Electricity and New Energy

Motor Control Using Variable-Frequency Drives

Variable-Frequency Drive Training System

Courseware Sample

52693-F0

Order no.: 52693-10
First Edition
Revision level: 07/2016

By the staff of Festo Didactic

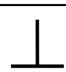
Internet: www.festo-didactic.com
e-mail: did@de.festo.com

Printed in Canada

ISBN 978-2-89747-610-6 (Printed version)
ISBN 978-2-89747-722-6 (CD-ROM)
Legal Deposit – Bibliothèque et Archives nationales du Québec, 2016
Legal Deposit – Library and Archives Canada, 2016

Safety and Common Symbols

The following safety and common symbols may be used in this manual and on the equipment:

Symbol	Description
⚠ DANGER	**DANGER** indicates a hazard with a high level of risk which, if not avoided, will result in death or serious injury.
⚠ WARNING	**WARNING** indicates a hazard with a medium level of risk which, if not avoided, could result in death or serious injury.
⚠ CAUTION	**CAUTION** indicates a hazard with a low level of risk which, if not avoided, could result in minor or moderate injury.
CAUTION	**CAUTION** used without the *Caution, risk of danger* sign ⚠, indicates a hazard with a potentially hazardous situation which, if not avoided, may result in property damage.
	Caution, risk of electric shock
	Caution, hot surface
	Caution, risk of danger
	Caution, lifting hazard
	Caution, hand entanglement hazard
	Notice, non-ionizing radiation
	Direct current
	Alternating current
	Both direct and alternating current
3~	Three-phase alternating current
	Earth (ground) terminal

Safety and Common Symbols

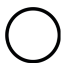
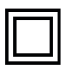
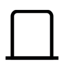
Symbol	Description
	Protective conductor terminal
	Frame or chassis terminal
	Equipotentiality
	On (supply)
	Off (supply)
	Equipment protected throughout by double insulation or reinforced insulation
	In position of a bi-stable push control
	Out position of a bi-stable push control

Table of Contents

Table of Contents

Table of Contents

Table of Contents

Table of Contents

Preface

In the past, only dc motors could be used in industrial applications requiring variable-speed operation. However, dc motors are relatively complex to build, and need frequent maintenance, limiting their use. For example, to control the air flow of a ventilation system, it was simpler and more reliable to use an induction motor rotating at fixed speed with a damper in the duct work than using a variable-speed dc motor. Ideally, a motor would have the reliability of an induction motor and the ease of operation at variable speeds of dc motors.

The advent of variable-frequency motor drives solved this problem. They allow precise and easy control of a motor speed. Early drawbacks of variable-frequency drives included poor reliability, as well as low efficiency. Nowadays, however, variable-frequency drives are very reliable and almost never fail. Furthermore, the efficiency of variable-frequency drives is constantly improving, to the point that competing alternatives for motor operation and control are no longer appealing.

Using variable-frequency drives in motor applications provides several important advantages, including: optimized motor starting, energy savings, power factor increase, elimination of control valves and gearboxes, and precise speed and torque control. Variable-frequency drives also feature a variety of functions for motor control, such as acceleration and deceleration ramps, various braking functions, jog functions, and a series of protection functions.

With such a wide variety of advantages and functions, the use of variable-frequency drives in motor applications in the industry will continue to increase in the future.

Figure 1. Various variable-frequency motor drives (© Siemens AG 2016, all rights reserved).

Preface

We invite readers of this manual to send us their tips, feedback, and suggestions for improving the book.

Please send these to did@de.festo.com.

The authors and Festo Didactic look forward to your comments.

About This Manual

Manual objectives

The aim of this manual is to provide students a solid knowledge of variable-frequency drives and their operation. To this end, the manual first introduces the basics of motor drives. It then covers in detail the operation of three-phase induction motors.

After this introduction, the manual covers the principal subject of this course: the fundamentals of variable-frequency drives. It describes the nature and function of their different components, V/f ratio operation, motor parameters required for motor drive operation, and the advantages and disadvantages of variable-frequency drives.

The second half of the manual covers more advanced functions of variable-frequency drives. It describes functions such as acceleration, deceleration, motor braking functions, jogging, and protective functions. The manual covers how variable-frequency drives operate with different load types. It then deals with advanced control functions such as flux vector control and direct torque control. After that, the manual details the different requirements of drive installation, maintenance, and troubleshooting.

The last exercise of the manual is optional and requires the Advanced PLC Training System, Model 3355, to perform the manipulations in the procedure. It covers the use of programmable logic controllers and human-machine interfaces in conjunction with variable-frequency drives. It introduces students to the key concepts of Industry 4.0.

Safety considerations

Safety symbols that may be used in this manual and on the equipment are listed in the Safety Symbols table at the beginning of the manual.

Safety procedures related to the tasks that you will be asked to perform are indicated in each exercise.

Make sure that you are wearing appropriate protective equipment when performing the tasks. You should never perform a task if you have any reason to think that a manipulation could be dangerous for you or your teammates.

Systems of units

Units are expressed using the International System of Units (SI) followed by units expressed in the U.S. customary system of units (between parentheses).

To the Instructor

You will find in this Instructor Guide all the elements included in the Student Manual together with the answers to all questions, results of measurements, graphs, explanations, suggestions, and, in some cases, instructions to help you guide the students through their learning process. All the information that applies to you is placed between markers and appears in red.

Accuracy of measurements

The numerical results of the hands-on exercises may differ from one student to another. For this reason, the results and answers given in this manual should be considered as a guide. Students who correctly performed the exercises should expect to demonstrate the principles involved and make observations and measurements similar to those given as answers.

Sample Exercise

Extracted from

Student Manual

Exercise 4

VFD Control Circuits and Functions

EXERCISE OBJECTIVE

When you have completed this exercise, you will be introduced to the basic drive control circuits of variable-frequency drives. You will be familiar with the most common functions implemented by variable-frequency drives, such as acceleration, deceleration, motor braking functions, jogging, and protective functions.

DISCUSSION OUTLINE

The Discussion of this exercise covers the following points:

- Variable-frequency drive control circuits
  Start and stop push-buttons. Forward/reverse switch. Speed potentiometer. Green and red indicator lights.
- Acceleration and deceleration functions
  Acceleration function. Deceleration function. S-curve acceleration and deceleration.
- Motor braking functions
  Coast to stop. Ramp stop. DC injection braking. Dynamic braking. Regenerative braking.
- Jogging function
- Protection functions
  Overload protection. DC bus overvoltage protection. Thermal protection. Motor operation without acceleration and deceleration ramps. Motor operation with acceleration and deceleration ramps. Coast to stop. DC injection braking.

DISCUSSION

Variable-frequency drive control circuits

In the industry, motor control by direct access to variable-frequency drives is generally not possible. Instead, most variable-frequency drives comprise a large selection of inputs that allow the connection of various control components. The control of variable-frequency drives using control components instead of direct drive access presents the following advantages:

- Safety. The control elements connected to the variable-frequency drive commonly operate at a voltage much lower than the motor power. This makes motor control by technicians and operators safer than direct interaction with motor power circuits.
- Ease of use. Control elements have clearly defined functions and operate through a simple mechanism (e.g., switch, push-button, potentiometer). This makes them much easier to operate than direct access to the drive, which requires a knowledge of the multitude of drive parameters and functions.
- Remote operation. Control elements can be located at a remote distance from the variable-frequency drive and motor they control. This can be an important advantage in certain motor applications where conditions near the motor are not optimal for technicians and operators.

- Multiple variable-frequency drives. Control elements allow the simultaneous control of multiple variable-frequency drives and motors.

The following subsections describe the most common control elements used in variable-frequency drive applications.

Start and stop push-buttons

Start and stop push-buttons are very common control elements in motor applications. They control motor starting and stopping. Pressing a start push-button causes the variable-frequency drive to start the motor, while pressing the stop push-button causes the variable-frequency drive to stop the motor.

Forward/reverse switch

A forward-reverse switch controls the direction of rotation of the motor. Before commuting this switch, it is important to know to which direction of rotation (clockwise or counterclockwise) corresponds the forward and reverse directions. Also, it is important never to commute the forward/reverse switch during motor operation. Doing so could severely damage the motor and equipment.

Speed potentiometer

A speed potentiometer controls the rotation speed of the motor. Rotating the knob of the potentiometer progressively increases the motor speed from 0 r/min to the maximum motor speed, and vice-versa. It is recommended to rotate the speed potentiometer slowly to prevent any drastic speed changes.

Green and red indicator lights

Green and red indicator lights are common visual indicators in motor applications. They can be connected in series with most processes and offer a quick visual indication to technicians and operators regarding the state of this particular process. For example, indicator lights are often used with start and stop push-buttons. When the start push-button is pressed, the green indicator light is on and the red is off. When the stop push-button is pressed, the red indicator light is on and the green is off.

Acceleration and deceleration functions

Acceleration and deceleration functions are very common functions in variable-frequency drives. The following subsections describe both functions in detail.

Acceleration function

The acceleration function determines the time required for the output frequency of the drive to increase from 0 Hz to the operating frequency. Consequently, it determines the time required for the motor speed to increase from 0 r/min to the nominal speed in the current loading conditions.

The main purpose of the acceleration function is to prevent the starting current of a motor from increasing above the overload current value. This would trip the overcurrent protection and interfere with or altogether stop the motor start-up. Increasing the motor acceleration time distributes the start-up current over a longer period. This reduces the motor current during the whole start-up process.

The time required to accelerate a motor to a fraction of nominal speed is equal to the same fraction of the acceleration parameter. For example, accelerating a motor to half its nominal speed requires half the length of time of the acceleration parameter.

Deceleration function

The deceleration function determines the time required for the output frequency of the drive to decrease from the operating frequency to 0 Hz. Consequently, it determines the time required for the motor speed to decrease from nominal speed in the current loading conditions to 0 r/min.

The main purpose of the deceleration function is to prevent the voltage across the dc bus of the variable-frequency drive from increasing above the overvoltage value. This is because, when reducing the speed of a motor, the mechanical energy is converted into electrical energy that increases the voltage across the dc bus of the drive. The deceleration function smooths out motor deceleration. It prevents the dc bus overvoltage protection of the variable-frequency drive from tripping. Increasing the motor deceleration time distributes the voltage increase during motor deceleration over a longer period. It thus reduces the dc bus voltage during the whole deceleration process.

The time required to decelerate a motor by a fraction of nominal speed is equal to the same fraction of the deceleration parameter. For example, decelerating a motor by half its nominal speed requires half the time of the deceleration parameter.

S-curve acceleration and deceleration

Most motor drives can implement a variety of acceleration and deceleration profiles. One of the most common profiles is s-curve acceleration and deceleration. Figure 44 shows an s-curve acceleration and deceleration profile in comparison to a basic trapezoidal profile. In an s-curve profile, acceleration and deceleration ramps are smoothed out in comparison to a trapezoidal profile. This prevents sudden and abrupt changes to the motor speed and, thus, decreases the strain on the mechanical components of the motor.

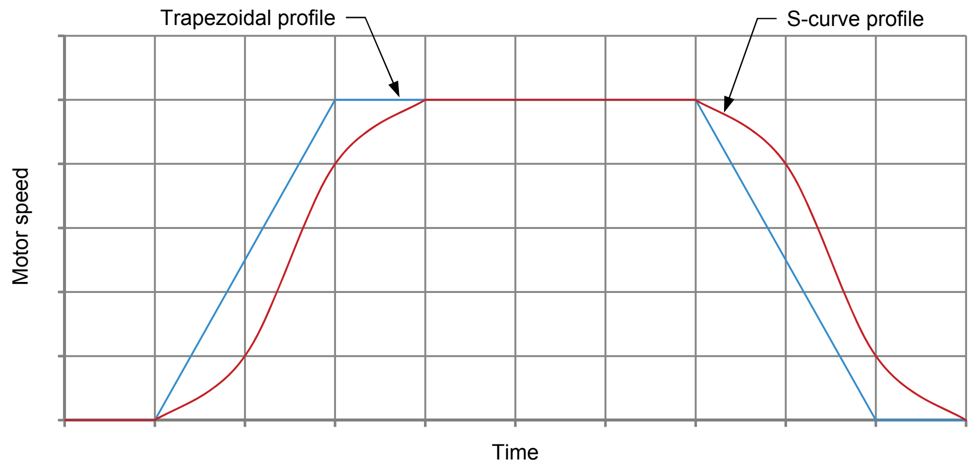


Figure 44. S-curve acceleration and deceleration profile in comparison to a basic trapezoidal profile.

Motor braking functions

An important feature of variable-frequency drives is the ability to implement different types of functions for braking and stopping a motor. The type of braking function to use depends on the application requirements, as well as on the motor type and ratings. The following stopping functions are among the most common:

- Coast to stop
- Ramp stop
- DC stop
- Dynamic braking
- Regenerative braking

The following subsections describe the five braking functions in more detail. The graph in Figure 45 gives typical stopping curves for the five stopping functions. These curves are for comparison purposes only.

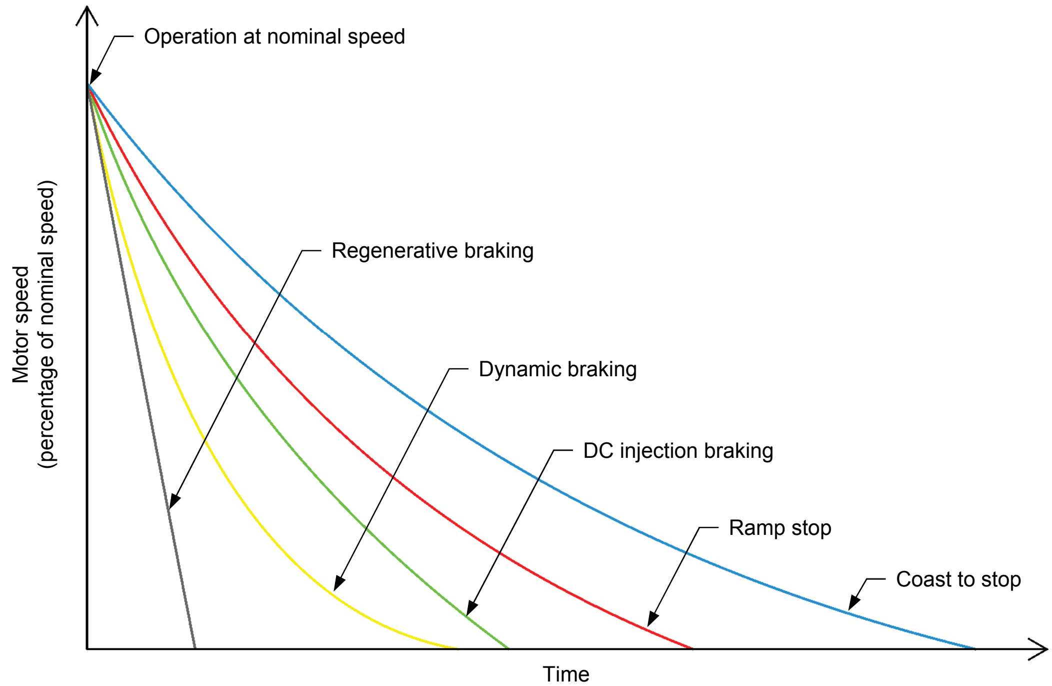


Figure 45. Typical stopping curves for different motor braking functions.

Coast to stop

The coast-to-stop function is the simplest way to stop a motor. It consists of disconnecting the power source from the motor circuit and letting the motor speed decrease to a stop. This is the least taxing way to stop a motor since it does not involve any abrupt change in speed. The length of time required for the motor to stop depends on the combined inertia of the motor and load. The higher the combined inertia of the motor and load, the longer it takes before the motor speed decreases to 0 r/min. Because of this, the coast-to-stop function can be unsuitable in applications with a high motor and load inertia.

Ramp stop

The ramp stop function consists of decreasing the output frequency of the drive from the current frequency to 0 Hz in a predetermined length of time. This causes the motor speed to decrease in a similar manner. In other words, the ramp stop function makes use of the deceleration parameter to stop the motor. As stated previously, this method causes the voltage across the dc bus of the drive to increase. The shorter the deceleration time, the higher the increase. To prevent the overvoltage protection from tripping, it is recommended to test different time lengths for the ramp stop and use one that does not cause the dc bus protection to trip.

DC injection braking

The **dc injection braking** function consists of applying a dc voltage across the motor stator windings (thus “injecting” direct current) for a certain time. This creates a constant, non-rotating magnetic field in the stator windings. The interaction between the stator and rotor magnetic fields produces a torque that opposes rotation, quickly bringing the motor to a stop.

The major inconvenience of dc injection braking is that the rapid motor braking causes the dissipation of energy through heat in the stator windings and rotor core. The higher the inertia of the motor and load, the greater the amount of energy dissipated as heat. Excessive heat for a prolonged length of time can cause serious and permanent damage to the motor. Because of this, applications with a high motor and load inertia where heat dissipation is insufficient cannot use dc injection braking.

Dynamic braking

The **dynamic braking** function is like dc injection braking, with the addition of a resistive component to the dc bus, as shown in Figure 46. In this example, a power electronics device called a chopper controls the connection of the resistive component to the dc bus.

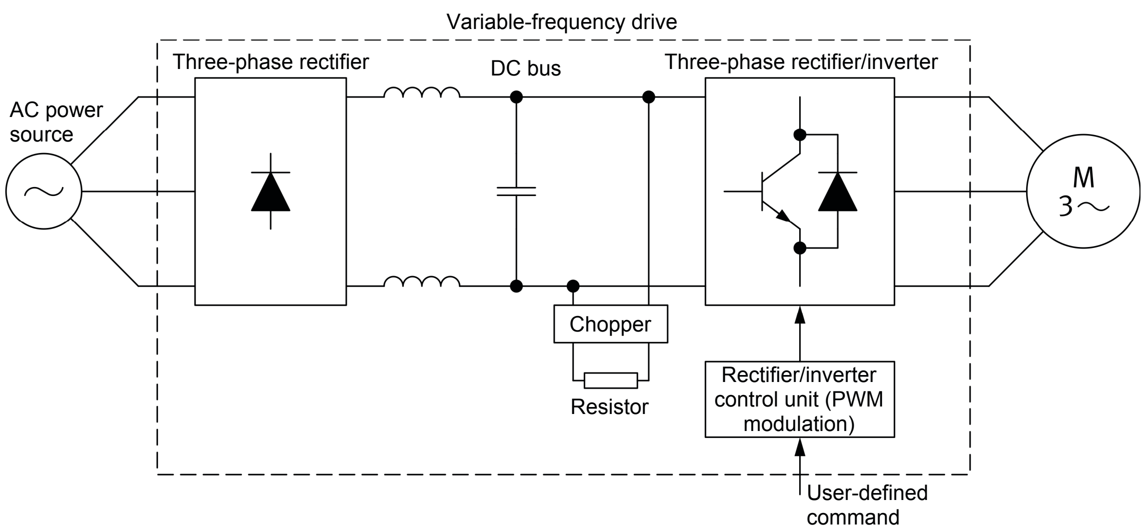


Figure 46. Simplified diagram of a variable-frequency drive designed for dynamic braking.

When motor speed is higher than the speed command of the drive (i.e., during motor braking), the voltage across the dc bus increases. When the voltage becomes too high, the variable-frequency drive makes current flow in the resistive component (generally through a power electronics device such as a chopper). The resistive component then dissipates the electrical energy as heat. In other words, dynamic braking converts kinetic energy from the motor into thermal energy dissipated using the resistive component, thereby braking the motor.

For dynamic braking to be effective, the temperature of the resistive component must be kept as low as possible. However, as soon as current begins to flow in the resistive component, it begins to heat up, reducing its effectiveness. To prevent this, the heat dissipation system of the resistive component must be efficient. Furthermore, the drive must maintain the braking time at a low percentage of the total operation time (10% maximum).

Regenerative braking

Certain rotating machines, such as induction machines, can operate both as a motor, i.e., convert electrical energy into mechanical energy to produce work, and as a generator, i.e., convert mechanical energy into electrical energy distributed to the power network.

The **regenerative braking** function uses the kinetic energy accumulated by a motor to make it operate as a generator. The drive then returns the electrical energy to the ac power source. Typical variable-frequency drives cannot perform regenerative braking. This is because, in the rectifier of the drive, current can only flow in a single direction: from the ac power source to the dc bus. Thus, to implement regenerative braking, it is necessary to replace the rectifier of the drive by a second IGBT bridge (just like the one used for the three-phase inverter) that can convert ac power to dc power, and vice-versa. Figure 47 shows this.

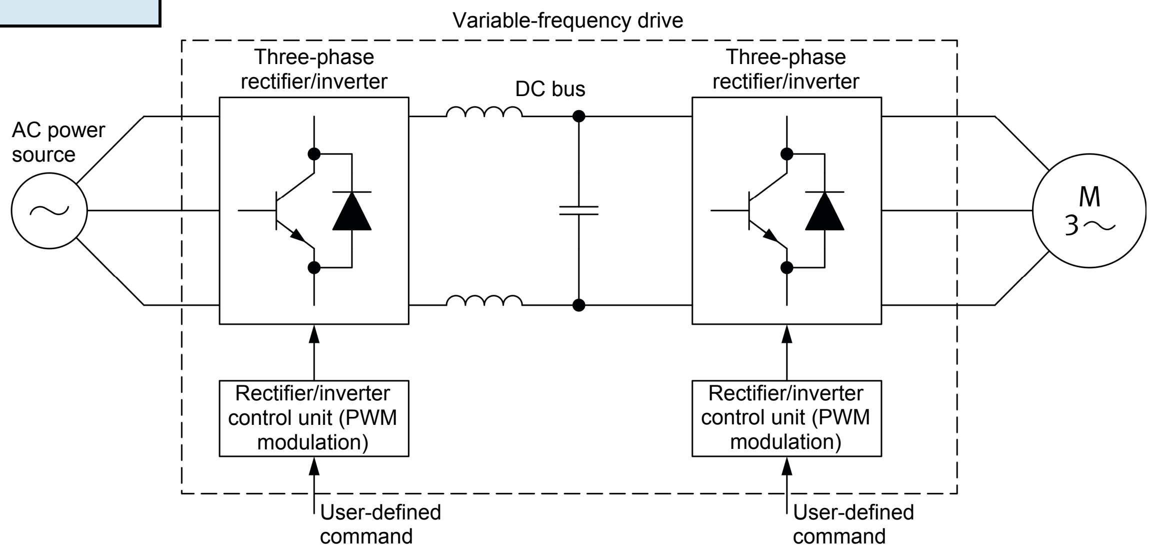


Figure 47. Simplified diagram of a variable-frequency drive designed for regenerative braking.

As the figure shows, both IGBT bridges can operate as rectifiers and inverters. This allows the flow of electrical current in both directions. Such a drive is a four-quadrant drive, since it can operate in both directions, and also implement regenerative braking in both directions.

During acceleration and constant-speed operation, the first three-phase rectifier/inverter operates as a rectifier, while the second one operates as an inverter, just like in a standard variable-frequency drive. However, when the motor speed becomes higher than the speed command (such as during braking), the direction of current flow is reversed and the voltage increases across the dc bridge. When this happens, the first three-phase rectifier/inverter switches to inverter operation and converts the dc power from the dc bus into ac power returned to the ac power network.

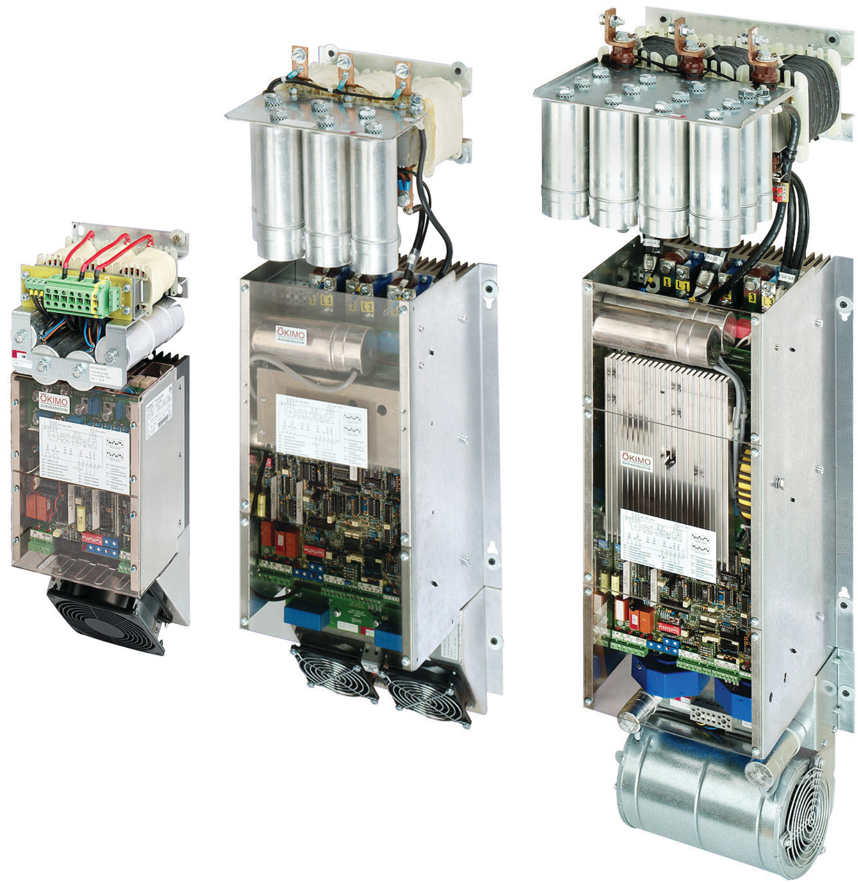


Figure 48. Series of variable-frequency drives with regenerative braking capability. Note the capacitors and inductors attached above the drives that serve to filter the ac power fed back to the ac power network (photo courtesy of Dr. Frank Oswald Hak).

Regenerative braking is the most efficient way to brake a motor. It enables part of the kinetic energy accumulated in the motor to be returned to the ac power network during braking. This allows significant energy savings. Regenerative braking is particularly efficient in applications where the motor often stops, such as in public transportation busses and trains.

Figure 49. Certain London Underground public transportation trains are equipped with a regenerative braking system, allowing up to 20% of their input energy to be returned to the ac power network.

Jogging function

In variable-frequency drives, jogging functions usually consist of a single push-button that, when pressed, causes the drive to power up the motor. This generates a torque just high enough to overcome static friction and make the motor rotate. Rotation continues as long as the user presses the push-button (continuous jog), or until the motor has rotated by a certain angle or for a certain length of time (incremental jog). All parameters of the jog function (e.g., mode, speed, direction, increment angle, increment time, etc.) can be set in advance in the variable-frequency drive.

The jogging function is used for motor positioning or alignment in applications where accelerating the motor up to nominal speed prohibits precise position control, as well as for maintenance (for example, to reach an access hatch in a large ball mill).

Protection functions

Another important feature of variable-frequency drives is the ability to implement different protection functions. Most variable-frequency drives enable the following protection functions:

- Overload protection
- DC bus overvoltage protection
- Thermal protection

The following subsections describe each of these protection functions in detail.

Overload protection

The overload protection function prevents the current flowing in the motor stator from reaching too high a value (i.e., the overload current value). In most variable-frequency drives, this value is generally one of the motor parameters that must be entered in the drive.

When controlling motor speed, the variable-frequency drive also monitors the motor current. If the motor current increases above the overload current value for a certain length of time, the variable-frequency drive trips and implements the selected stopping function. This stops current flow in the motor stator windings and prevents any damage to the equipment.

As stated before, the current flowing in the stator windings of an induction motor increases greatly during start-up. Because of this, overload protection is particularly important to prevent high inrush currents from damaging the motor. If the overload protection constantly trips during start-up, an effective solution is to increase the acceleration time of the drive to reduce the high inrush currents.

DC bus overvoltage protection

The dc bus overvoltage protection function prevents the voltage across the dc bus from reaching too high a value. When available in a variable-frequency drive, the dc bus overvoltage value is one of the motor parameters that must be entered in the drive.

When controlling a motor speed, the variable-frequency drive simultaneously monitors the voltage across the dc bus. If the dc bus voltage increases above the dc bus overvoltage value for a certain length of time, the variable-frequency drive trips and implements dynamic braking or regenerative braking. These stopping methods help progressively decrease the dc bus voltage.

As stated before, the voltage across the dc bus increases during motor braking. Because of this, overvoltage protection is particularly important when braking a motor to prevent high voltages from building across the dc bus. If the overvoltage protection constantly trips during motor braking, an effective solution is to increase the deceleration time entered in the drive to reduce the voltage buildups.

Thermal protection

The thermal protection function prevents the temperature of the variable-frequency drive from reaching too high a value. This is important to prevent drive temperature from increasing above a certain limit during extended operation. Excessive temperatures in the drive could damage the drive, as well as the motor if the drive ceases to operate properly.

It is also possible to add thermal protection in order to prevent the temperature inside the motor from reaching too high a value. This is usually achieved by connecting the thermal-protection device on the motor (a thermistor, for example) to an input of the drive. In this case, when controlling motor speed, the variable-frequency drive simultaneously monitors the motor temperature through the dedicated input. If it increases above the maximum temperature value, the variable-frequency drive trips and implements the selected stopping function. This stops the motor and allows it to cool down.

High motor temperatures are mainly caused by high stator currents for extended periods of time. Thus, to make sure thermal protection does not trip, it is necessary to maintain stator currents that are close to the motor nominal current. If the thermal protection constantly trips, it may be indicative that the motor controlled by the drive is not suited to the application, or that heat dissipation is insufficient for the motor needs.

PROCEDURE OUTLINE

The Procedure is divided into the following sections:

- Set up
- VFD control circuit with forward and reverse start/stop switches (two-wire control)
- Acceleration and deceleration ramps (three-wire control)
- Motor braking functions
- Jog function

PROCEDURE

Set up

In this section, you will set up the Variable-Frequency Drive Training System.

1. Install the Variable-Frequency Drive Training System on a stable surface. Open the suitcase.

2. Make sure the main power switch and the main circuit-breaker on the training system are set to the O (off) position.

3. Make sure all fault switches are set to the O (off) position. This indicates that no fault is inserted in the operation of the Variable-Frequency Drive Training System.

4. Connect the equipment as shown in Figure 50. As the figure shows, two switches add control elements to the drive:

   - Forward start/stop selector switch
   - Reverse start/stop selector switch

   The use of both forward and reverse start-stop push-buttons indicates a two-wire motor control circuit. This setup is the equivalent of a single start-stop push-button combined with a forward/reverse selector switch.

   In addition, two indicator lights are connected to the opto outputs for status indication:

   - Green indicator light for motor running indication
   - Red indicator light for at frequency set point indication

   Make sure that both selector switches are set to the 0 (stop) position.

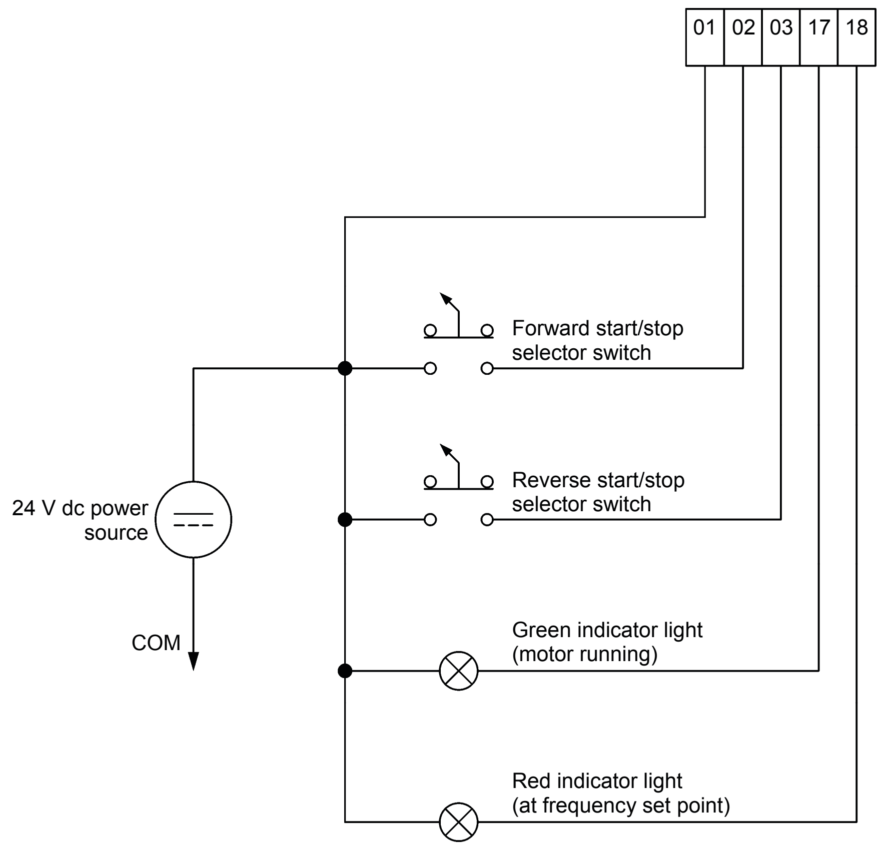


Figure 50. VFD control circuit with start/stop and forward/reverse switches.

5. Connect the Power Input of the training system to an ac power outlet.

6. On the training system, perform the following manipulations:
   - Set the main power switch to the **I** (on) position.
   - Set the main circuit breaker to the **I** (on) position.
   - Wait a few seconds, then press and hold slightly the safety reset button.
   - On the variable-frequency drive, press the red stop key to clear the fault.

7. On the variable-frequency drive, set parameter P053 (Reset To Defaults) to 1. This resets the variable-frequency drive to its default parameters, except for custom groups, language, and communication parameters.

   On the variable-frequency drive, press the red stop key to clear the fault.

8. Turn the host computer on, then start the CCW software.

If the CCW software is not installed on the computer, install it by performing the steps in the CCW installation section of Appendix B.

9. Using an EtherNet cable, connect the EtherNet/IP coupler on the training system to an EtherNet port on the computer.

10. Perform the following manipulations:

- On the computer, configure the IP address and subnet mask of the EtherNet connection by performing the steps of the IP address and subnet mask configuration subsection of Appendix B.
- Setup the CCW software by performing the steps of the CCW setup subsection of Appendix B.
- Connect the computer to the variable-frequency drive by performing the steps of the Connection to the VFD subsection of Appendix B.
- Configure the variable-frequency drive for operation with the induction motor by performing the steps of the Startup wizard subsection of Appendix B.

VFD control circuit with forward and reverse start/stop switches (two-wire control)

In this section, you will operate the variable-frequency drive using both forward and reverse start/stop switches (two-wire control), as well as status indicator lights. You will first operate the drive using the forward start/stop switch and observe motor operation and the status of the indicator lights. You will then repeat the process using the reverse start/stop switch.

11. On the variable-frequency drive (or in the CCW software):

- Set parameter P046 (Start Source 1) to 2 (DigIn TrmBlk). This sets the primary start source of the drive to the digital inputs and enables the start/stop selector switches to start or stop drive operation.
- Set parameter t069 (Opto Out1 Sel) to 2 (MotorRunning). This causes opto output 1 to send a signal when the motor is running, which is then indicated by the green indicator light.
- Set parameter t072 (Opto Out2 Sel) to 1 (At Frequency). This causes opto output 2 to send a signal when the output frequency of the drive is at the set point, which is then indicated by the red indicator light.

12. On the variable-frequency drive, turn the potentiometer fully clockwise. Then, press the Start button to start variable-frequency drive operation.

What happens as you do so? Briefly explain why.

The motor does not start and its speed does not increase. This is because both start/stop switches are at the stop position, preventing the operation of the drive.

13. On the training system, set the forward start/stop switch to the start position.

What happens as you do so? What does this indicate?

When the forward start/stop switch is set to the forward direction, the motor starts rotating in the forward direction. Simultaneously, the green indicator light lights up, indicating that the motor is running.

14. Wait for the motor to reach its maximum speed. What happens as it does? What does this indicate?

When the motor reaches its maximum speed, the red indicator light lights up. This indicates that the output frequency of the variable-frequency drive is equal to its set point value.

15. On the variable-frequency drive, turn the potentiometer about half way counterclockwise.

What happens as you do so? What does this indicate?

When the drive potentiometer is turned half way counterclockwise, motor speed decreases and the red indicator light turns off. This indicates that the output frequency of the variable-frequency drive is no longer equal to its set point value. After a few seconds, the motor speed stabilizes and the red indicator light lights up again.

16. On the training system, set the forward start/stop switch to the 1 (stop) position.

Does the motor stop rotating?

❑ Yes ❑ No

Yes

17. On the training system, set the reverse start/stop switch to the 0 (start) position.

Does the motor start rotating in the reverse direction?

❑ Yes ❑ No

Yes

18. On the training system, set the reverse start/stop switch to the 1 (stop) position.

Does the motor stop rotating?

❑ Yes ❑ No

Yes

19. Based on your observations, can you conclude that the forward and reverse start/stop switches effectively control the operation and direction of rotation of the motor? Briefly explain.

Yes. The forward start/stop switch enables control of motor operation in the forward direction. Conversely, the reverse start/stop switch enables control of motor operation in the reverse direction.

Acceleration and deceleration ramps (three-wire control)

In this section, you will first operate the variable-frequency drive and motor without acceleration and deceleration ramps and observe the time required for the drive to accelerate and decelerate the motor. You will then add acceleration and deceleration ramps to the drive and perform the same observations. You will analyze the results.

20. Connect the control circuit shown in Figure 51. As the figure shows, the control circuit of the variable-frequency drive contains the following elements:

- Stop push-button
- Start push-button
- Forward/reverse selector switch
- Jog push-button
- Output frequency potentiometer

The use of a start push-button, a stop push-button, and a forward/reverse selector switch indicates a three-wire motor control circuit.

Make sure to set the forward/reverse switch to the forward position and rotate the output frequency potentiometer to its minimum value.

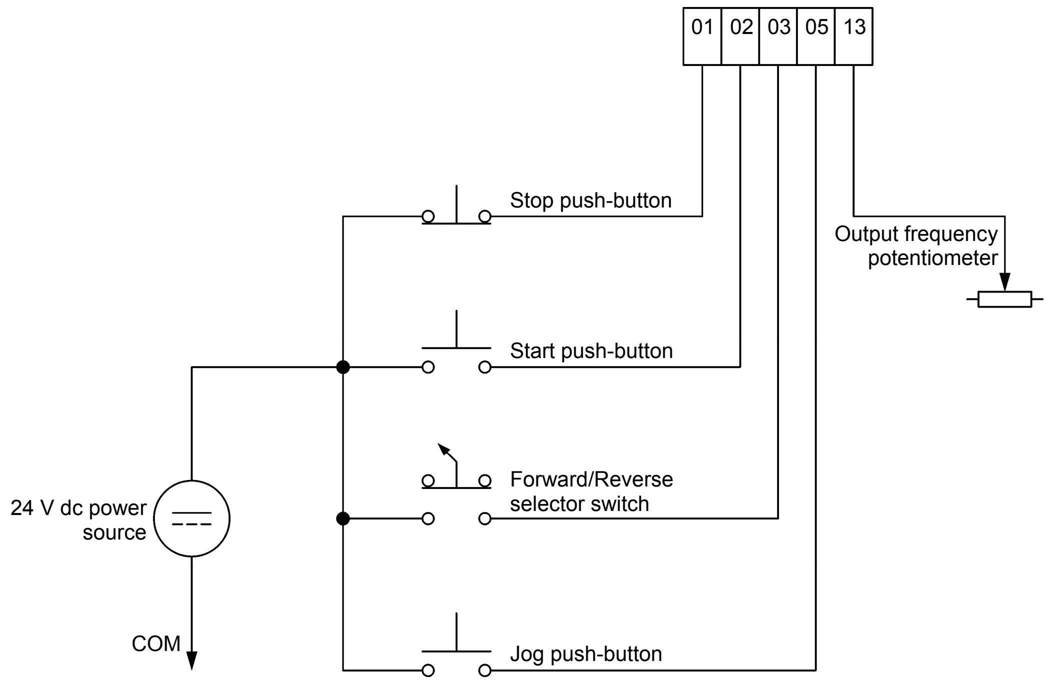


Figure 51. VFD control circuit containing start and stop push-buttons, a jog push-button, a forward/reverse switch, and an output frequency potentiometer.

21. On the variable-frequency drive (or in the CCW software):

- Set parameter t062 (DigIn TermBlk 02) to 49 (3-Wire Start). This causes digital input 02 to start/stop motor operation using a three-wire circuit, enabling control using the start and stop push-buttons.
- Set parameter t063 (DigIn TermBlk 03) to 51 (3-Wire Dir). This causes digital input 03 to determine the direction of rotation of the motor.
- Set parameter P047 (Speed Reference1) to 5 (0-10V Input). This causes the output frequency of the drive to be controlled using the 0-10 V potentiometer of the training system.

Motor operation without acceleration and deceleration ramps

22. On the variable-frequency drive (or in the CCW software):

- Set parameter P041 (Accel Time 1) to 0. This sets the acceleration ramp of the motor to 0 s.
- Set parameter P042 (Decel Time 1) to 0. This sets the deceleration ramp of the motor to 0 s.

23. On the training system, turn the 0-10 V potentiometer fully clockwise. Then, press the start push-button. What happens as you do so?

The motor speed instantly increases to its maximum value.

24. If the variable-frequency drive were driving an actual motor with a high-inertia load, what would happen if the motor were started with the current acceleration ramp? Briefly explain.

If used to start an actual motor with a high-inertia load, an acceleration ramp of 0 s would cause the output current of the drive to greatly increase. This could trip the overcurrent protection of the drive and damage the equipment.

25. On the training system, press the stop push-button. What happens as you do so?

The motor speed instantly decreases to 0 r/min.

26. If the variable-frequency drive were driving an actual motor with a high-inertia load, what would happen if the motor were stopped while operating at nominal speed with the current deceleration ramp? Briefly explain.

If used to stop an actual motor with a high-inertia load operating at nominal speed, a deceleration ramp of 0 s would cause the dc bus voltage of the drive to greatly increase. This could trip the dc bus overvoltage protection of the drive and damage the equipment.

27. Are the observations you just made expected, considering the current acceleration and deceleration ramps of the variable-frequency drive? Briefly explain.

Yes, these observations are expected. Both the acceleration and deceleration ramps are set to 0 s. Therefore, changes in the output frequency of the drive are not gradual but instantaneous.

Motor operation with acceleration and deceleration ramps

28. On the variable-frequency drive (or in the CCW software):

- Set parameter P041 (Accel Time 1) to 20.
- Set parameter P042 (Decel Time 1) to 20.

29. On the training system, press the start push-button. What happens as you do so?

The motor speed increases very slowly to its maximum value.

30. On the training system, press the stop push-button. What happens as you do so?

The motor speed decreases very slowly to 0 r/min.

31. In what type of motor applications would the current acceleration and deceleration ramps be advantageous? Briefly explain.

The current acceleration and deceleration ramps would be advantageous in a motor application with a high-inertia load. This is because the lengthy ramps would divide the increase in output current during acceleration, as well as the increase in dc bus voltage during deceleration, over a longer period of time. This would reduce both the maximum value of the output current and of the dc bus voltage during acceleration and deceleration, respectively.

Motor braking functions

In this section, you will operate the variable-frequency drive and motor at nominal speed and stop the motor using the following braking functions: coast-to-stop and dc injection braking. Using your observations, you will then compare all motor braking functions you used in this exercise.

Coast to stop

32. On the variable-frequency drive (or in the CCW software):

- Set parameter P045 (Stop Mode) to 1 (Coast, CF). This sets the stop mode of the motor to coast to stop.
- Set parameter P041 (Accel Time 1) to 5.

33. On the training system, press the start push-button. Wait for the motor to reach its nominal speed,

While observing the output frequency of the drive (parameter b001), press the stop push-button. What happens as you do so?

As the stop push-button is pressed, the output frequency of the drive instantly decreases to 0 Hz (drive operation stops). However, the motor does not stop immediately and its speed naturally coasts to a stop.

DC injection braking

34. On the variable-frequency drive (or in the CCW software):

- Set parameter P045 (Stop Mode) to 2 (DC Brake, CF). This sets the stop mode of the motor to dc braking.
- Set parameter A434 (DC Brake Time) to 0.3. This sets the dc braking time to 0.3 s (almost instantaneous).
- Set parameter A435 (DC Brake Level) to 2. This sets the amplitude of the direct current injected in the motor stator windings to 2 A, which is enough to stop the induction motor.

35. On the training system, press the start push-button. Wait for the motor to reach its nominal speed.

While observing the output frequency of the drive (parameter b001), press the stop push-button. What happens as you do so?

As the stop push-button is pressed, the output frequency of the drive instantly decreases to 0 Hz (drive operation stops). Very shortly after, dc braking is applied and the motor stops almost instantaneously.

Briefly describe what happens during motor braking in dc injection braking mode.

When braking in dc injection braking mode, the drive applies a dc voltage across the motor stator windings, creating a non-rotating magnetic field in the stator windings. The interaction between the stator and rotor magnetic fields produces a torque that opposes rotation, quickly bringing the motor to a stop.

36. Compare the three braking methods you have used thus far (coast to stop and dc injection braking in this section, 20 s ramp stop in the previous section).

Rate the three different methods by braking time.

The braking methods by order of braking time are, from fastest to slowest: dc injection braking, coast to stop, 20 s ramp stop.

Jog function

In this section, you will operate the variable-frequency drive in jog mode. While in this mode, you will vary the direction of rotation as well as the jog frequency, and perform a positioning exercise.

37. To perform this section, the timing belt coupled to the induction motor must be marked. If it is already done, proceed to the next step. Otherwise, perform the following manipulations:

- Perform the Lockout procedure subsection described in Exercise 1.
- Using the provided screwdriver, unscrew the safety panel of the motor enclosure. Open the safety panel.
- On the side of the timing belt, make a small mark using a suitable black marker.
- Close the safety panel, then screw it back in place using the provided screwdriver.
- Perform the Lockout removal procedure subsection described in Exercise 1.

38. On the variable-frequency drive (or in the CCW software):

- Set parameter t065 (DigIn TermBlk 05) to 8 (Jog). This causes digital input 05 to operate the motor in jog mode. The direction of rotation of the motor is the same as in standard operation.
- Set parameter A431 (Jog Frequency) to 1. This sets the output frequency of the drive during jog operation to 1 Hz.
- Set parameter A432 (Jog Accel/Decel) to 0.1. This sets the acceleration and deceleration time during jog operation to 0.1 s.

39. On the training system, push the jog push-button for a few seconds, then release it.

What happens as you do so?

While the jog button is pushed, the motor rotates at a low speed. When the jog button is released, the motor stops rotating.

40. On the training system, change the position of the forward/reverse selector switch.

Push the jog push-button for a few seconds, then release it.

Does the forward/reverse selector switch continue to determine the direction of rotation of the motor in jog mode?

❑ Yes ❑ No

Yes

41. By pushing the jog push-button, align successively the mark you made on the timing belt with the 0, 5, 10, and 15 cm (0, 1.5, 3, 4.5, and 6 in) positions of the ruler on the motor safety panel.

Adjust the direction of rotation of the motor to obtain the above positions on the ruler in the correct sequence.

Does the jog mode allow precise positioning of the motor rotor?

❑ Yes ❑ No

Yes

42. On the variable-frequency drive (or in the CCW software):

- Set parameter A431 (Jog Frequency) to 20.

43. On the training system, push the jog push-button for a few seconds, then release it.

What is the effect of increasing jog frequency on jog operation?

Increasing jog frequency increases the speed at which the motor rotates during jog operation.

44. On the training system, set the main circuit breaker and main power switch to the O (off) position.

45. Disconnect all leads from the training system and return all the equipment you used in this exercise to its storage location.

Conclusion

In this exercise, you were introduced to the basic drive control circuits of variable-frequency drives. You became familiar with the most common functions implemented by variable-frequency drives, such as acceleration, deceleration, motor braking functions, jogging, and protective functions.

Review Questions

1. What is the main use of the acceleration function in a variable-frequency drive? Briefly explain.

The main purpose of the acceleration function is to prevent the starting current of a motor from increasing above the overload current value and tripping the overcurrent protection, which could negatively interfere with or altogether stop the motor start-up. Increasing the motor acceleration time distributes the current required to start the motor over a longer time period, reducing the motor current during the whole start-up process.

2. What is the main use of the deceleration function in a variable-frequency drive? Briefly explain.

The main purpose of the deceleration function is to prevent the voltage across the dc bus of the variable-frequency drive from increasing above the overvoltage value during deceleration. The deceleration function smooths out the motor deceleration and prevents the dc bus overvoltage protection of the variable-frequency drive from tripping.

3. What is the main difference between dc injection braking and dynamic braking? Briefly explain.

Dynamic braking requires the addition of a resistive component to the dc bus. During motor braking, the resistive component dissipates electrical energy as heat. This prevents the dc bus voltage from reaching excessive values, a common drawback of dc injection braking.

4. What is regenerative braking and what is the main advantage of this braking method?

Regenerative braking consists of using the kinetic energy accumulated by a motor to make it operate as a generator and return electrical energy to the ac power source. Its main advantage is efficiency, since it enables part of the kinetic energy accumulated in the motor to be returned to the ac power network during braking, allowing significant energy savings.

5. What is the purpose of an overload protection function in a variable-frequency drive?

In a variable-frequency drive, the overload protection function prevents the current flowing in the motor stator from reaching a too high value (i.e., the overload current value).

Bibliography

Hughes, Austin and Drury, Bill, *Electric Motors and Drives*, 4th ed., Burlington: Newnes, 2013, ISBN 978-0080983325.

Polka, David, *Motors & Drives*, 1st ed., Research Triangle Park: Instrumentation, Systems, and Automation Society, 2003, ISBN 978-1556178009.

Valentine, Richard, *Motor Control Electronics Handbook*, 1st ed., New York: McGraw-Hill, 1998, ISBN 978-0070668102.