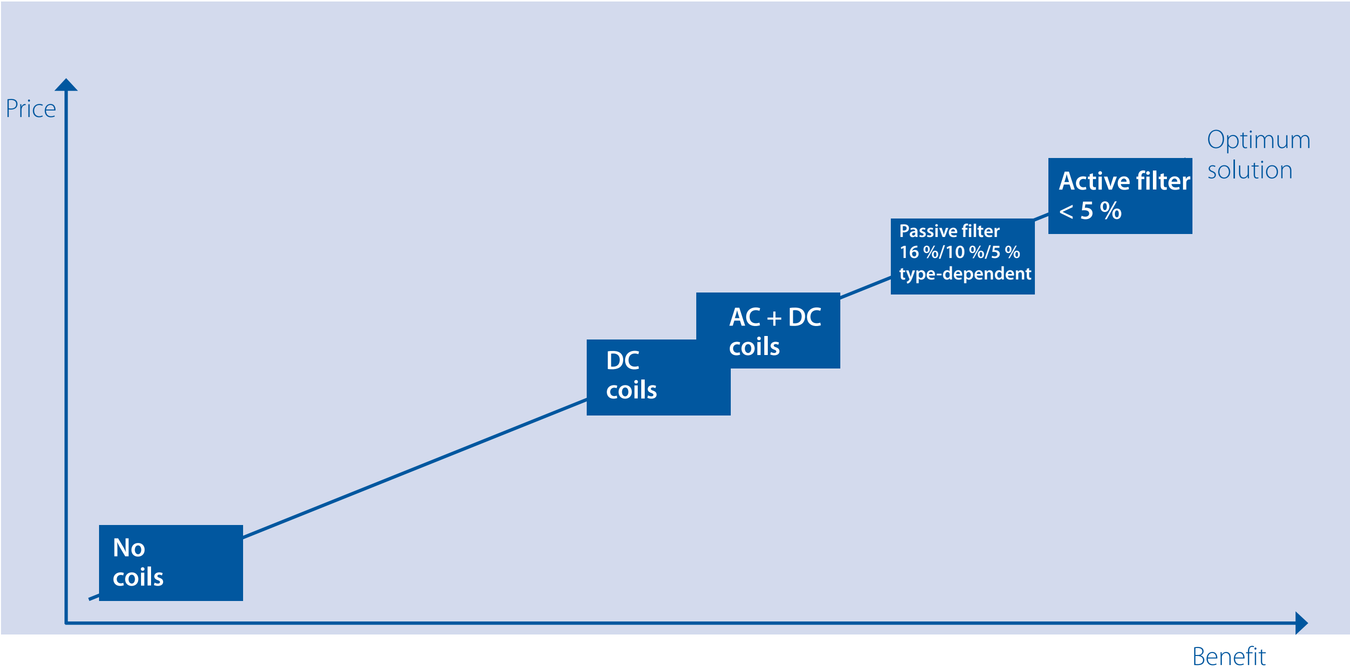


Input voltage and current when using an input choke and a DC link choke



Input voltage and current when using a passive filter

Mains disturbances can be reduced by passive or active devices. Mitsubishi Electric offers frequency inverters with integrated chokes or external chokes and harmonic filters. Harmonic distortion can be significantly decreased below 5 % by active filters.



Overview of measures for reducing harmonics

DC link chokes (DC)

DC link chokes are direct current chokes and are connected in the DC link circuit after the rectifier. These enable the harmonic content of B6 rectifiers to be significantly reduced. Compared with an inverter without chokes, the value of the total harmonic distortion of the current can be reduced from about 120 % to 32 % by the use of the DC link choke FFR-HEL-(H)-E. DC link chokes are more effective and generate lower losses than chokes connected on the mains side.

Mains input chokes (AC)

Mains input chokes are connected on the input side of the inverter. Although they are simultaneously used to compensate for short-term commutation notches, they also have the negative effect of reducing the voltage.

Passive filters

A special passive harmonic filter can be used if a further reduction in the harmonic content is required. This consists of LC series resonant circuits which are tuned to and attenuate the individual harmonics. THDI values of down to 5 % can be achieved with the help of the filter. The passive harmonic filter is connected before the inverter.

Active filters

Active filters are intended to reduce mains disturbances from non-linear loads as much as possible. Active filters initiate a compensating current to cancel out the harmonics and reactive currents. The aim is to achieve a "pure" sinusoidal load current (THDI = 0). In practice, active filters are used when the harmonic distortion has to be reduced to less than 5 % THDI.

Selection guide

You will find all the harmonic filters, mains input chokes and DC link chokes which are available from Mitsubishi Electric in the technical catalogue for your inverter. Choose the appropriate filter option for your application and make a note of it in the line below. Then transfer the filter option to Item 4 in the selection guide..

Item	What do you need or what is available?			
4	☐ DC link chokes	☐ Mains input chokes	☐ Passive filters	☐ Active filters

Motor output filters

Output filters are optional filters which are connected in the motor cable between the inverter and the motor. These filters are available as du/dt or sinusoidal output filters.

du/dt output filters

The du/dt filter is used mainly to reduce the steepness of the voltage edges at the output. This protects the insulation of the motor winding against voltage flashovers. du/dt filters are usually simple in design and are therefore reasonably priced.

Sinusoidal output filters

The sinusoidal output filter produces a sinusoidal output voltage with low voltage ripple. However, the voltage drop across the filter results in a lower voltage at the motor terminals.

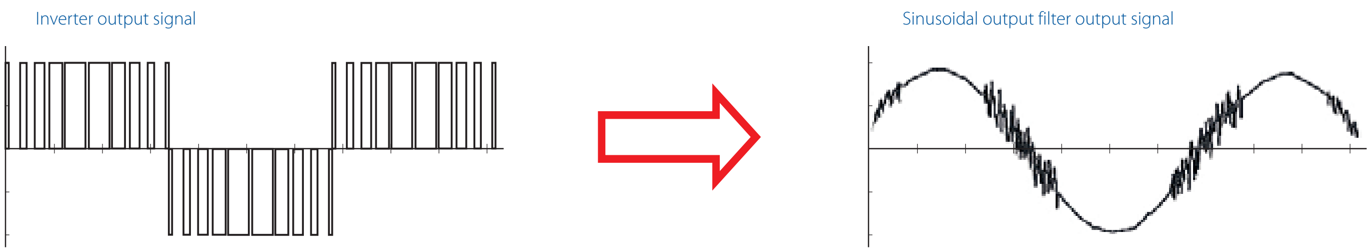
The use of this filter is expedient in the following applications:

- When operating several motors on one inverter
- With long motor cables, the sinusoidal filter prevents harmful voltage overshoots which can occur on the falling voltage edges of the inverter output signal as a result of the high cable impedance.
- In installations where the EMC requirements cannot be met.
- In addition, the use of a sinusoidal filter is recommended when connecting an older motor in order to protect it against harmful voltage edges.

Motor cables

When choosing the cable, pay attention to the required rated voltage class and the dielectric strength.

	du/dt filter	Sinusoidal filter
Stress on motor insulation	Reduced – operation with longer motor cables possible	Reduced – operation with longer motor cables possible
Load on motor bearings	Slightly reduced	Reduced circulating currents but no common-mode currents
Electromagnetic compatibility	Prevents overshoots in motor cables. No change in EMC class	Prevents overshoots in motor cables. No change in EMC class
Max. motor cable length EMC compliant	Dependent on manufacturer. max. 150 m screened	Dependent on manufacturer. max. 150 m screened or max. 300 m unscreened
Clock frequency noise at motor	No effect	Reduced
Relative size (with respect to converter)	15–50 % (power-dependent)	100 %
Voltage drop	0.5 %	4–10 %



Filtering effect of a sinusoidal output filter

Selection guide

Mitsubishi Electric provides matching du/dt and sinusoidal output filters for all its inverter models. Information on these is included in the inverter technical catalogue. Make a note of whether you need an output filter and which one in the line below and transfer this to Item 5 in the selection guide.

Item	What do you need or what is available?			
5	☐	Motor output filter	☐	Rated voltage class and dielectric strength of motor cable

Location

Installation concept

The proportion of inverters which are operated when installed in an electrical cabinet is about 70 %. Installation in an electrical cabinet has the advantage that all electronic components are mounted close together and are protected against external influences such as dust and water. However, the spatial proximity of the individual assemblies means that there is a risk of them interfering with one another. An EMC-compliant system design is therefore the top priority. When the inverter is installed in an electrical cabinet, the entire wiring can be carried out in advance in the workshop. The electrical cabinet is then delivered to the place of use as a finished unit.

If the inverter is mounted on the wall, it can be installed closer to the motor. This variant is less critical from the point of view of EMC. However, increased wiring effort is required on site, as the control cables still have to be connected. The motor cables are usually shorter due to the spatial proximity of inverter and motor. This saves costs.

With protection class of IP00/20 or IP54 the frequency inverters of Mitsubishi Electric are suitable for operation under nearly all environmental conditions.

Inverters mounted in an electrical cabinet

Floor-standing unit in IP20 design

Alternatives

Inverters for mounting in electrical cabinets usually have the protection class IP00 or IP20. As well as these designs, however, floor-standing units (FSU) are also available. These enable the inverter to be set up anywhere in the room while maintaining protection class IP20 (protection against accidental contact). The stable FSUs are pre-assembled and have the option of incorporating a DC link choke or – if necessary – an additional EMC filter. This obviates the need for designing and manufacturing an electrical cabinet.

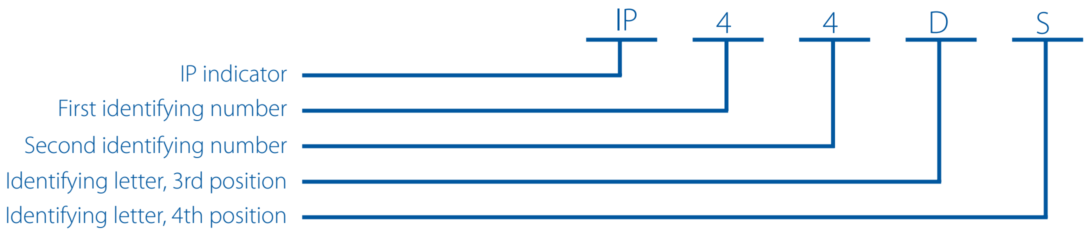
A further possibility is offered by the use of the FR-F746 inverter with protection class IP54. This inverter is protected against spray water and can be installed outside, directly by the machine.

Selection guide

Choose a suitable installation option for your drive and make a note of this in the line below. Then transfer the installation option to Item 6 in the selection guide.

Item	What do you need or what is available?	
6	Location/Installation concept	

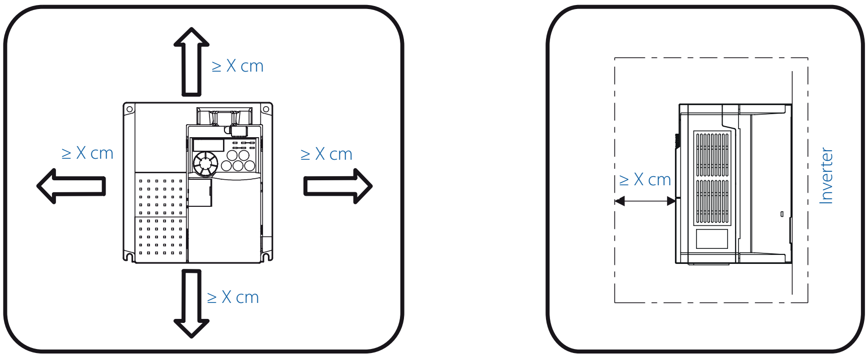
IP protection class structure according to IEC 60529



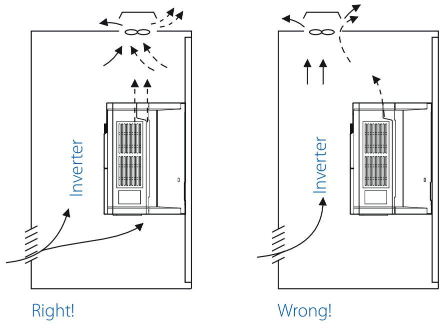
Meaning of first identifying number			Meaning of second identifying number	
Identifying number	**Protection against accidental contact**	**Protection against foreign bodies**	**Identifying number**	**Protection against water**
0	No special protection		0	No special protection
1	Against large bodies	Large foreign bodies Diameter ≥ 50 mm	1	Against vertically falling drops
2	Against fingers or objects of similar size	Medium-sized foreign bodies Diameter ≥ 12 mm	2	Against drops falling at an angle (up to 15°)
3	Against tools, wires and the like with a thickness of ≥ 2.5 mm	Small foreign bodies Diameter ≥ 2.5 mm	3	Against spray water (from any direction up to 60°)
4	Against tools, wires and the like with a thickness of ≥ 1.0 mm	Granular foreign bodies Diameter ≥ 1.0 mm	4	Against water splashed from all directions
			4K	Against water splashed with increased pressure
5	Complete protection	Dust deposits are permissible but not to such an extent that they are detrimental to the operation of the unit	5	Against jets of water projected from a nozzle from all directions
6	Complete protection	Dust-tight	6	Against flooding, e.g. for use on board ship
			6K	Against spray water with increased pressure
			7	Against immersion
			8	Against submersion
			9K	Against water used for high-pressure cleaning

Identifying letter for the 3rd position		Identifying letter for the 4th position	
Identifying letter	**Meaning**	**Identifying letter**	**Meaning**
A	Back-of-hand protection or foreign bodies with diameter ≥ 50 mm	H	High-voltage equipment
B	Protection against fingers with diameter ≥ 12 mm and 80 mm length	M	Tested when moving parts are in operation
C	Protection against tools with diameter ≥ 2.5 mm and up to 100 mm length	S	Tested when moving parts are stationary
D	Protection against wires with diameter ≥ 1.0 mm and up to 100 mm length	W	Tested under specified weather conditions

Ambient conditions



Minimum distances when installing the inverter in an electrical cabinet



Arrangement of an inverter in an electrical cabinet with cooling air ducts

Ambient temperature

The failure rate of inverters is greatly dependent on the ambient conditions, in particular the temperature. According to the RRT rule (Reaction Rate Temperature rule or Arrhenius' law), the failure rate of electronic components doubles for a temperature increase of about 10 °C.

Permissible temperature ranges are specified for all inverters. Operation outside these temperature ranges shortens the life of the semiconductors, components, capacitors, etc. The following measures can be used to match the environment to the permissible temperature range.

- Measures against too high temperatures:
  - Use forced cooling or a similar cooling system (see Page 25).
  - Install the electrical cabinet in an air-conditioned room.
  - Avoid direct sunlight.
  - Use heat shields and deflector plates to shield the inverter against direct radiation and heated air from other heat sources.
  - Ensure adequate ventilation of the area around the electrical cabinet.
- Measures against too low temperatures:
  - Use a heater in the electrical cabinet.
  - Do not switch off the supply to the inverter.
- Sudden temperature changes:
  - Choose a location where no sudden temperature changes occur.
  - Avoid installing an inverter in the vicinity of the air outlet of an air conditioning system.
  - If the temperature change is caused by opening and closing a door, do not install the inverter in the vicinity of the door.

Minimum distances

Maintain the minimum distances specified in the manuals in order to ensure good heat dissipation and good accessibility to the inverter for maintenance purposes.

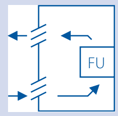
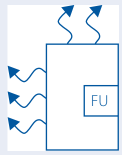
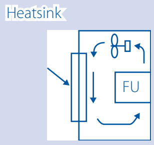
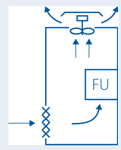
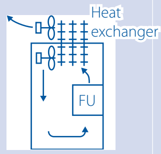
Arrangement of fans in the electrical cabinet

The heat generated by the inverter is removed upwards by the cooling fan. The fan or fans in a force-ventilated enclosure must be installed taking into account the optimum cooling air flow (see diagram below). Provide air ducts if necessary.

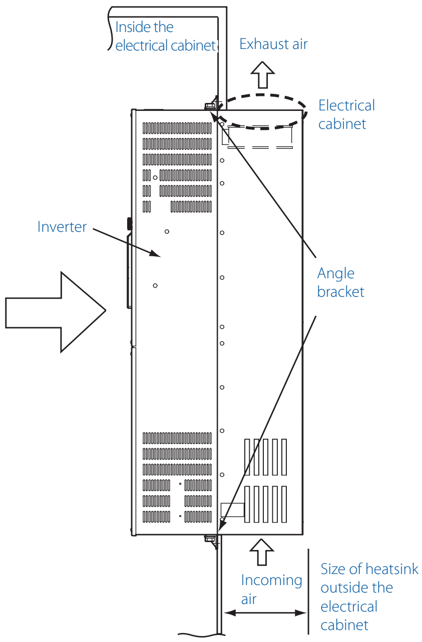
Electrical cabinet cooling systems

To ensure that the internal temperature of the electrical cabinet complies with the permissible values for the inverter, the heat generated by the converter and by other assemblies (transformers, lamps, resistors, etc.) and the heat acting on the cabinet from the outside (direct sunlight) must be dissipated or reduced. Different cooling systems lend themselves for this purpose:

- Natural convection via the wall of the electrical cabinet (for cabinets enclosed on all sides)
- Cooling by means of a heatsink (e.g. aluminium heatsink)
- Air cooling (forced ventilation, piped air to and from the enclosure)
- Cooling by means of a heat exchanger or refrigerant

Cooling system		Cabinet design	Description
Natural convection	Natural ventilation (closed or open)		The design is inexpensive and is frequently used. A larger cabinet is required as the power of the inverter increases. More suitable for relatively small powers.
	Natural ventilation (enclosed on all sides)		An electrical cabinet enclosed on all sides is particularly suitable for use in aggressive environments containing dust, dirt, oil mist, etc. A larger cabinet is required as the power of the inverter increases.
Forced ventilation	Heatsink		The design of the cabinet is restricted by the mounting position and the area of the heatsink. More suitable for relatively small powers.
	Forced ventilation		The design is generally only suitable for indoor locations. The size and cost of the enclosure are relatively small. Often used.
	Heat exchanger		The design is suitable for an electrical cabinet enclosed on all sides while keeping the cabinet small.

Electrical cabinet cooling systems (in the diagrams, "FU" stands for "inverter")



Mounting of the external cooling air option

External cooling air feed

When an inverter is installed in an electrical cabinet, the temperature in the cabinet can be significantly reduced if the heatsink of the inverter is located outside the cabinet. The protection class is then IP20. This method lends itself particularly when the inverter is installed in a compact electrical cabinet.

As an alternative to the above cooling systems, Mitsubishi Electric offers an installation kit (FR-A7CN) for feeding external cooling air to inverters FR-F700 and FR-A700.

Take care for the cooling air feed and climate control of your cabinet already during the planning phase for always assuring the reliable operation of the system.

Selection guide

When you have found a suitable method for controlling the temperature of your electrical cabinet, make a note of this in the line below. Then transfer the type of cooling to Item 7 in the selection guide.

Item	What do you need or what is available?									
7	☐	Natural ventilation (closed or open)	☐	Natural ventilation (enclosed on all sides)	☐	Heatsink	☐	Forced ventilation	☐	Heat exchanger

Humidity

Mitsubishi Electric inverter should be operated in an environment with a relative humidity between 45 % and 90 %.

- **Measures to avoid excessive humidity:**
  - Use an electrical cabinet which is enclosed on all sides and a humidity-reducing agent.
  - Feed dry air into the electrical cabinet.
  - Use a heater in the electrical cabinet.
  - Do not switch off the supply to the inverter. Only switch off the start signal.
- **Measures to avoid insufficient humidity:**
  - Feed air with the appropriate humidity into the electrical cabinet.

Dust, dirt and oil mist

The thermal insulating effect of dust and dirt deposits causes a reduction in cooling, and the internal temperature of the electrical cabinet rises as a result of contaminated filters.

Conductive dusts in the ambient air can quickly lead to malfunctions, insulation faults and short circuits. Similar complications are also caused by oil mist.

- **Measures to prevent dust, dirt and oil mist:**
  - Use an electrical cabinet which is enclosed on all sides.
  - Clean the air which is fed into the cabinet.
  - Increase the pressure inside the electrical cabinet by pumping in clean air.

Mitsubishi Electric inverters have a protective function which generates a warning if the cooling air capacity is reduced as a result of contamination. In addition, the integral service timer ensures a longer life for the inverter and the fan.

Aggressive gases and aerosols

Printed circuit boards and contacts corrode if an inverter is exposed to aggressive gases. To avoid this, all Mitsubishi Electric printed circuit boards are coated with a special protective varnish.

Mitsubishi Electric also provides units with double or triple coating for very aggressive ambient conditions.

Explosive, easily inflammable gases

In environments where there is a risk of explosion due to explosive gases, dusts or contamination, the electrical cabinet must be designed so that it complies with the requirements of the directives for equipment at risk of explosion.

The printed circuit boards of Mitsubishi Electric frequency inverters are double varnished as standard or optional triple varnished for operation under very aggressive conditions.

Selection guide

Many Mitsubishi Electric inverters are available with printed circuit boards which are double-varnished against the effect of aggressive gases.

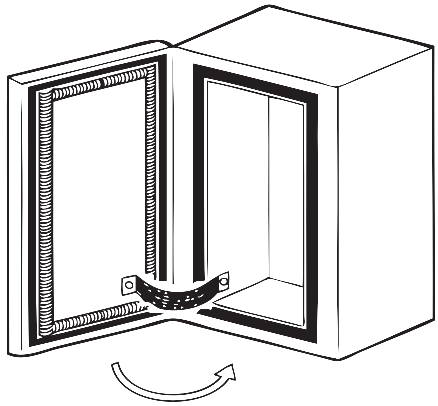
If further measures against harmful environmental influences are necessary, please make a note of these in the line below. Transfer these measures to Item 8 in the selection guide

Item	What do you need or what is available?					
8	☐	Humidity	☐	Pollution due to dust, dirt, or oil mist	☐	Aggressive and/ or inflammable gases

Installation and cabling

Special measures for maintaining the electromagnetic compatibility (EMC) and for complying with the low-voltage directive must be taken when installing and cabling the inverter. Retrospective modifications for improving the characteristics are usually considerably more expensive than when all requirements are taken into account directly at the system planning stage. Paying attention to the following points during installation and cabling of the inverter has a significant effect on the EMC characteristics of the whole system:

- To reduce radiated interference, install the units in a closed, earthed metal cabinet.
- To reduce conducted interference, use a radio interference filter on the mains supply side.
- Ensure good earthing to avoid the antenna effect.
- Use screened cables to reduce radiated interference.
- To reduce the coupling effect, position sensitive devices as far as possible from sources of interference or install the source of interference in a separate electrical cabinet.
- Spatially separate signal and power cables from one another to reduce the coupling effect.



Electrical cabinet with earthed door

Installation in an electrical cabinet

The construction and design of the electrical cabinet are decisive for compliance with the EMC Directive. Use an earthed metal cabinet. There must be a good electrical connection between the door of the cabinet and the enclosure. Examples of this are a conductive door seal and a braided earth cable. If you want to install a mains filter on the side wall of the cabinet, you must also make sure that the fixing points have good conductivity. Remove the paint if necessary. Inverters and controllers (PLCs) should be mounted as far as possible from one another in the electrical cabinet. Openings or cable entry points in the electrical cabinet should have a maximum diameter of 10 cm. If an opening of more than 10 cm is required, cover it with a metal grille.

Power circuit wiring

Choose the cross sections of the cables for connecting the inverter power circuit so that the maximum voltage drop in the cables on load is 2 %. The power circuit includes the connections for the mains voltage supply, the motor, the external braking resistor or braking unit, the DC link choke and the protective earth.

Cable routing

Run the control signal cables at a minimum distance of 30 cm from all power cables. In particular, the mains cables to the inverter and the motor cable should under no circumstances be run parallel to control signal cables, telephone cables, data cables etc. Furthermore, the control signal cables from or to the inverter should only be run within the earthed electrical cabinet enclosure wherever possible. Please use screened signal cables if cables are laid outside the cabinet.

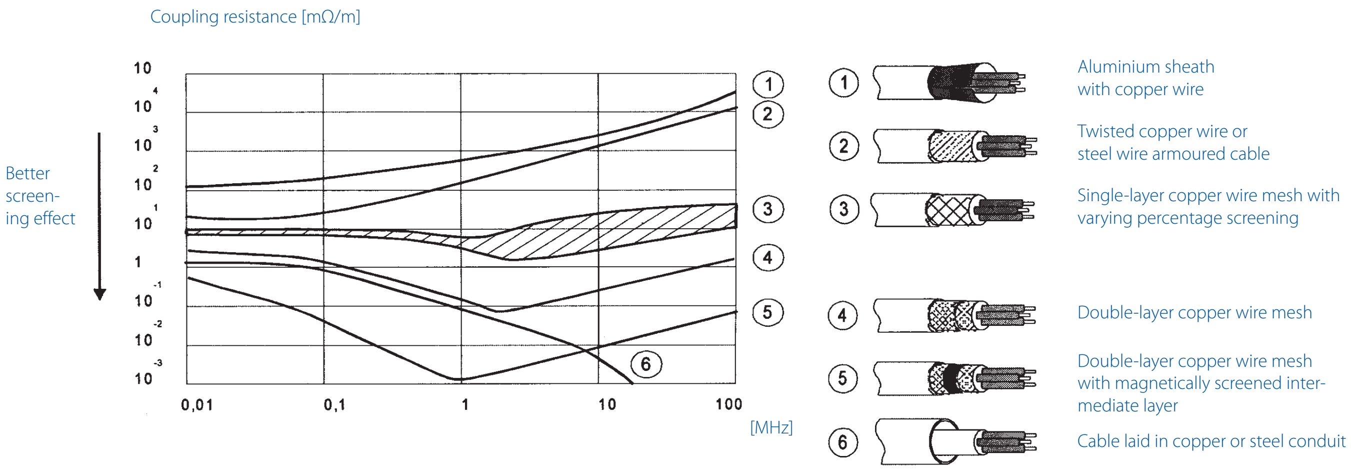
Make a note requirements for installation of the inverter and its wiring in the line below and transfer this to Item 16 in the selection guide.

Selection guide

Make a note requirements for installation of the inverter and its wiring in the line below and transfer this to Item 9 in the selection guide

Item	What do you need or what is available?					
9	☐	EMC-compliant electrical cabinet interpretation	☐	Cross sections of power circuit	☐	Cable routing

Screening



Coupling resistances for different types of screened cable

In order to reduce the radiated interference from motor cables and to increase the resistance of control cables to interference, it is necessary to use screened cables. The screening reduces the coupling of interference in both directions, while the structure and the material of the screen have a major effect on its effectiveness. The screening effect of screened electrical conductors is determined by the transfer impedance or coupling resistance. The smaller the coupling resistance of a conductor, the better its screening effect. Factors which determine the coupling resistance are:

- The screen coverage, i.e. the surface area of the conductor covered by the screen. This should be at least 85 %.
- The structure of the screen. This can be twisted, braided or tubular. The best effect is achieved by the braided or tubular variants.
- The transfer resistance between the individual conductors of the screen. This value should be as small as possible.

The adjacent diagram shows the coupling resistances of different types of cable.

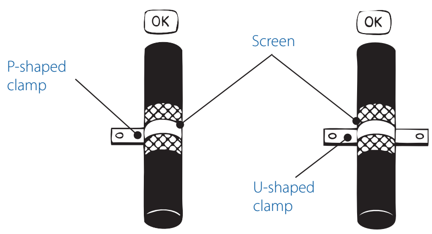
Ground connection

A cable screen is only effective when the screen is connected to the ground area right around the cable and over as large an area as possible. Cables with high interference and signal levels, such as motor cables, should be connected to ground at both ends and with a large surface area. As a rule, control cables must also be earthed at both ends. On the other hand, screens of analogue signal cables, such as temperature sensors for example, can be connected at only one end, namely at the evaluation electronics end. Such signals only vary slightly over time and therefore have a low interference potential.

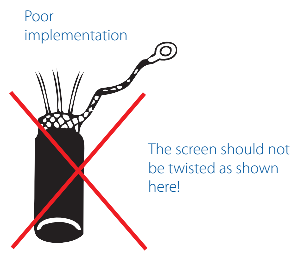
Cable feeds

Feed the cable into the enclosure through a metal cable gland, or fix the cable as soon as possible after entering the enclosure using a P or U-shaped clamp. The screen is connected to earth, either with the help of the cable gland or with the clamp (see diagrams below).

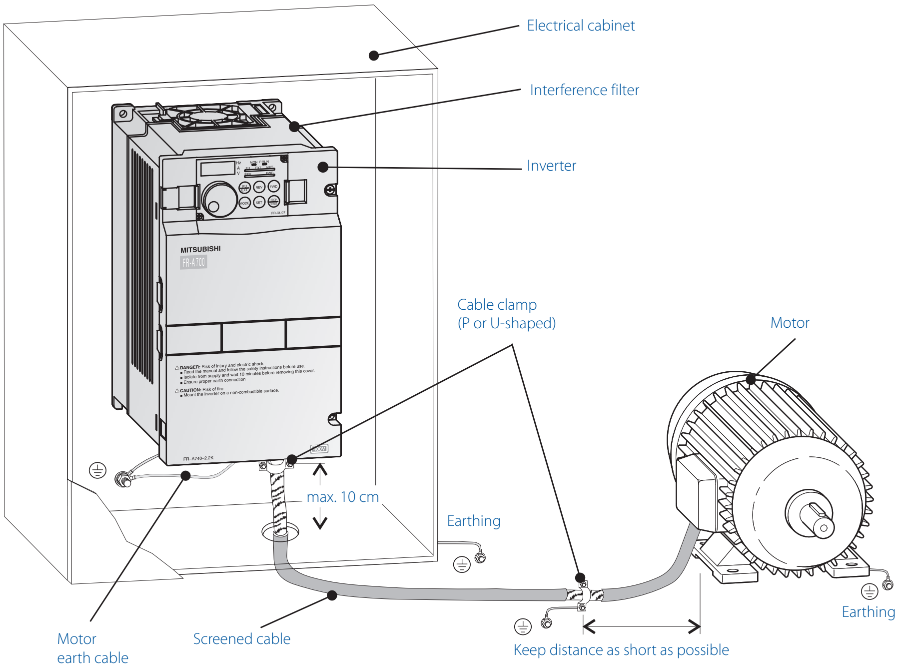
When connecting the screen with the help of a P or U-shaped clamp, it must be ensured that the clamp sits cleanly and the cable is not excessively crushed.



Correct connection



Incorrect connection



Screening by means of P or U-clamp

Installing the motor cable

The motor cable should always be screened in order to reduce conducted interference. The above diagram shows an example of EMC-compliant motor wiring. If possible, ensure that there are no interruptions in the screen over the whole cable length. If chokes, contactors, terminals or safety switches are required in the motor output, i.e. the screen has to be interrupted, then the unscreened part should be kept as short as possible. It is better to install the choke, contactor, terminals or safety switch in a metal housing with the highest possible HF suppression.

The screen should be connected to the metal housing with the lowest possible HF impedance. If screened motor cable is not available, lay the cable in a metal conduit with the best possible screening effect. The metal conduit should have good HF contact with the drive system and the motor housing, e.g. be connected by means of a copper tape. A mesh screen, which is drawn over the cable, can be used as an alternative to a metal conduit. If a braking resistor, for example, is to be connected to the DC link circuit, then this connecting cable should also be screened. The screen must be connected over a large area at both ends (e.g. to the earth terminal of the braking resistor).

Length of motor cable

Basically, the motor cable should be as short as possible. However, this requirement cannot always be satisfied due to local conditions or when using cables that have already been installed. The steep edges on the inverter output give rise to harmonics. The radiation from these harmonics is increasingly amplified as unscreened motor cables become longer due to the antenna effect. The EMC characteristics of the system become worse. The use of a sinusoidal filter at the output of the inverter is recommended with long unscreened motor cables, as this suppresses a significant portion of the harmonics. The voltage drop produced by the filter must be taken into account, as this is added to the voltage drop across the long motor cable. In this case, it is expedient to use a inverter with a higher output current. You will find further information on output filters on Page 21.

Wiring of control and signal cables

Analogue and digital control and regulator cables (rotary pulse generator connection, all analogue inputs and the serial interfaces etc.) should be screened in order to guarantee reliable operation of the drive system. The effective screen area should be as large as possible, i.e. do not cut back the screen any further than is absolutely necessary. As a rule, the screen must be connected to earth at both ends. As a basic principle, the screen of these cables should also not be interrupted.

Selection guide

The measures illustrated are based on experience and can only be looked upon as a recommendation, as the reaction of the system to interference is also affected by the individual execution of the wiring and the circumstances at the installation site.

Make a note of the screening measures you have planned in the line below. Transfer these together with the required material to Item 10 in the selection guide.

Item	What do you need or what is available?			
10	☐	Screened motor cable	☐	Screened signal cables

Earthing

Earthing has fundamentally different tasks. According to the applicable regulations (DIN VDE 0100) and the Low-Voltage Directive, earthing is a protective measure. Furthermore, proper earthing prevents radiated interference and emissions with regard to electromagnetic compatibility (EMC). In addition, the earthing defines the common reference potential point which is necessary for the operation of equipment. As well as the general norms and directives, the earthing requirements of the particular country must also be taken into account.

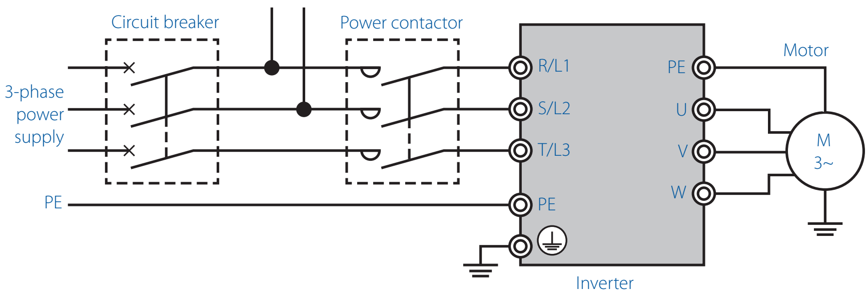
With protective earthing, electrically conductive parts, such as the enclosure, mounting plates, etc., which could become live in the event of a fault, are connected to earth. Such a fault causes the tripping of protective devices, such as overcurrent switches, RCDs or earth leakage circuit breakers, which safely isolate the equipment from the mains.

The following points must be taken into account when earthing the inverter and other installed equipment:

- For earthing purposes, the inverter and other equipment should be connected separately to their respective PE terminals on an equipotential bonding rail.
- Use the largest possible cable cross section for the protective conductor.
- The earth cable should be as short as possible. The earthing point is to be chosen as near as possible to the inverter.
- Motor and inverter must always be earthed.

With Mitsubishi units, the earthing points are identified with "PE" and/or the ⏚ symbol.

Earthed electrical cabinet



Earthing of the inverter

Selection guide

You will find further information on earthing in the operating manual for your Mitsubishi inverter. Make a note of the result of your consideration of how your system is to be earthed in the line below and then transfer it to Item 11 in the selection guide.

Item	What do you need or what is available?	
11	Method of earthing	

Circuit breakers/ Residual current devices

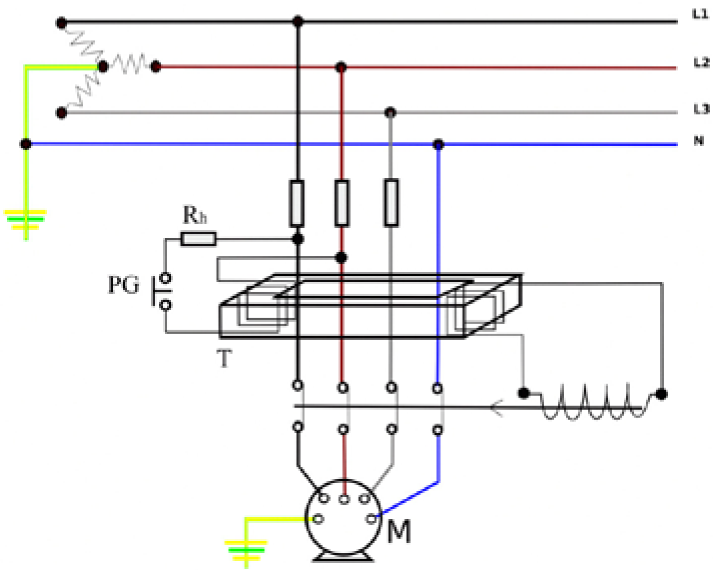
Overcurrent protection

In order to protect against overload due to excessive current consumption or in the event of a short circuit, the load must be disconnected from the mains supply. This measure protects the cables against damage due to heating, which, in the extreme case, can cause the conductors to melt or a fire to break out. So-called circuit breakers, which automatically switch off the circuit in the event of an overload, are used in order to avoid these negative effects. The circuit breaker is a fuse element which can be reused after it has tripped, i.e. the switch can be manually reclosed after the fault has been rectified. The toggle switch on the front is used for this purpose. It can also be used to isolate the circuit from the mains for maintenance purposes.

The criteria for selecting circuit breakers are the rated current and the trip characteristic.

Latching relay

As a result of the international norms, the fault-current circuit breaker is today referred to as the Residual Current protective Device (RCD). RCDs are usually connected upstream of the overcurrent protective devices (circuit breakers) and installed together with these in low-voltage distribution boards. They monitor fault currents which can occur as a result of insulation faults. A maximum fault current of 300 mA, which must cause the circuit breaker to trip, is allowed for fire prevention, whereas for protection against accidental contact, a maximum fault current of 30 mA is permitted. When the trip current is exceeded, the circuit breaker automatically disconnects the load from the supply network.



Principle of a 3-phase residual current device

Type selection for inverters

DIN VDE 0100-530 governs the use of residual current devices in low-voltage systems with electrical equipment. Since 01.06.2007, this norm has specified that AC/DC-sensitive RCDs of type B must be used for newly erected electrical systems which are capable of producing a smooth DC fault current, which is typical for all three-phase inverters. Protective devices of this type trip not only for alternating fault currents, but also for fault currents caused by pure direct voltage.

Further selection criteria

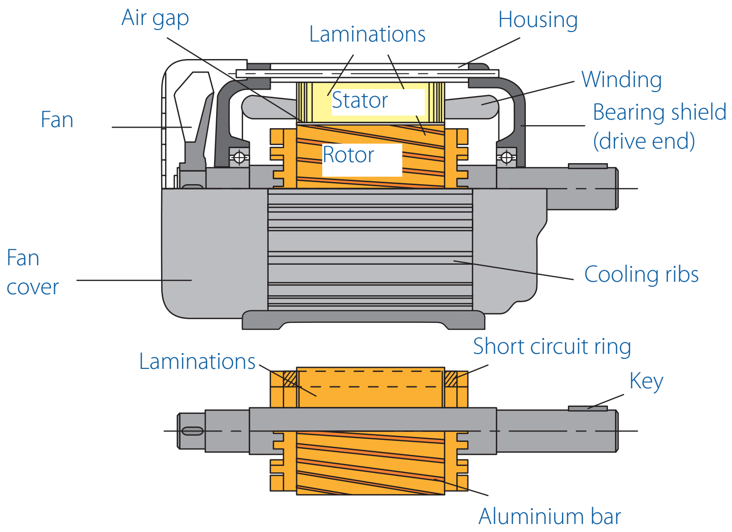
When choosing a residual current device (RCD), the leakage currents caused by mains filters, the length of the screened motor cable and the clock frequency must also be considered. The operating manual for Mitsubishi inverters contains the basis for calculating the trip currents of residual current devices.

Selection guide

Refer to the additional information relating to circuit breakers and residual current devices in the operating manual for your Mitsubishi inverter. Here you will also find recommendations for the circuit breakers and contactors to be used for every inverter model.
Make a note of the circuit breakers required for your system in the line below and transfer it to Item 12 in the selection guide.

Item	What do you need or what is available?			
12	☐	Circuit breakers	☐	Residual current devices

Motors for use with inverters



Longitudinal cut through a asynchronous motor

The inverter generates an alternating voltage which can be varied in frequency and amplitude and is used to directly supply electrical machines such as induction motors (IM) designed for a three-phase supply. Induction motors are basically divided into synchronous and asynchronous motors, wherein the design of the stator of both types of motor is substantially identical. The difference lies in the design of the rotor which, in the case of the asynchronous motor (ASM), in principle consists of a short-circuited winding.

In the synchronous motor, instead of this, the rotor is equipped with polarised permanent magnets in order to produce a torque. Because of the use of permanent magnets, this motor is also referred to as a PM motor.

In practice, three-phase low-voltage AC induction motors with so-called squirrel cage rotors are frequently used today. In motors with squirrel cage rotors, the rotor consists of several aluminium bars which are connected to one another at the ends by means of so-called short-circuit rings. The advantage compared with the original DC drive technology is that, due to the absence of brushes and commutator, these motors do not generate sparks (brush arcing), and therefore pollute the mains with high-frequency interference to a considerably lesser extent.

Advantages of asynchronous motors

- Low maintenance, robustness and long life
- No brush arcing
- Can be used in hazardous environments
- High short-term overload capability (up to greater than 2 × rated torque)
- Geringe Herstellungskosten
- Suitable for high speeds
- The unpowered rotor can run in liquids, gases and vacuum (e.g. for circulating pumps)
- Starting against high counter-torques

Number of poles

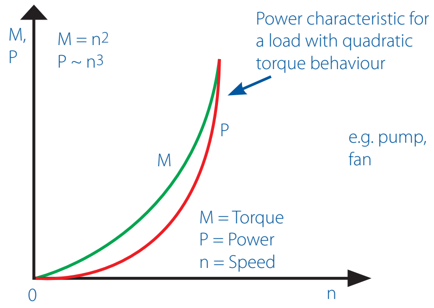
Induction motors are equipped with different numbers of poles. The ratio between the supply frequency and the rotational speed of the rotating field is determined by the number of poles.

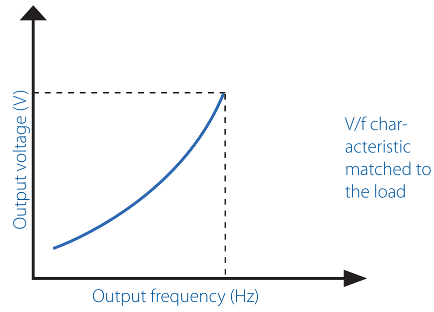
The no-load speed in rpm is given by the supply frequency divided by the number of pairs of poles.

With the squirrel cage motor, a slip occurs due to the principle of operation, i.e. the speed is less than the frequency of the motor input voltage (asynchronous operation). In contrast with this, the IPM motor runs synchronously with respect to the supply frequency.

Number of poles	Number of pairs of poles	Speed n_{sync}
Supply frequency 50 Hz		
2	1	3000 rpm
4	2	1500 rpm
6	3	1000 rpm
8	4	750 rpm
10	5	600 rpm
12	6	500 rpm
14	7	429 rpm
16	8	375 rpm

Frequency inverters of Mitsubishi Electric are able to control ASM motors as well as IPM motors.





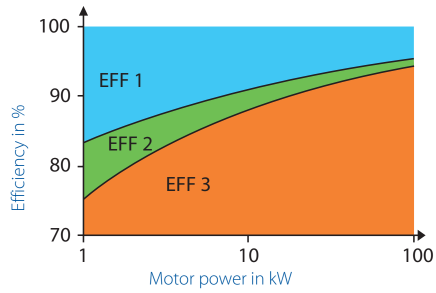
Typical ASM characteristic

Choosing the load characteristic

A drive can be operated with lower losses the closer the V/f characteristic is to the actual power demanded by the load. For pump and fan applications, attention should therefore be paid to the choice of V/f characteristic for loads with quadratic torque behaviour, as this enables energy savings of up to 5 % to be made compared with the linear V/f characteristic. In addition, a further reduction in energy requirement of 2–3 % is possible when the Mitsubishi Electric energy-saving function "Optimum Excitation Control" (OEC) is activated, as this continuously determines the output voltage required for every working point.

DIN IEC 60034-17

Part 17 of DIN IEC 60034 for rotating electrical machines includes a user guide for converter-fed squirrel cage induction motors.



CEMEP efficiency classes

CEMEP classification (EFF)

Electrical drives account for approx. 65 % of industrial power consumption within the EU. In 1998, the CEMEP (Comité Européen de Constructeurs de Machines Electriques et d'Electronique de Puissance) therefore began to classify electric motors into so-called efficiency classes (EFF) as a voluntary commitment on the part of the manufacturers. These include the three classes EFF1 (highest efficiency class), EFF2 and EFF3 (lowest efficiency class).

IE classes according to DIN IEC 60034

In 2008, the voluntary CEMEP agreement was replaced by the extended norm IEC 60034-30: 2008. New IE classes now take the place of the older EFF classes.

IEC 60034-30	EFF classes
IE1 (Standard)	EFF2
IE2 (High)	EFF1
IE3 (Premium)	approx. 15–20 % better than IE2

The objective of the norm is that only asynchronous motors which at least comply with energy efficiency class IE2 are allowed to be used for new installations in Europe from 16th June 2011. From January 2015, only large motors (≥ 7.5 kW) with energy efficiency class IE3 or motors with class IE2 and variable motor control (inverters) will be allowed to be put into circulation. From January 2017, the minimum efficiency class IE3 will apply for all motors (0.75 to 375 kW) or IE2 for motors with converter supply.

The DIN IEC 60034-31 guide describes limits for class IE4, but these will not be binding for the time being. IE4 defines the relevant aspects for variable speed motors.

Basically, the IE classification currently only applies to asynchronous motors under certain conditions of use.

Use of energy-efficient motors

As a result of the continuous development of materials for permanently excited high-power magnets, ever more efficient synchronous motors are being developed and are gradually replacing asynchronous motors due to their significantly higher efficiency and more compact design.

Mitsubishi Electric inverters are capable of driving both ASM and IPM motors.

Your motor parameters

You will find more information on your existing motor, such as number of poles, rated power, rated speed and rated torque, in the technical data and on the rating plate of your motor.

The unique OEC function (Optimum Excitation Control) enables the frequency inverter of Mitsubishi Electric to save 10 % of energy in addition.

Motor cooling and motor protection

Self-ventilated motors for pump applications

Only some of the electrical energy fed to the motor is converted to mechanical energy. The remainder disappears as heat losses. High temperatures cause more rapid ageing and reduce the life of the motor. In addition, when operating with a inverter, the motor is subject to higher loading than with purely mains operation. It is therefore important to pay particular attention to adequate cooling, as the rapidly rising and falling switching edges and the higher output frequencies of the inverter place a greater thermal stress on the windings and laminations of the motor. Furthermore, the harmonics produced by the converter give rise to additional iron losses and heat losses, although these can be effectively reduced with the motor output filters described on Page 21.

The objective of all cooling measures must be to dissipate the resulting heat from the motor as well as possible and to effectively limit the temperature rise inevitably caused by the losses.

Thermal losses

The additional thermal losses which the drive system produces in the motor must be taken into account when sizing the inverter/motor combination. A inverter from a larger power class may be expedient.

Check whether part-load operation would be sufficient after converting your system for use with a inverter.

Motor cooling

Cooling of the motor effects a reduction in the thermal stress. Motors are differentiated depending on the type of ventilation. With self-ventilated motors, the cooling fan is mounted permanently on the motor shaft. With this variant, the cooling power of the fan depends directly on the speed of the motor. In this case, the thermally permissible torque must be reduced in order to also guarantee adequate cooling when operating at low speeds.

Forced ventilated motors do not have this problem, as these are cooled by an independent fan which is "driven" by the mains voltage. However, from the installation point of view, this method of cooling requires additional outlay for the separate cooling fan and its connection to the mains.

Thermal switches

In order to protect the motor against too high temperatures, certain motors are already fitted with a thermal switch during manufacture. An external thermal switch or PTC element can also be fitted to the motor housing in order to shut down the motor using an appropriate protection circuit. Some models of Mitsubishi inverters are equipped with inputs for such protective switches.
In the event of an overload, the converter switches off the motor current and outputs an alarm signal.

Further literature

Due to the abundance of available motors and the complexity of the calculations, the criteria for motor selection can only be described in outline terms in this primer. For further information, we would refer you to the relevant technical literature, examples of which include Peter F. Brosch: Frequency Inverters (Bibliothek der Technik Volume 36, Verlag Moderne Industrie). When selecting the motor, be sure to take into account the current norms and regulations.

Selection guide

Check the type and performance data of your existing motor. Ask the manufacturer whether your motor is suitable for operation with a inverter. You will also find information on motors in the operating manual for your inverter. Make a note of the performance characteristics of your existing or required motor and any thermal switches etc. which may be required in the line below and then transfer this to Item 13 in the selection guide

Item	What do you need or what is available?							
13	☐	Type of motor	☐	Motor parameters	☐	Type of motor cooling	☐	Motor protection - thermal switches

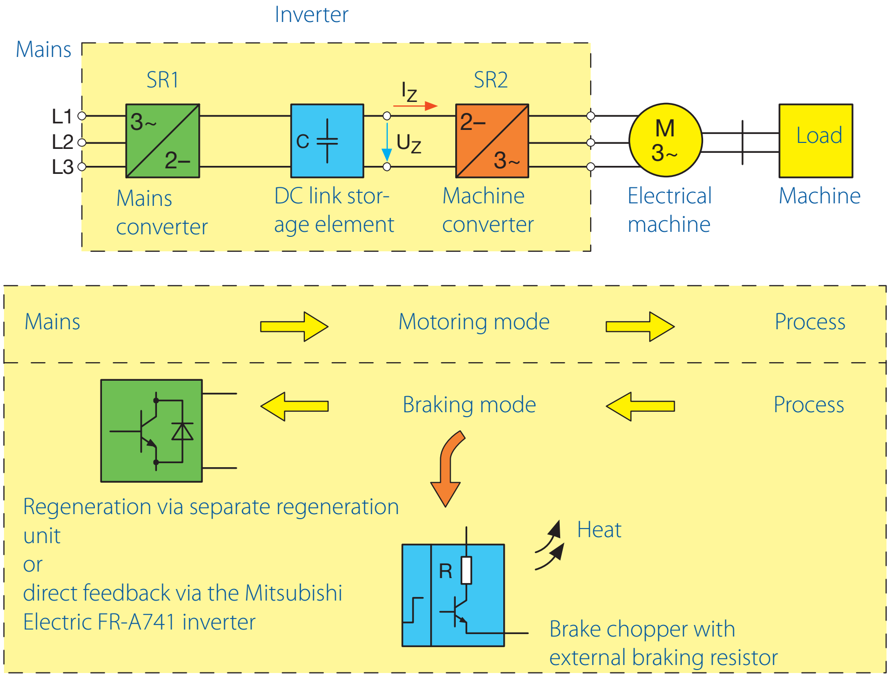
Motor operating modes

Motoring mode

In its main operating mode, the inverter works in motoring mode, i.e. it drives a machine (process). For this purpose, energy is taken from the mains and transmitted to the motor via the mains converter, the DC link circuit and the machine converter (inverter). Most of the energy is stored in the machine as kinetic energy as a result of movement, in that a mass is set into rotation by a motor. When the speed is reduced, the kinetic energy must be dissipated once more, for example by braking.

Generating mode

For braking, with a inverter, use is made of the fact that the motor acts electrically like a generator when turned by the effect of external force. In this case, the motor works super synchronously, as its rotor frequency is higher than the supply frequency and the direction of the energy flow reverses in generating mode. The motor supplies the converted mechanical energy back into the inverter via the output stage and causes the voltage in the DC link circuit to increase. This must be dissipated in order to protect the components against damage due to overvoltage.



Energy flow for inverter in motoring and braking mode

Resistive braking

One way of dissipating this energy is to convert it into heat. In this case, use is made of an external braking resistor and a high-speed electronic switch, also referred to as a brake chopper. Most Mitsubishi Electric inverters have an integral brake chopper. If the DC link voltage exceeds a defined threshold during braking, the chopper connects the link circuit to the braking resistor, which dissipates the excess energy in the form of heat. If the DC link voltage falls below the permissible threshold once more, the chopper disconnects the braking resistor from the inverter.

This process is repeated if the threshold is exceeded again. As the excess energy is dissipated as heat, it must be ensured that adequate cooling is provided for the braking resistor at the place where it is installed. Furthermore, adjacent parts of the system must not be overheated as a result.

Application

As a basic principle, braking resistors are used in applications where rapid changes in speed are required and where the excess energy cannot be dissipated by means of loads or losses in the drive machine. Examples of such applications are lifting devices such as cranes, lift drives, vertical conveyors, etc. Braking resistors for smaller powers can often be installed in the electrical cabinet along with other equipment. If, on the other hand, large amounts of heat have to be dissipated, the resistors are mounted separately in their own enclosure.

Types of construction

High-power resistors are available in various types of construction. These include:

- High-power resistors in metal enclosures
- Wire-wound resistors
- Steel grid resistors
- Cast resistors

Selecting the resistor

The kinetic energy of the drive unit and the number of braking operations per unit time are the deciding factors for the conversion of braking energy. However, the energy of the mass to be braked is often unknown, so that the magnitude of the braking power is usually assumed to be that of the drive power or the rated power of the inverter. However, this procedure cannot be applied when large inertias have to be braked in a very short time. The resistor must always be able to store the major part of the braking energy involved.

Braking units

If a braking torque of more than 20 % or a relative duty cycle of more than 30 % is necessary for an application, it will be necessary to connect an external braking unit with appropriate resistors. Mitsubishi braking units can be cascaded, thus enabling optimum matching to be achieved at all times.

Inverter FR-A741

Regeneration

Another possibility for dissipating the regenerative motor energy is to feed the energy back into the supply network. However, this is not practical in all cases, as the network must be capable of absorbing the electrical energy.

Mitsubishi provides a range of inverters (FR-A741) which has an integral energy feedback function.

Selection guide

Mitsubishi Electric has a comprehensive range of braking resistors and braking units which are specially matched and optimised for your inverter. Information on these can be found in the inverter technical catalogue. Now make a note of the type of braking you have decided upon and which components are required in the line below. Then transfer your decision to Item 14 in the Selection guide

Item	What do you need or what is available?					
14	☐	Braking resistor	☐	Braking units	☐	Regeneration

Functional safety

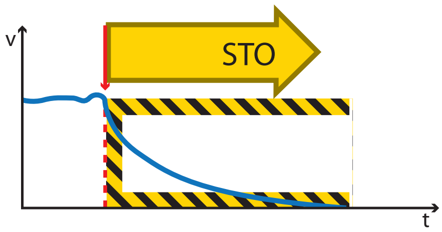
Machinery Directive

The Machinery Directive 2006/42/EC sets out a common level of protection for machines in order to prevent accidents. In accordance with this, the machine manufacturer must ensure that an individual risk assessment is carried out in order to determine the health and safety protection requirements applicable to the machine. The machine must be planned, designed and constructed accordingly, taking into account the results of the risk assessment. The risk assessment is therefore a process which must be carried out right at the planning stage. It should not left until the machine has been built by retrospectively checking out the risks on the finished machine. Hazards which are not established until then can only be remedied or reduced with considerable effort.

Safety functions

In the meantime, inverters are also equipped with integral safety functions. The integral safety functions require less material and maintenance than the traditional design with relay technology. The switching times for an electronic solution are also considerably shorter.

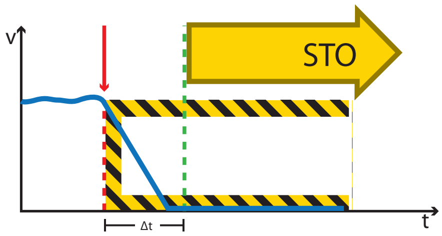
Mitsubishi Electric provides inverter models which are equipped with the "Safe Torque Off" (STO) safety function. In order to be able to use STO for safety devices such as emergency stop buttons, light curtains, etc., these must always be connected to the safety terminals of the inverter via a certified safety module.



Motor speed for Safe Torque Off (STO)

STO function

The STO function is referred to as "safe stop" or "safe torque off". It is the most common safety function integrated in drives, and prevents the motor from generally restarting by switching off the supply of energy to the motor. The connected motor therefore has no torque and freewheels to a stop. STO is used where the motor comes to a stop by itself in a sufficiently short time as a result of friction or load, and freewheeling has no effect on safety. According to EN 60204-1 Section 5.4., STO is a device for preventing unexpected start-up, and the state is monitored by the drive (safe stop category 0).



Motor speed for Safe Stop 1 (SS1)

Function SS1

SS1 is the abbreviation for the term "Safe Stop 1". This function causes a motor to stop rapidly and safely and switches the motor to torque-free mode after it has come to a stop, i.e. STO is activated. SS1 is used when the drive must stop as quickly as possible with a subsequent transition to the STO state in the event of a safety- related incident. It is thus used to brake high-speed motors or motors with large centrifugal mass as quickly as possible in order to protect the operating personnel. According to EN 60204-1, SS1 provides safe stopping in accordance with Safe Stop Category 1. The drive brakes autonomously and rapidly on a short braking ramp, and changes over to the STO function after a set, safe deceleration time Δt.

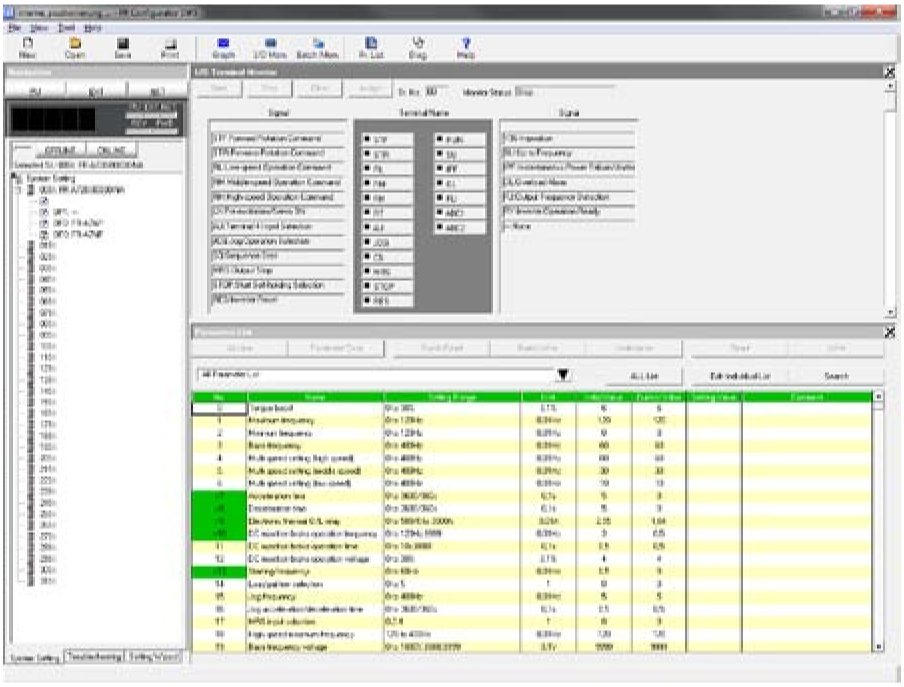
Selection guide

Now make a note in the line below of whether you want to use the safety functions in conjunction with the obligatory safety module for your system. Then transfer your result to Item 15 in the selection guide.

Item	What do you need or what is available?
15	☐ Safety module

Operating and setup software

Operating panel FR-PU07



FR Configurator menu view

The inverter is fitted with an operating panel which allows manual access to all parameters and operating modes. With some models, the standard operating panel can also be removed from the inverter and used remotely if the inverter has to be installed in an enclosed electrical cabinet because of environmental conditions. All models of Mitsubishi Electric inverters use a common operating concept..

FR-PU07

The FR-PU07 external operating panel is available as an option and has a 4-line LC display for text output and a keypad with 10 keys. It can be used instead of the removable standard operating panel in order to benefit from the enhanced functions of this operating panel.

You will find further information on operation and the optionally available operating panels in the technical catalogue and in the operating manual for the particular inverter.

FR Configurator

Mitsubishi Electric offers the FR configurator software for setting up and operating its inverters. Thanks to the networking capability, the software can be used to set up, operate and monitor several inverters simultaneously using a PC or laptop.

Software functions

The FR Configurator software includes the following functions:

- System set-up and operation of up to 32 inverter on the network
- Parameter setting with general overview and function-related overviews
- Display function including data, analogue, oscilloscope and alarm displays
- Inverter state diagnostics for operational and fault analysis
- Test mode for simulated operation and auto tuning
- File management for saving and printing parameters
- Online help

Selection guide

Make a note in the line below of whether you need an optional external operating panel and transfer this to Item 16 in the selection guide. Also note whether you want to use the FR Configurator for your system configuration.

Item	What do you need or what is available?		
16	☐ Integral standard operating panel	☐ PU07	☐ FR Configurator

Communication

Various interfaces can be provided for communication with modern inverters.

Digital inputs and outputs

The simplest type of communication is the input and output of static digital signals, which can only assume the states ON and OFF. Examples of input signals include start switches, motor circuit breakers and signals for switching off the output. Typical output signals are ready to run and the occurrence of an alarm, overload, etc. The outputs can be in the form of open collector outputs and/or relay outputs.

Analogue inputs and outputs

Inverters also have analogue inputs and outputs. Analogue inputs are used, for example, to adjust the setpoint of the converter frequency by means of a potentiometer or a variable DC source. These inputs can be designed as voltage or current inputs. Various actual values, such as output current, output power, DC link voltage, etc., can be output as voltage values by means of an analogue output.

Assigning functions to terminals

With Mitsubishi inverters, you can assign various functions to digital and analogue inputs and outputs by setting parameters. The control panel shows the current switching states of the terminals.

Data communication

Inverters are today equipped as standard with an RS485 interface for data communication. In the meantime, many units also feature the widely prevalent USB interface. Both interfaces are used mainly for data communication, e.g. with a personal computer.

Bus systems

It has been shown in practice that, when a inverter is working independently, only a fraction of its functions are used by the user. The units often only work as a speed controller and information relating to important system data is not available. Access can be made via a central computer system to the relevant status data of all inverters incorporated in the system by means of a fieldbus connection. The bus system makes it easier for the user to wire, commission, control, diagnose and maintain the whole system. The data which are now available make effective system management possible for the first time. Faults can now also be diagnosed in advance on site to identify suitable countermeasures.

Choosing the bus system

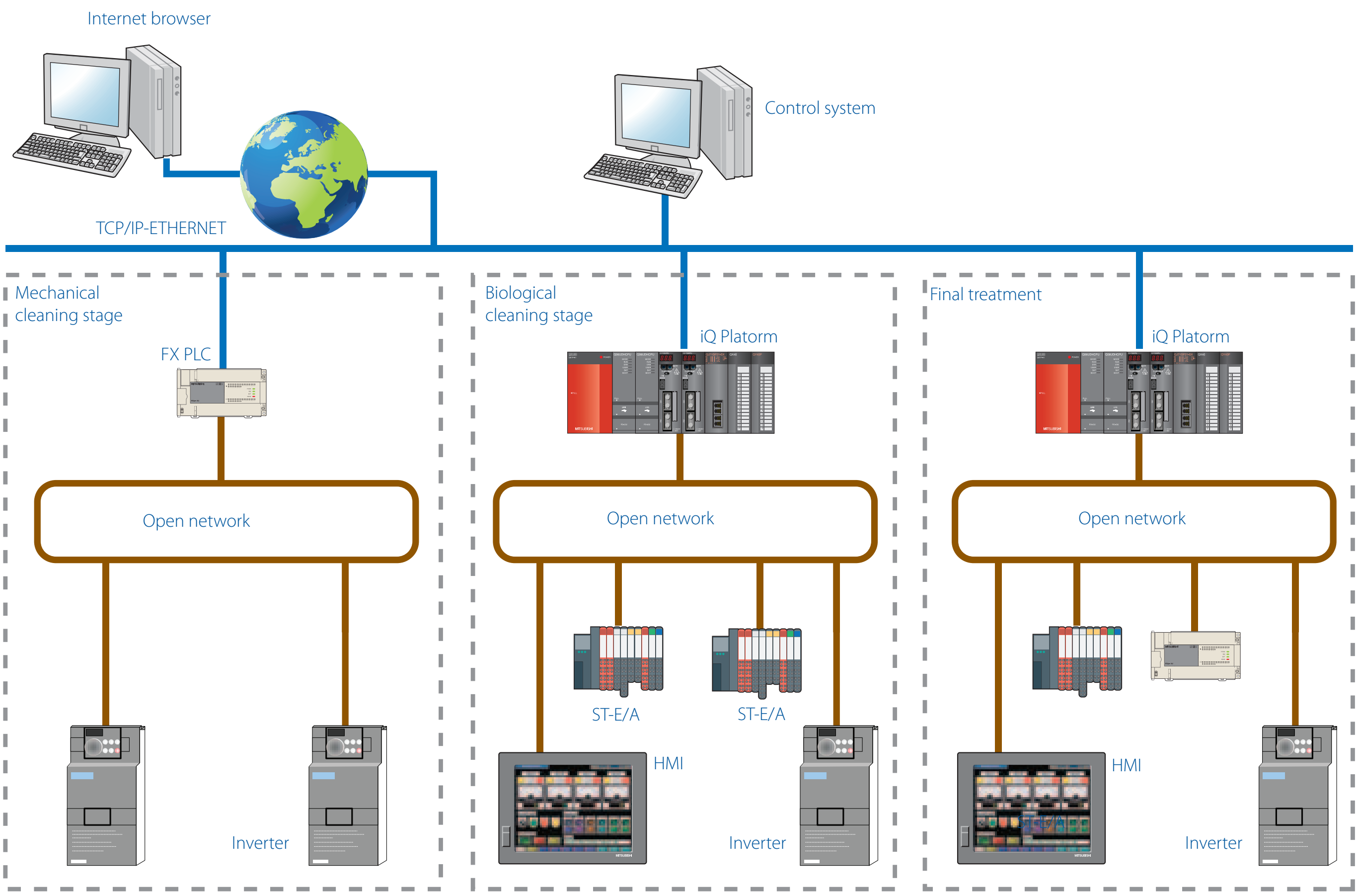
The requirements that need to be supported by the particular fieldbus protocol for your application are decisive for the choice of your bus system. Furthermore, you should also consider whether bus systems which you want to use for data communication with your new system are already in use in your company.

The following interfaces and network connections are possible with Mitsubishi inverters:

Name	Number of nodes	Max. transmission rate
CC-Link	64/128	1000 MBit/s
DeviceNet	64	0.5 MBit/s
MODBUS®	32	1 MBit/s
Profibus DP	125	12 MBit/s
LONWorks	32.000	1.25 MBit/s
SSCNETIII	96	150 MBit/s
RS485	32	12 MBit/s
USB	1	480 MBit/s
BACnet	Uses RS485 as the transmission path	
Ethernet	1024	100 MBit/s

The frequency inverters of the FR-F/A700 series of Mitsubishi Electric provide multiple network interfaces for a seamless integration into complete automation concepts.

Networks



Networked system for water treatment with Internet connection

The above diagram shows parts of a networked system with inverters for water treatment, in which various Mitsubishi Electric components are used for control, operation and monitoring. At the top level is the control computer system where all the process data for the system come together.

As all data are centrally available, the system can now be optimised for maximum performance with minimum energy usage. The logging of alarms in the central control room also helps in rapidly diagnosing and rectifying faults.

Data access via the Internet

If it is also required to access system data for monitoring and evaluation over a larger distance, individual or networked systems can be accessed via the Internet. Mitsubishi Electric offers special web server modules for PLC systems on the network for this purpose. These support open standards such as HTML, JAVA, HTTP or FTP.

Data access by telephone

Another option for the remote maintenance and diagnosis of a system which includes inverters is the use of special modems which exchange data via telecommunications networks. Such modems are suitable both for mobile radio networks (GSM) and for connecting to a landline.

The smartRTU™ of Mitsubishi Electric also provides for secure and reliable monitoring and control of far-out systems.

Selection guide

Make a note of the communications platform you have decided upon in the line below. Transfer your result and what you need for this to Item 17 in the selection guide.

Item	What do you need or what is available?
17	Networks

Overview of Mitsubishi Electric inverter

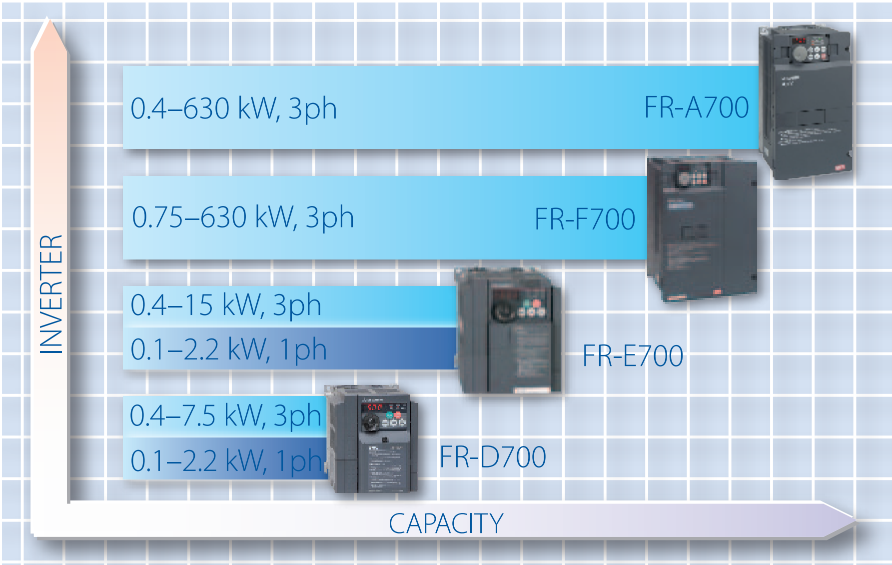
The great diversity of Mitsubishi Electric inverter models makes it easier for the user to choose the optimum inverter for his individual drive task. There are basically four different ranges of inverters available.

Mitsubishi Electric inverters have an overload capability of up to 250 % as standard. They are equipped with an active overcurrent limit which continuously limits the motor current, thus avoiding an undesirable shutdown of the inverter.

The inverters can communicate without any problems using standardised industrial bus systems such as Ethernet TCP/IP, Profibus DP, DeviceNet, CC-Link, LON Network RS485 and Modbus RTU. This enables the inverter to be incorporated into complete automation concepts.

Mitsubishi Electric inverter are true energy-savers, and produce maximum drive power at minimal input power. At the same time, the Optimum Excitation Control function (OEC) ensures that the connected motor is supplied with exactly the magnetic flux necessary for the most efficient operation. This is of particular advantage in the low speed range.

Mitsubishi Electric inverters have many special functions, such as the cascading of pumps, where pumps are automatically connected to a system depending upon a required setpoint. Here, one motor is controlled by the inverter at any one time, while it automatically connects and disconnects the others from the supply. This is effective motor management and a tremendous advantage when a fast and flexible response is required in water supply systems.



Overload capacity

The overload capacity indicates the percentage of the rated current, the output current of the inverter can be temporarily increased.

Inverter		Overload capacity for a given time			Max. ambient temperature
		60 s	3 s	0.5 s	
FR-D700		150 %	—	200 %	+ 50 °C
FR-E700		150 %	200 %	—	+ 50 °C
FR-F700	SLD	110 %	120 %	—	+ 40 °C, + 30 °C: FR-F746
	LD	120 %	150 %	—	+ 50 °C
FR-A700	SLD	110 %	120 %	—	+ 40 °C
	LD	120 %	150 %	—	+ 50 °C
	ND	150 %	200 %	—	+ 50 °C
	HD	200 %	250 %	—	+ 50 °C
FR-A741		150 %	200 %	—	+ 50 °C

SLD = Super light duty
LD = Light duty
ND = Normal duty
HD = Heavy duty

Frequency inverters of Mitsubishi Electric are designed for an overload capacity of 250 %.

Feature	FR-D700	FR-E700	FR-F700	FR-A700
Motor rated power	0.1–7.5 kW	0.1–15 kW	0.75–630 kW	0.4–630 kW
Unit rated current	0.8–16 A	1.6–30 A	2.3–1212 A	1.5–962 A
Frequency range	0.2–400 Hz	0.2–400 Hz	0.5–400 Hz	0.2–400 Hz
Power supply	1-phase, 200–240 V (-15 %/+10 %) 3-phase, 380–480 V (-15 %/+10 %)	1-phase, 200–240 V (-15 %/+10 %) 3-phase, 380–480 V (-15 %/+10 %)	3-phase, 380–500 V (-15 %/+10 %)	3-phase, 380–500 V (-15 %/+10 %)
Protection class	IP20	IP20	FR-F700: IP00/IP20 FR-F746: IP54	FR-A740: IP00/IP20 FR-A741: IP00
Regeneration	No	No	No	FR-A741
Standard operating panel	Integral - Digital Dial		Integral - Digital Dial, removable	
Safety function	Yes	Yes	possible	possible
Standard interfaces	RS485/Modbus RTU	RS485 Modbus RTU/USB	2 x RS485/Modbus RTU	2 x RS485/Modbus RTU/USB
Open networks	—	Profibus DP, Device Net, CC-Link	Profibus DP, Device Net, CC-Link, LONWorks, Ethernet, Siemens FLN, Metasys N2	Profibus DP, Device Net, CC-Link, LONWorks, Ethernet
Other internal options	—	Maximum 1 option card	Maximum 1 option card 16-Bit DIN 1 DIN + 2 AOUT+3 ROUT for more information, see technical catalogue	Maximum 3 option cards 16-Bit DIN 1 DIN + 2 AOUT+3 ROUT Pulstachorückführung for more information, see technical catalogue
Starting torque	150 % at 1 Hz	200 % at 0.5 Hz	120 % at 3 Hz	200 % at 0.3 Hz
Max. overload	150 % for 60 s 200 % for 0.5 s	150 % for 60 s 200 % for 3 s	120 % for 60 s 150 % for 3 s	150 % for 60 s 250 % for 3 s 200 % for 3 s FR A 741
Integral PLC	No	No	No	Yes
PI(D) controller	—	Yes	Yes, with sleep function	—
Approvals	UL/CSA/CE/EN/GOST/CCC		FR-F740:CE/UL/cUL/GOST/DNV F746: CE/GOST/CCC	CE/UL/cUL/DNV/GOST/CCC FR-A741: CE/UL/cUL/GOST
Special functions	• Sensorless vector control • V/f control • Brake transistor • Safe Torque Off (STO) according EN 61800-5-2 • Energy saving control (Optimum excitation control) • Maintenance timer	• V/f control • Sensorless vector control • Brake transistor • Safe Torque Off (STO) according EN 61800-5-2 • Torque limit • Ext. brake control • Flying start • Remote I/O • Energy saving control (Optimum excitation control) • Maintenance timer	• Energy saving control (Optimum excitation control) • Simple magnetic flux vector control • V/f control • Traverse function • Switch motor to direct mains operation • Advanced PID function (multi pump function) • Regeneration avoidance function • Flying start • Life time diagnostics	• Torque control • Positon control • Real Sensorless Vector Control • Closed loop vector control • Continuous energy recovery capability (FR-A741) • Regeneration avoidance function • Integrated PLC function • Easy gain tuning • Life time diagnostics
Highlights of Mitsubishi Electric frequency inverters	• The maintenance timer of Mitsubishi Electric frequency inverters monitors different inverter components at the same time so that maintenance on a regular basis is not necessary. • With the standard "Optimum Excitation Control = OEC" it is possible to save 10 % of energy in addition. • The Mitsubishi Electric frequency inverters have a built-in overcurrent protection and provide automatic restart after alarm. • The four quadrant inverter FR-A741 of Mitsubishi-Electric has an integrated energy recovery. Due to feeding back the braking energy into the supply network, smaller drive systems can be applied whereby the required mounting space and energy costs are reduced. • The standard overload capacity of 200 to 250 % at 50 °C allocated by most of the Mitsubishi Electric frequency inverters offer the possibility to apply an inverter with reduced rated power by some stages. • The capacitors inside the frequency inverters of Mitsubishi Electric are extreme valuable and temperature resistant (T_{op} = 105 °C) to ensure reliable operation even under adverse temperature conditions.			

Selection guide

You will find further information on the units and their features in the technical catalogue or in the inverter manuals which you will find at www.mitsubishi-automation.de. Now select your model of inverter and make a note of it in the line below. Then transfer the model to Item 18 in the selection guide.

Item	What do you need or what is available?			
18	☐ FR-D700	☐ FR-E700	☐ FR-F700	☐ FR-A700

Further options

The focus of this practical primer is on the use of inverters in the water industry. However, this application represents only one of the possible applications of Mitsubishi Electric inverters. They are also found in modern building services engineering in heating, air conditioning and ventilation systems, for driving cranes and hoists, and in transport systems such as conveyor belts etc.

Further examples of typical applications for Mitsubishi Electric inverters are given below:

- Building management
  - Smoke detection monitoring
  - Ventilation and temperature control
  - Lift (elevator) control
  - Automated revolving doors
  - Telephone management
  - Energy management
- Construction
  - Steel bridge manufacturing
  - Tunnel boring systems
  - Chain conveyors
  - Feed conveyors
  - Cranes and hoists
  - Stone crushers
- Agriculture
  - Plant handling systems
  - Sawmills
- Food and drink
  - Food preparation
  - Food processing
  - Palletising
- Pharmaceutical/chemical
  - Dosing control
  - Packaging
  - Handling systems
- Plastics
  - Spindle drives
  - Injection moulding machines
  - Extruders
- Printing industry
- Textile industry
  - Winders
  - Feed systems
- Processing industry
  - Milling and grinding machines
  - Drilling machines
  - Saws
  - Hydraulic systems
  - Processing machines for metal, stone, wood and plasticf
  - stone, wood and plastic
  - High-bay warehouses

Index

Selection guide

This selection guide will give you the confidence that you have taken all the relevant aspects for a safe and reasonably priced drive into account.

Use the line at the end of each subject to help you choose the appropriate criteria and components for the required drive, or transfer the results of your deliberations directly to the selection guide. In the „Details" column, make a note of specific features and measures which are important for your drive, e.g. the power of the selected frequency converter model and the matching choice of filter.

Item	Kriterium	What do you need or what is available?					Details
The load profile							
1	Determining the load characteristic	Constant torque ☐	Linearly increasing torque ☐	Quadratically increasing torque ☐	Constant power over the operating range ☐		
Check of Power supply							
2	Types of supply network	TN-S network ☐	TN-C network ☐	TT network ☐	IT network ☐		
3	EMC filter	Category C1 ☐	Category C2 ☐	Category C3 ☐	Category C4 ☐		
4	DC link chokes						
	Mains input chokes						
	Passive filters						
	Active filters						
Motor and Installation							
5	Motor output filter						
	Rated voltage class and dielectric strength of motor cable						
Ambient conditions							
6	Location/Installation concept						
7	Cooling system/ Heating system	Natural ventilation					
		closed or open ☐	enclosed on all sides ☐	Heatsink ☐	Forced ventilation ☐	Heat exchanger ☐	
8	Humidity						
	Pollution due to dust, dirt, oil mist or aggressive gases						

Item	Kriterium	What do you need or what is available?	Details
Connecting the inverter			
9	EMC-compliant electrical cabinet interpretation		
	Cross sections of power circuit		
	Cable routing		
10	Screened motor cable		
	Screened signal cables		
11	Method of earthing		
12	Circuit breakers		
	Residual current devices		
Motor and motor protection			
13	Type of motor		
	Motor parameters		
	Type of motor cooling		
	Motor protection - thermal switches		
Choosing the inverter			
14	Braking resistor	Brake chopper ☐ External braking resistor ☐	
	Braking units		
	Regeneration	External regeneration ☐ FR-A741 ☐	
15	Safety module		
16	Integral standard operating panel		
	PU07		
	FR Configurator		
17	Networks		
18	Inverter	FR-D700 ☐ FR-E700 ☐ FR-F700 ☐ FR-A700 ☐ FR-A741 ☐	

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