Technical Explanation for Inverters

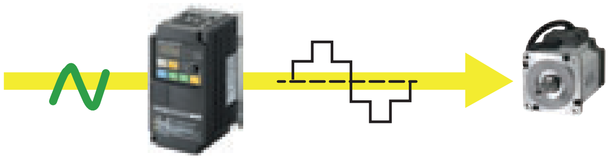
Introduction

What Is an Inverter?

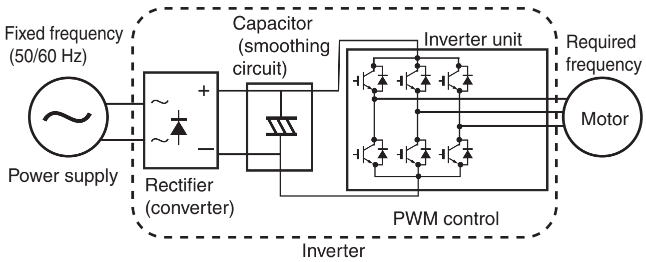
An inverter controls the frequency of power supplied to an AC motor to control the rotation speed of the motor.
Without an inverter, the AC motor would operate at full speed as soon as the power supply was turned ON. You would not be able to control the speed, making the applications for the motor limited. The use of an inverter to adjust the speed and acceleration of an AC motor increases the range of applications of the motor compared with a motor that operates at a constant speed. The speed of a motor is normally measured as the number of revolutions per minute (rpm). The acceleration rate is given as the change in speed over a specific period of time.

Features

Freely Set and Change AC Power Frequency and Voltage
An inverter uses this feature to freely control the speed and torque of a motor.



This type of control, in which the frequency and voltage are freely set, is called pulse width modulation, or PWM. The inverter first converts the input AC power to DC power and again creates AC power from the converted DC power using PWM control. The inverter outputs a pulsed voltage, and the pulses are smoothed by the motor coil so that a sine wave current flows to the motor to control the speed and torque of the motor.



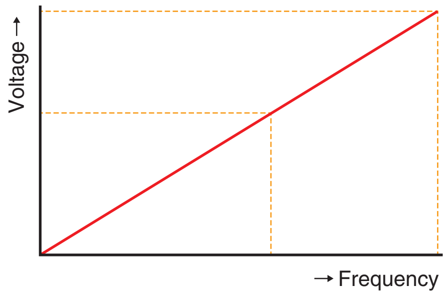
The voltage output from the inverter is in pulse form.
The pulses are smoothed by the motor coil, and a sine wave current flows. As a result, the output from a general-purpose inverter cannot be used for equipment other than motors.

Principles

Control Modes

V/f Control
V/f control is a method of controlling a motor by supplying a specific current to the coil to output a specific torque.
Therefore, the voltage and frequency are in a proportional relationship. This is called the V/f characteristics.

V/f Characteristics

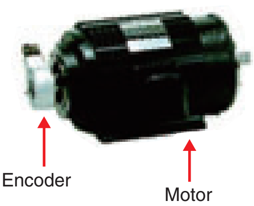


Vector Control
Vector control is used to correct the output waveform according to the voltage and current output from the inverter to an induction motor. The motor speed and output torque are estimated from the voltage and current output to control them.
Although induction motors have unstable characteristics, the use of vector control produces stable characteristics where the actual speed can follow a reference frequency in the same way as a servomotor.
There are mainly the following two types of vector control.

Sensorless Vector Control
Sensorless means that there is no feedback from an encoder.
Although there is no feedback signal from a sensor, the current and voltage output from the inverter to the motor are used to correct the output waveform. This enables finer speed control.

Vector Control with Encoder Feedback

As opposed to sensorless vector control, control is performed using feedback from an encoder.
The encoder is also called a pulse generator, and this type of control is also called vector control with PG.

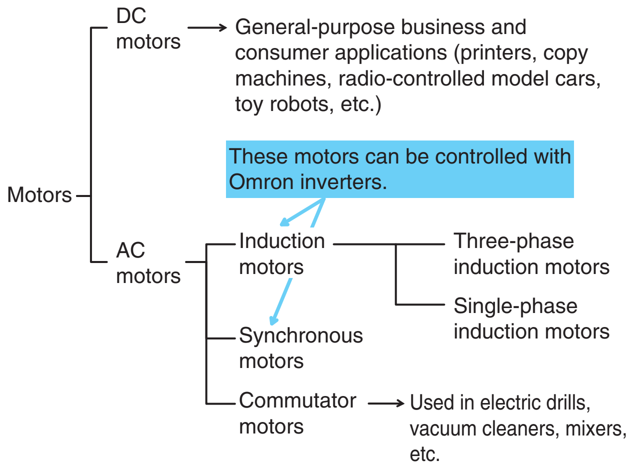


With this method, the inverter monitors the output voltage, the output current, and the encoder feedback from the motor. The encoder feedback is used to adjust the output waveform to perform precise speed control.

Main Basic Functions

Applicable Motors

Omron inverters can control induction motors. Omron also provides inverters that can control synchronous motors.



As induction motors can be used to achieve simple speed control at a relatively low cost, they are used in many applications. They can be operated just by connecting an AC power supply, so installation is extremely easy. Generally, a cooling fan is attached to the back to help dissipate heat generated by the motor.

Torque Boost (Torque Compensation)

In low-frequency ranges, voltage drop has a large impact, reducing the motor torque. To compensate for this, adjustments are made to output a high voltage at the required frequency. This function is called torque boost or torque compensation. Two torque boost options are available: Manual torque adjustment and automatic torque adjustment.

Inverter Overload Detection

There are two types of overloads with an inverter: inverter overload and motor overload. Overload detection is performed to protect both the inverter and motor from burning.

Inverter Overvoltage Detection and Braking Function

When a motor decelerates, or when the load descends, the motor serves as a generator to feed back the energy to the inverter. This phenomenon is known as regeneration.
If the regenerative energy is too large to be stored in the inverter, it causes an overvoltage.
Regenerative processing uses the braking circuits built into the inverter to convert the regenerated energy into heat via resistors, preventing an overvoltage.

Explanation of Terms

Performance

Output Voltage
The voltage between the output terminals of an inverter.

Maximum Voltage
The maximum value of a voltage equivalent to the effective value that an inverter can output at the rated input voltage.

Output Current
The current that flows at the output terminals of an inverter.

Output Frequency
The voltage frequency between the output terminals of an inverter.

Braking Resistor
An external resistor that is connected to an inverter to absorb the regenerative energy generated when a load decelerates or an elevating axis descends.
This resistor prevents overvoltage trip of the inverter.

Regenerative Braking Function
The regenerative braking function uses the built-in or an external regenerative braking circuit to decrease the internal DC voltage of the inverter by converting the regenerated energy from the motor into heat via external braking resistors. This function is enabled only when the inverter is connected with one or more external braking resistors/external regenerative braking units.

Regenerative Energy
A load connected to a motor has kinetic energy while it rotates and has potential energy while it stays in a high position. The energy that returns to an inverter when a motor decelerates or a load descends.
This phenomenon is known as regeneration, and the energy is called regenerative energy.

Noise Filter
A high-frequency filter that is connected to the power supply side or load side of an inverter to absorb noise that is generated in an inverter when a power device switches.

Cooling Fan
A fan used to cool heating components, such as semiconductors, in the main circuit of an inverter.

Reactor
A reactor is used to suppress harmonics generated from an inverter.
There are DC reactors and AC reactors. Both of them work to suppress rapid changes in the current.

Harmonics
The current distortion from the normal current sine wave generated when AC is converted to DC and then smoothed. Inverters generate harmonics, which can affect electrical equipment and peripheral devices.

Functions

Speed Control (ASR)
A function that controls the rotation speed of a motor.
(Automatic Speed Regulator)

Control Mode
A method to control the motor speed with an inverter including V/f control, vector control, etc.

V/f Control and V/f Characteristics
A method and characteristics of controlling a motor by applying a specific current to the coil to output a specific torque.
Refer to *Principles* for details.

Constant Torque Characteristics
This setting enables the output of a constant torque based on the frequency, according to the V/f characteristics that represent the proportional relationship between the output frequency and the output voltage.
However, the output voltage is proportional from 0 Hz to the base frequency, it is constant independent of the frequency, from the base frequency to the maximum frequency. This setting is suitable for cart, conveyor, overhead traveling crane, and other applications where a torque is required, independent of the motor rotation speed.

Reduced Torque Characteristics
This setting is suitable for fan, pump, and other applications that do not require large torque at low speeds.
It provides high efficiency, reduced noise, and reduced vibration, because the output voltage is reduced in the low speed range.

Special Reduced Torque Characteristics (Squared Reduced Load Torque Characteristics)
Characteristics that are virtually constant with the square of the speed (i.e., characteristics at which the torque generation curve is a square curve) and require a large torque at low speeds.

Base Frequency
The maximum frequency at which a motor can generate the rated torque continuously. An inverter has 50 Hz or 60 Hz as its base frequency.

Vector Control
A control method that corrects the output waveform according to the voltage and current output from the inverter to an induction motor.
Refer to *Principles* for details.

Sensorless Vector Control (Vector Control without PG)
Vector control with no feedback from an encoder.
Refer to *Principles* for details.

Vector Control with PG
Vector control with feedback from an encoder.
Refer to *Principles* for details.

Acceleration Time
The time required for the output frequency to go from 0 Hz to the maximum frequency.

Deceleration Time
The time within which an output frequency is reduced to 0 Hz from the maximum output frequency.

Starting Frequency
The frequency at which the inverter starts its output when the RUN signal turns ON.

Maximum Frequency
The maximum value of the frequency that an inverter can output.

Minimum Output Frequency
An output frequency shown when the minimum value of a frequency setting signal is input (e.g., 4 mA for 4 to 20 mA input).

Zero Speed
The condition when the frequency is lower than the minimum output frequency.

Carrier Frequency
A frequency that determines the pulse-width-modulation cycle.
Set a higher carrier frequency value to reduce the metallic noise generated by the motor.

Torque Control
A control method that enables the torque generated by a motor to be equal to a torque reference input.

Starting Torque
The torque that is output when the motor starts.
The motor will not rotate if a load larger than this torque is applied to the motor.

Torque Limit
A function that limits the output torque of a motor.

DC Braking
A function that applies a DC voltage to the induction motor for braking control (i.e., firmly stops motor rotation).
The function operates either when the motor starts or stops.

- DC Braking at Startup:
  DC braking is used to stop the motor rotating by inertia without regenerative processing before starting it.
- DC Braking at Stopping:
  DC braking is used if the load is large or if it will rotate by inertia and not stop with normal deceleration.

Tripping
Turning OFF the power supply from the inverter to the motor by operating the protection function of the inverter against overvoltage, overcurrent, or other factors.

Fault Retry
A function that automatically restarts a tripped inverter.

Stalled Status
The status in which the rotor at the motor stator cannot follow the rotating magnetic field because the load applied to the motor is too large or the acceleration or deceleration is too rapid.
The motor loses speed or will be out of step.

Overcurrent
The status in which a larger current than the rated output current flows in the circuit.

Overcurrent Suppression Function
A function that suppresses the overcurrent caused by a steep current increase due to an impact load etc.
It causes the inverter to stop accelerating when the output current reaches a certain percentage of the rated current.

Overvoltage
The status in which more than the rated voltage is applied to a circuit.

Overvoltage Suppression Function during Deceleration
A function that prevents overvoltage trip caused by the regenerative energy from the motor during deceleration.
Two options are available: Automatic deceleration while keeping the voltage rise at a certain level and starting acceleration when the voltage rise exceeds a certain level.

Undervoltage
A status in which the power supply voltage is below the rated value.

Overtorque
A status in which the output torque is higher than the rated value.

Overtorque Detection
A function that detects that the estimated motor output torque value exceeded the set level and output the overtorque signal.

Undertorque Detection
A function that detects that the estimated motor output torque value fell below the set level and output the underorque signal.

Electronic Thermal Function
A function that prevents a motor from overloading and burning.

Motor Overload
The status in which a load that is higher than the rated torque is applied to a motor.

Inverter Overload
The status in which the inverter overload protection has been operated by an electronic thermal.

Motor Protection
A function that enables an inverter to internally have the characteristics data of the motor and to internally perform calculations during operation to protect the motor.

Input Phase Loss
A function that detects phase loss in the input power supply. Detection is performed using the fluctuation in the main circuit's DC voltage. Detection can thus also be performed using the power supply fluctuation and unbalance or degradation in the main circuit capacitor.

Output Phase-loss Detection
A function that detects phase loss in the inverter output terminals. Detection is performed using the values of the currents flowing at the output phases.

Drive Mode
A mode in which operation commands can be received.

Digital Operator
A unit used to operate an inverter and provide display.
A digital operator can be removed from the inverter body and installed on a control panel. It can be also used for remote control.

Frequency Reference
A reference provided by the frequency of the power supply to a motor.

Analog Reference
A frequency reference of an inverter that is set with an analog signal.
Analog signal: A signal that expresses continuous quantities through the size of the signal. 0 to 5 V, 0 to 10 V, 4 to 20 mA, etc.

STOP Command
A command that stops a motor via an inverter using the digital operator or a contact input.
It enables either a free-run stop or a deceleration stop.

Deceleration Stop
A function that decelerates a motor at a certain ratio until the motor stops.

Free-run Stop
A method of shutting off the inverter output to stop the motor rotation.
Executing the free-run stop function causes the motor to fall a free-run state, in which it decelerates due to the load and friction forces exerted on the motor and/or machine and comes to a stop.

Multi-function Input
The functions, such as RUN commands and STOP commands, can be allocated to the multi-function input terminals to use them.

Multi-function Output
The functions, such as a signal during RUN, can be allocated to the multi-function output terminals to output signals.

AVR (Automatic Voltage Regulator) Function
A function that has the inverter automatically compensate for the output voltage to the motor even if the incoming voltage fluctuates.
It is useful as a preventive measure against low output torque to the motor or overexcitation.
Note, however, that the inverter cannot output voltage exceeding the incoming voltage to the inverter.

Multi-step Speed Operation
A function that sets RUN speeds using multi-step speed references and switches the set speeds via external signal input.

Jogging Operation
A function that allows you to determine and fine-tune the motor stop position.

PID Control
A control method that matches a feedback (detected) value to a set target value by combining proportional (P), integral (I), and derivative (D) operations that control the flow rate, air volume, pressure, and other processes.

- Proportional (P) Operation:
  In this operation, the control volume is proportional to the deviation (difference between the target value and the current value).
- Integral (I) Operation:
  In this operation, the control volume is proportional to the time integral value of the deviation.
  The P operation is less effective as the current value approaches the target value due to smaller deviation, taking a long time to reach the target value. The I operation compensates this disadvantage.
- Derivative (D) Operation:
  In this operation, the control volume is proportional to the percentage of change in the deviation.
  Because using only the PI operation is time-consuming, the D operation is used to effectively compensate for the disadvantage in responsiveness.

Auto-tuning
A function to automatically measure and record the circuit constants of a motor, including the constants of motor coil or amount of moment of inertia.
Auto-tuning is generally used for vector control.
There are two measuring methods: measurement using a rotating motor and using a motor that does not rotate.

Jump Frequency
A frequency that is set to maintain a stable output by not changing the output frequency to within a specified frequency zone and thus avoid a resonance frequency of a machine.

Restart During Momentary Power Interruption
A function that allows selecting tripping or retrying (i.e., restarting) when the power is momentarily interrupted or there is an undervoltage.

Torque Boost
A function that raises the output torque if it is not sufficient at low speeds.
The inverter provides two torque boost options: Manual torque boost for manual torque adjustment and Automatic torque boost for automatic torque adjustment.

Automatic Torque Boost
A function that automatically controls the output voltage by detecting an output current of an inverter to increase the torque when it is insufficient at low speeds.

Automatic Energy-saving Operation Function
A function that automatically adjusts the inverter output power to a minimum during constant speed operation.
This is suitable for the load of reduced torque characteristics, such as a fan and pump.

Brake Control Function
A function that allows the inverter to control the external brake (non-excitation electromagnetic brake on an induction motor) of equipment, including an elevating system.

RUN Direction Limit Selection
A function that limits the RUN direction of the motor. (Generally, when viewed from the shaft, the forward rotation is defined as the direction in which the motor rotates counterclockwise and the reverse rotation as the direction in which the motor rotates clockwise.)

Speed Limit
Controlling the rotation speed of a motor.

Speed Deviation
The difference between the value of a set speed and the rotation speed of a motor.

Slip Compensation
A function that calculates the output torque from the output current to compensate the output frequency.

Torque Compensation
A function that increases the output torque when an increase in the motor load is detected.

Torque Compensation Limit
A limit that restricts the torque during vector control if the maximum motor torque is insufficient or to prevent outputting excessive torque.

Others

Induction Motor
A motor that rotates a rotor by means of electromagnetic induction. An induction motor uses AC to supply current to the inner coils of the motor.

Number of Motor Poles
The number of magnetic poles in a motor.
It is equivalent to the number of magnetic poles wound on the shaft generating torque.

Motor Ratings
The limit within which a motor can be used under specified conditions. The motor ratings include the current, voltage, torque, etc.

Braking Torque
The torque that operates in the direction that prevents motor rotation.

Output Torque
The output torque of a motor. That is the moment of force generated by the rotating shaft.

Load Torque
The torque required for the motor to operate the load.
The load torque fluctuates according to the speed.

Load Ratio
The percentage of load current or load torque to the rated current or torque.

Leakage Inductance
A value that indicates the magnetic field that is leaked to the environment or given off as heat (core loss) without generating torque. It is usually given as the inductance (coil) component that generates the magnetic field.

Further Information

Motor Capacity Selection

Before selecting an inverter, first the motor should be chosen. In selecting the motor, calculate the load inertia appropriate to the application, and then calculate the required capacity and torque.

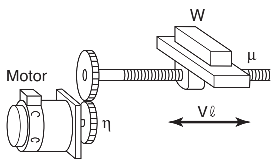
Simplified Selection Method (Required Output Calculation)

This method of calculation helps you select a motor by calculating the output (kW) required by the motor to maintain its steady rotations. To use this method for motor selection, make allowance for the calculated result because it does not include acceleration/deceleration and other transient state calculations. The simplified selection method is suitable for fan, conveyor, mixer, and other applications where a constant state continues for a while.

The simplified selection method cannot be used for the following applications. For these applications, use the detailed selection method.

- Those requiring rapid startup (acceleration)
- Those that frequently repeat run and stop
- Those that have a large inertia at the power transfer part
- Those that have an inefficient power transfer part

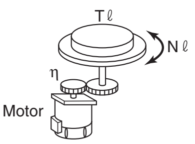
For linear motion: Steady power P0 [kW]



$$P_o = \frac{\mu \cdot W \cdot V\ell}{6120 \cdot \eta}$$

μ : Friction coefficient
W : Mass of linear motion part [kg]
Vℓ : Speed of linear motion part [m/min]
η : Efficiency of transfer part

For rotation motion: Steady power P0 [kW]



$$P_o\ [kW] = \frac{2\pi \cdot T\ell \cdot N\ell}{60 \cdot \eta} \times 10^{-3}$$

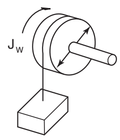
Tℓ : Load torque (Load shaft) [N·m]
Nℓ : Rotation speed of load shaft [r/min]
η : Efficiency of transfer part (η ≤ 1)

Detailed Selection Method (RMS Calculation)

This method helps you select a motor by calculating the effective torque and maximum torque values required to achieve a certain pattern of operation for the application. It selects a motor that is optimal for a particular operation pattern.

Calculation of load inertia and motor-shaft conversion inertia

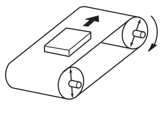
Depending on the type of the motor transfer system, calculate the inertia for all parts and convert it into the motor-shaft inertia.



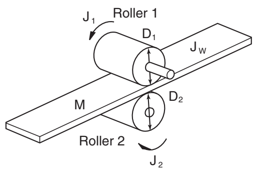
$$J_W = J_1 + J_2 = \left(\frac{M_1 \cdot D^2}{8} + \frac{M_2 \cdot D^2}{4}\right) \times 10^{-6}\ [kg \cdot m^2]$$

J_W : Shaft conversion inertia [kg·m²]
J_1 : Inertia of cylinder (Shaft conversion) [kg·m²]
J_2 : Inertia of workpiece (Shaft conversion) [k·m²]
D : Diameter of cylinder [mm]
M_1 : Mass of cylinder [kg]
M_2 : Mass of workpiece [kg]

$$J_W = J_1 + J_2 + J_3 + J_4 = \left(\frac{M_1 \cdot D_1^2}{8} + \frac{M_2 \cdot D_2^2}{8} \cdot \frac{D_1^2}{D_2^2} + \frac{M_3 \cdot D_1^2}{4} + \frac{M_4 \cdot D_1^2}{4}\right) \times 10^{-6}\ [kg \cdot m^2]$$

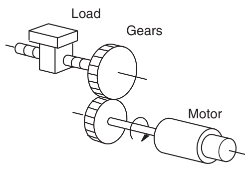


J_W : Shaft conversion inertia [kg·m²]
J_1 : Inertia of cylinder 1 [kg·m²]
J_2 : Inertia of cylinder 2 [kg·m²]
J_3 : Inertia of workpiece [kg·m²]
J_4 : Inertia of belt [kg·m²]
D_1 : Diameter of cylinder 1 [mm]
D_2 : Diameter of cylinder 2 [mm]
M_1 : Mass of cylinder 1 [kg]
M_2 : Mass of cylinder 2 [kg]
M_3 : Mass of workpiece [kg]
M_4 : Mass of belt [kg]



$$J_W = J_1 + \left(\frac{D_1}{D_2}\right)^2 J_2 + \frac{M \cdot D_1^2}{4} \times 10^{-6}\ [kg \cdot m^2]$$

J_W : Shaft conversion inertia [kg·m²]
J_1 : Inertia of roller 1 [kg·m²]
J_2 : Inertia of roller 2 [kg·m²]
D_1 : Diameter of roller 1 [mm]
D_2 : Diameter of roller 2 [mm]
M : Mass of workpiece [kg]



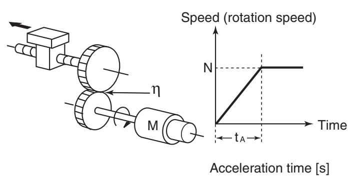
$$J_L = J_1 + G^2 (J_2 + J_W)\ [kg \cdot m^2]$$

J_L : Motor-shaft conversion inertia [kg·m²]
J_W : Load inertia [kg·m²]
J_1 : Inertia of motor-side gear [kg·m²]
J_2 : Inertia of load-side gear [kg·m²]
Z_1 : Number of motor-side gear teeth
Z_2 : Number of load-side gear teeth
Gear ratio $G = Z_1/Z_2$

Calculation of motor-shaft conversion torque and effective torque

Calculate the acceleration torque from the motor-shaft conversion load inertia, the motor-rotor inertia, and the acceleration. Then, calculate the load torque from the external force (gravity and tension) and friction force applied to the load. Finally, combine these calculation results to calculate the torque required for the motor.

- Calculation of acceleration torque

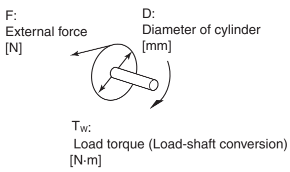


Acceleration torque (TA)

$$T_A = \frac{2\pi N}{60 t_A}\left(J_M + \frac{J_L}{\eta}\right)\ [N \cdot m]$$

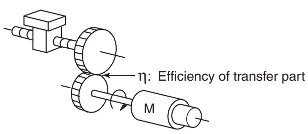
T_A : Acceleration torque [N·m]
J_L : Motor-shaft conversion load inertia [kg·m²]
J_M : Motor-rotor inertia [kg·m²]
η : Efficiency of transfer part (η ≤ 1)
N : Motor rotation speed [r/min]

- Calculation of motor-shaft conversion load torque



$$T_W = F \cdot \frac{D}{2} \times 10^{-3}\ [N \cdot m]$$

(Generally, the friction force can be calculated as below:
F=μW μ : Coefficient of friction
W : Mass of motion part [kg])



$$T_L = T_W \cdot \frac{G}{\eta}\ [N \cdot m]$$

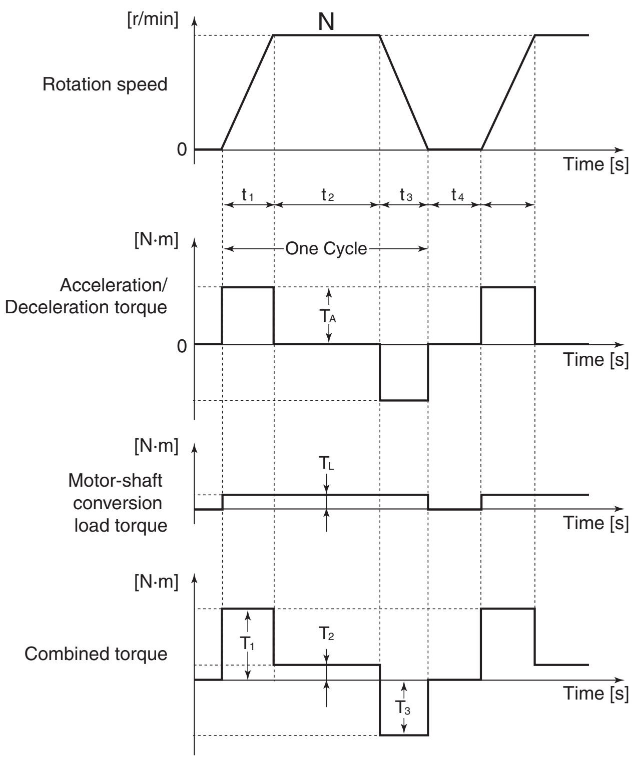
T_1 : Motor-shaft conversion load torque [N·m]
T_W : Load torque (Load-shaft conversion) [N·m]
Z_1 : Number of motor-side gear teeth
Z_2 : Number of load-side gear teeth
Gear ratio (Speed reduction ratio) G = Z1/Z2

• Calculation of combined torque and effective torque

Effective torque: T_{RMS} [N·m]

$$= \sqrt{\frac{\Sigma (T_i)^2 \cdot t_i}{\Sigma t_i}} = \sqrt{\frac{T_1^2 \cdot t_1 + T_2^2 \cdot t_2 + T_3^2 \cdot t_3 + T_4^2 \cdot t_4}{t_1 + t_2 + t_3 + t_4}}$$

Maximum torque: T_{MAX} [N·m] = T_1 = T_A + T_L



Motor selection

Based on the above calculation results, select the motor capacity by using the following formulae.
Select the larger of the two calculated values as the motor capacity.
Also, when selecting a motor, take into consideration the errors in calculation and modeling. Select a motor whose capacity is at least approximately 20% larger.

• Motor capacity conversion to effective torque
  Motor capacity [kW] = $1.048 \cdot N \cdot T_{RMS} \cdot 10^{-4}$
  N: Maximum rotation speed [r/min]

• Motor capacity required for maximum torque output
  Motor capacity [kW] = $1.048 \cdot N \cdot T_{MAX} \cdot 10^{-4}/1.5$
  N: Maximum rotation speed [r/min]

Inverter Capacity Selection

Select an inverter that can be used with the motor you selected based on the result of motor capacity selection.
Basically, select an inverter which fits the maximum applicable motor capacity of the selected motor.
After selecting an inverter, check if it meets the both of the following conditions. If not, select an inverter with one size larger in capacity and check again.

Rated motor current ≤ Rated output current of inverter
Max. continuous torque output time for application ≤ 1 min

Note: 1. If the inverter overload capacity is 120% of the rated output current for 1 minute, check it for 0.8 minute.
2. If you want to use 0-Hz sensorless vector control, need a holding torque at a rotation speed of 0 (r/min), or frequently require 150% of the rated torque or more, use an inverter with one size larger in capacity than the one selected by the above method.

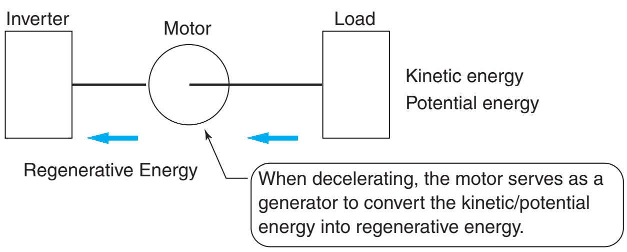
Overview of Braking Resistor Selection

Requirement of Braking Resistor

If the regenerative energy generated in deceleration or descent in an application is too large, the main circuit voltage in the inverter may increase, which results in damage to the inverter.
Normally, the inverter has a built-in overvoltage protection function, which detects an overvoltage (0 V) in the main circuit to prevent inverter damage.
However, because it detects a fault to stop the motor, stable and continuous operation will be prevented.
Therefore, you need to use one or more braking resistors/ regenerative braking units to absorb this regenerative energy outside the inverter.

What is Regenerative Energy?

The load connected to a motor has kinetic energy when rotating, and potential energy when it is subject to the gravity.
When the motor decelerates, or when the load descends, the energy is fed back to an inverter.
This phenomenon is known as regeneration, and the energy is called regenerative energy.



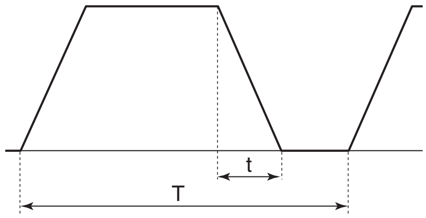
Preventing an overvoltage (0 V) in the main circuit without use of braking resistors

The following are methods to prevent the occurrence of an overvoltage (0 V) in the main circuit without connection of braking resistors.
Since these methods prolong the deceleration time, check that the selected method will not cause application problems.

- Enable the Overvoltage Suppression Function during Deceleration (It is enabled by default.) (It automatically increases the deceleration time to prevent the occurrence of an overvoltage in the main circuit.)
- Set a longer deceleration time (This decreases the amount of regenerative energy per unit time.)
- Select free-run stop (This prevents the regenerative energy from being fed back to the inverter.)

Simplified Braking Resistor Selection

This is a simple method to select an appropriate braking resistor based on the percentage of the time in which regenerative energy is produced in a normal operation pattern. Calculate the usage rate from the following operating pattern.



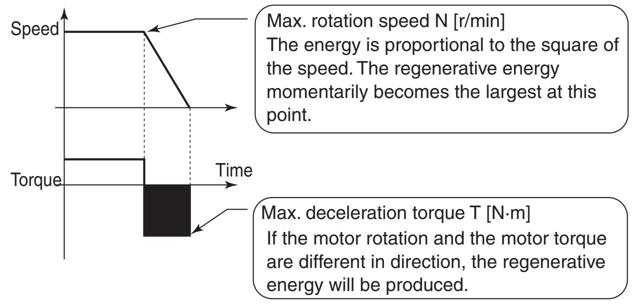
Usage rate = t/T × 100 [% ED]

t : Deceleration time (regeneration time) [s]
T : 1 cycle operation time [s]

Detailed Braking Resistor Selection

When the usage rate of the braking resistor selected on the previous page exceeds 10% ED, or when an extremely large braking torque is required, use the method below to calculate a regenerative energy and make your selection.

Calculation of required braking resistance



$$\text{Resistance of braking resistor: } R \le \frac{V^2}{1.048\times(T-0.2\times Tm)\times N\times 10^{-1}}$$

V : 200-V class inverter 385 [V]
400-V class inverter 760 [V]

T : Maximum braking torque [N·m]

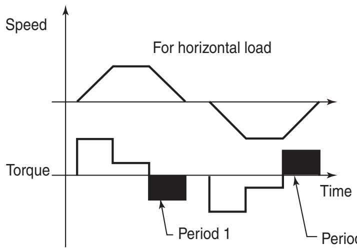
Tm : Motor rating torque [N·m]

N : Maximum rotation speed [r/min]

Note: Calculate a braking torque according to Inverter Capacity Selection in the Motor Capacity Selection section.

Calculation of average regenerative energy

Regenerative energy is produced when the motor rotation and the torque are opposite in direction.
Use the following formula to calculate the regenerative energy for each period in a cycle.



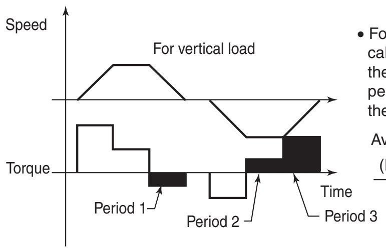
$P_i = N \times T \times t \times 1.048 \times 10^{-1}$

P_i : Regenerative energy in Period i [J]

N : Motor rotation speed [r/min]
When the number of rotations changes, take an average value.
Ex: For linear deceleration:
(N max + N min)/2

T : Deceleration torque [N·m]

t : Deceleration time [s]



- For the average regenerative energy, calculate the time average by adding the regenerative energy for all periods in a cycle and dividing it by the cycle time, as shown below.

$$\text{Average regenerative energy [W]} = \frac{(P1+P2+\cdots+P\,i)\ [J]}{1 \text{ cycle time [s]}}$$

Note: 1. For Speed, the forward rotation direction is indicated as positive. For Torque, the torque in the forward rotation direction is indicated as positive.
2. Calculate a braking torque according to Inverter Capacity Selection in the Motor Capacity Selection section.

Braking Resistor Selection

Select a braking resistor from the required braking resistance and the average regenerative energy described on the left section.

- Required braking resistance ≥ Resistance of braking resistor ≥ Min. connection resistance of inverter or regenerative braking unit
- Average regenerative energy ≤ Resistance capacity of braking resistor

Note: 1. Connecting a braking resistor whose resistance is less than the minimum connection resistance value of the inverter or regenerative braking unit results in damage to the internal braking transistor. If the required braking resistance is less than the minimum connection resistance, change the inverter or regenerative braking unit to one having a larger capacity and ensure that the required braking resistance is not less than the minimum connection resistance.
2. Two or more regenerative braking units can be connected in parallel. Refer to the following formula to know the braking resistance value in such a case:
Braking resistance (Ω) =
(Required braking resistance calculated as above) ×
(No. of units)
3. Make allowance for the resistance capacity of the braking resistor. Select a braking resistor whose capacity is at least 20% larger than the calculated value. Otherwise, it may be overheated.