

Drive

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SYSTEM COMPONENTS

Systems

Concepts

Terminology

GE Industrial Control Systems

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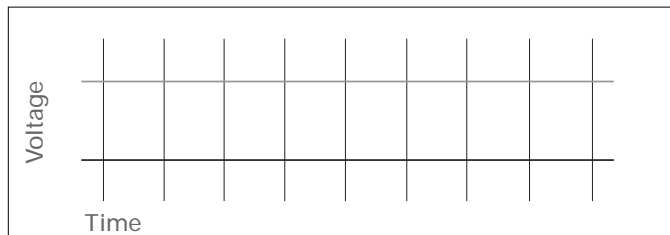


GE Industrial Systems

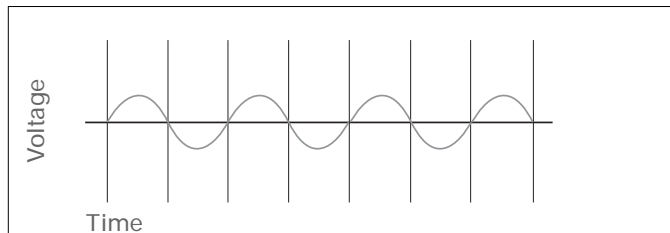
BASIC ELECTRICITY

Electricity is a flow of electrons. The actual flow (and strength of flow) is referred to as **current**. Current is measured in units of amperes (amps). **Voltage** is the force that pushes or pulls electrons, causing them to flow. Voltage is measured in units of volts. There are two types of electricity: **DC (direct current)** and **AC (alternating current)**. In DC systems, electrons flow continually in one direction. In AC systems, electrons alternate in direction as the voltage force alternates between pushing and pulling on electrons. In DC systems, plotting voltage versus time yields a straight line, while a plot of voltage in AC systems yields a sine wave. **Frequency** refers to how often AC changes direction, and is measured in units of hertz (or cycles/second). AC power also comes in multiple phases. The number of **phases** refers to how many currents (or voltage forces) are transmitted at one time. A three phase power supply has three separate voltage forces, each one acting on a different current. However, the phases alternate so that each has a different level of voltage at any one time.

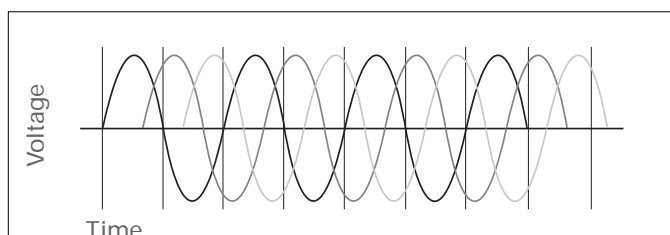
DC Power



AC Single Phase Power



AC Three Phase Power



Local power companies only supply AC power.

Typically the power supplied is not constant.

Voltage and frequency may fluctuate due to resistance, load, and environmental concerns.

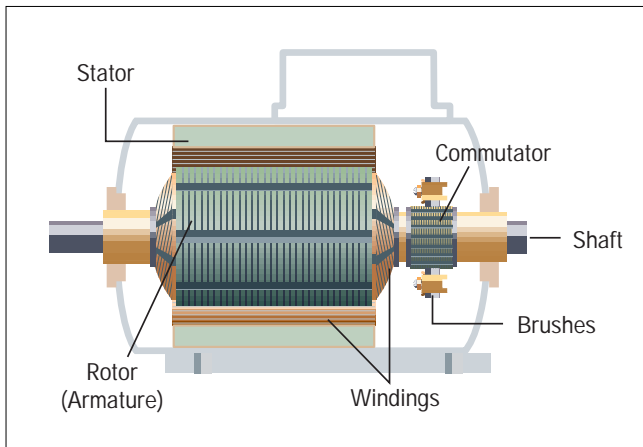
Resistance is the “frictional” force in wires opposing the flow of current. **Load** refers to any machines that are operating on power. The more machines, the higher the load. The more load, the more power the power companies need to supply. When load increases drastically, the power across the power line will temporarily drop until the power system can respond.

In DC systems, electrons flow continually in one direction.

In AC systems, electrons alternate in direction as the voltage force alternates between pushing and pulling on electrons.

MOTOR REVIEW

There are two main types of motors: DC and AC. DC motors operate on DC power, while AC motors operate on AC power.



All motors have two basic components—a stationary part, called the **stator**, and a rotational part, called the **rotor**. In DC motors, the rotor is more commonly referred to as the **armature**. The rotor/armature sits inside of

the stator. Electricity (current) flowing through the motor creates a magnetic field, which attracts (or repels) the rotor, causing it to spin. The **shaft** is the part of the rotor that extends outside of the motor and connects to the equipment to be rotated.

DC Motors

DC motors are based on a stationary magnetic field. The stator of a DC motor consists of windings that are made of coiled wire to form a magnetic pole: When current flows through the windings, they produce a magnetic field. The poles are connected to the inside of the frame (or shell) of the motor.

The armature also has windings that create a magnetic field when voltage is applied (in most DC motors, the armature and stator receive electricity from separate sources). There are a series of windings running lengthwise down the armature. Voltage is applied to one set of windings in the armature at a time. When this occurs, the windings become magnetic and are attracted to

the magnetic field in the stator. The armature spins to align itself with the stator. When the rotor moves, another set of windings in the armature becomes connected to the power supply. The windings become magnetic and attracted to the stator field, and the rotor moves again to align itself with the stator. This process keeps the rotor spinning within the stationary magnetic field in the stator.

AC Motors

AC motors utilize a rotating magnetic field within the stator. The stator of an AC motor is also made up of windings. There is a set of windings for each phase of AC power, distributed around the stator. A set of three windings (one from each phase) forms the magnetic pole. When AC voltage is applied, one set of windings is activated by one phase and creates a magnetic field. The next set of windings becomes magnetic when the next phase of power is fully active. The rotor of an AC motor is made out of metallic bars. The bars feel the pull of the magnetic field in the active windings, spinning the rotor as they align. When the next set of windings is excited by the next phase, the rotor spins

DC motors are based on a stationary magnetic field.

AC motors utilize a rotating magnetic field within the stator.

again. AC electricity creates a rotating magnetic field in the stator, to which the rotor continually tries to align itself. The speed at which the AC motor rotor rotates depends on how many poles are in the stator and the frequency of applied power. The more poles there are, the slower the rotor will spin. The higher the frequency of power, the faster the motor will spin.

Torque and Horsepower

The motor **torque** refers to how much force the motor shaft exerts as it rotates. Torque is dependent on the strength of the magnetic fields in the motor—a stronger magnetic field will exert a stronger pull on the rotor, creating more torque. The force of the magnetic field, and thus torque, is determined by the amount of voltage and frequency supplied to the motor. The **horsepower** of a motor refers to how much work the motor can do, or how much torque it can deliver over time. The relationship between torque and horsepower is:

$$\text{HORSEPOWER (HP)} = \frac{\text{TORQUE (FT-LB)} \times \text{SPEED (RPM)}}{5252}$$

KEY POINTS

The speed at which the AC motor rotor rotates depends on how many poles are in the stator and the frequency of applied power.

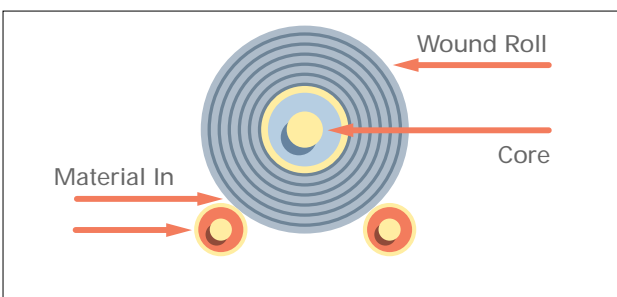
Torque is dependent on the strength of the magnetic fields in the motor—a stronger magnetic field will exert a stronger pull on the rotor, creating more torque.

LOADS

Motors are used to rotate other mechanical machines. The equipment being driven by the motor is called a load. The load dictates what type of motor is needed and how the motor needs to be controlled. Some load characteristics that need to be considered are speed, torque, weight, tension, and inertia. Whether or not these characteristics are constant or vary over time also needs to be considered. In a simple load, only one of these characteristics affects the load at one time. In a complex load, multiple characteristics may change over time. Load characteristics also determine whether or not the load can be classified as constant horsepower, constant torque, or variable torque.

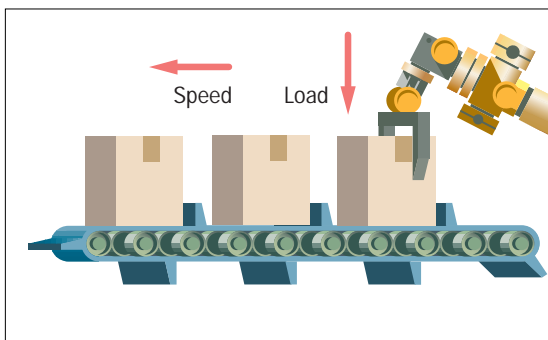
Constant horsepower loads are those in applications where the amount of work to be done is independent of speed and torque. Loads that require constant tension require constant horsepower. An example of a constant horsepower application is a winder. A winder is a roller onto which processed material, such as paper, is wound. As the process of making paper continues, more and more paper is wound around the winder. The diameter of the roll increases, as does the weight of the load. As the diameter of the roll increases, the speed of the winder must slow down to maintain constant tension (otherwise the paper would tear or sag). However, the amount of work that needs to be done doesn't change.

Other applications involving constant horsepower loads are: Drills, grinders, lathes, milling machines, wire drawing machines, and cutting machines.



Motor Driven Surface Winder Roll

Constant torque loads are the most common in industrial applications. The amount of force needed is independent of speed. An example of a constant torque application is a conveyor belt. No matter how fast the conveyor belt is going, or how much is loaded onto it, the conveyor must exhibit the same force so that the conveyor runs smoothly without throwing off the load.



Other applications with a constant torque load include: Coaters, cranes, elevators, forming mills, galvanizing lines, planers, and textile spinners.

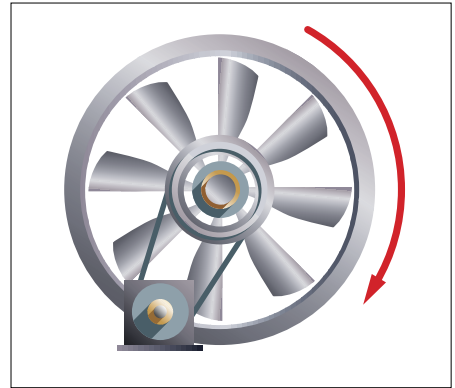
Typically, drives that are built to handle constant torque loads are capable of handling up to 150% of rated current for 60 seconds. **Rated current** is the amount of current flowing through the drive/motor when under full load.

The load dictates what type of motor is needed and how the motor needs to be controlled.

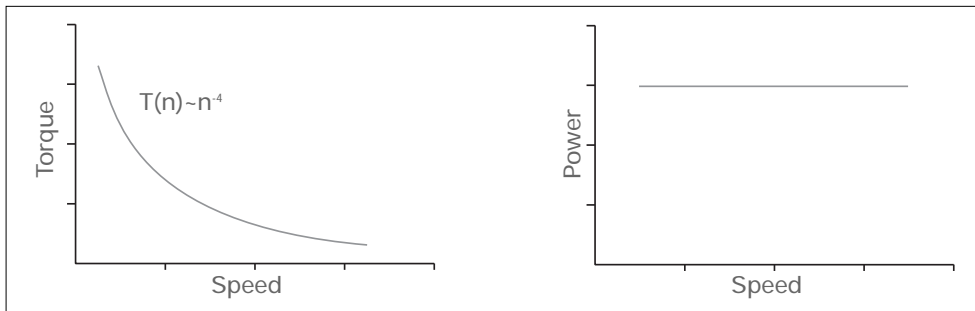
Some load characteristics that need to be considered are speed, torque, weight, tension, and inertia. Whether or not these characteristics are constant or vary over time also needs to be considered.

LOADS

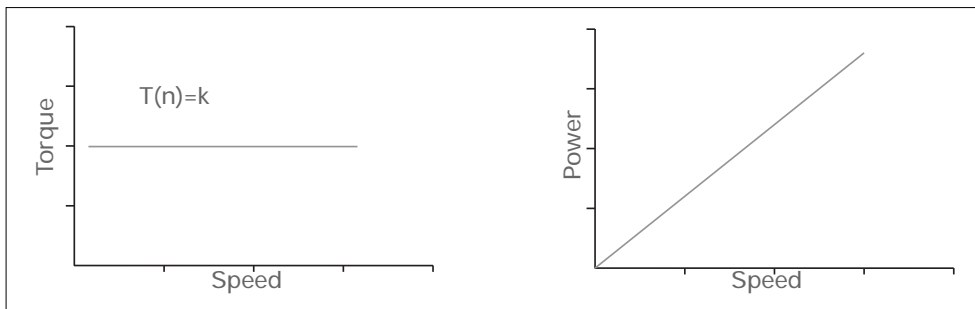
Variable torque loads exhibit both an increase in torque and horsepower as speed increases. An example of a variable torque load is a fan. The load includes the fan blades, as well as the centrifugal force felt by the fan. As the fan spins faster, there is more air resistance and centrifugal force to deal with. Pumps are another example of variable torque loads.



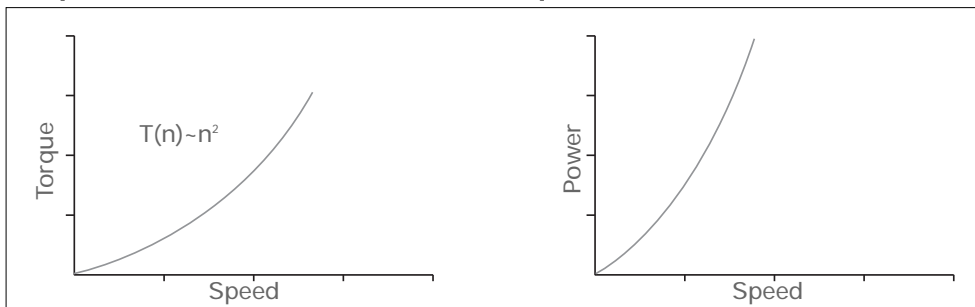
Torque Characteristics of Constant Horsepower Loads



Torque Characteristics of Constant Torque Loads



Torque Characteristics of Variable Torque Loads



Note that the two curves for each type of load reflect the relationship between speed, torque, and horsepower.

Drives built to handle variable torque loads can generally handle 110-120% of rated current for 60 seconds.

If the nature of the load is not obvious, it must be determined by a **field test**. The nature of the load dictates what type of motor is needed and how it needs to be controlled.

The nature of the load dictates what type of motor is needed and how it needs to be controlled.

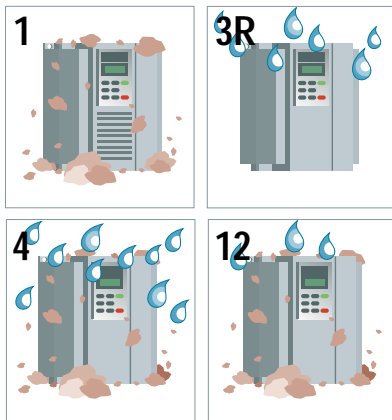
Drives enhance the performance of motors. In the case of DC motors, a drive is one alternative to creating and controlling a supply of DC electricity. In the case of AC motors, drives allow for a more controlled form of AC power to be supplied. In either case, a drive may be used to increase the efficiency of a process, provide accurate motor speed, control motor torque, enable the motor to run at a range of speeds, or to automate and optimize a process. All of these features work to improve the quality of a process run by motors.

The control aspects of the drive are made up of electrical devices, which are protected by an outer covering, or **enclosure**. The degree of protection provided by the enclosure is dictated by the drive's operating environment.

There are several Standards Associations that define different enclosure types that are suitable for different environments. **NEMA (National Electrical Manufacturers Association)** creates standards that are primarily followed in the USA, while the **IEC (International Electro-technical Commission)** writes international standards.

NEMA has defined four enclosure types that are the most widely used on drives. Type 1 is an enclosure offering protection for indoor locations and must provide protection against limited amounts of falling dirt, but does not need to prevent the entry of dust or liquids into the drive. NEMA Type 3R enclosures are intended for use in the outdoors, and offer protection against falling rain and external ice formation.

A Type 4 enclosure is intended for indoor or outdoor use, and provides protection against falling rain, external ice formation, and wind-blown rain and dust. Type 12 enclosures are intended for indoor use and provide protection against dirt, dust, nonflammable fibers, splashes, drips (of non-corrosive liquids), and seepage.



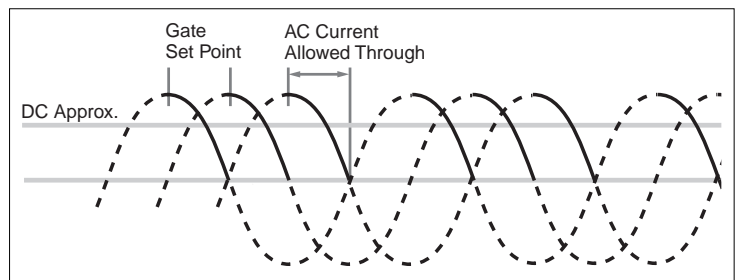
NEMA Classifications

The enclosure protects the electrical components that comprise the drive. The internal parts of a drive include electrical devices such as capacitors, rectifiers, resistors, processor chips, and relays. These devices work together to change and control current and voltage.

A drive may be used to increase the efficiency of a process, provide accurate motor speed, control motor torque, enable the motor to run at a range of speeds, or to automate and optimize a process.

DC Drives

DC drives have two main components: A **converter** and a regulator. A converter is an electrical circuit that converts AC power to DC power. DC drive converters typically use a device called a **silicon control rectifier (SCR)** for this conversion process. SCRs transform AC current into a tightly controlled form of DC current. An SCR is a gated transistor that only allows current to pass through it when the current reaches a certain value (the point at which the gate is set), which turns on the SCR. SCRs are only "on" when power is applied to its gate. When SCRs are on, they have the effect of chopping the sine wave of an AC power supply into fragments that approximate a DC power supply.



Sine Wave and DC Approximation

A **regulator** is the control portion of the drive. The regulator is the "smarts" or processing logic that determines what voltage and current is supplied to the motor. The voltage output from the drive can manipulate the speed or the torque of the motor (thus, the tension of a process load can also be controlled). The changes to the power supplied to the motor depend on the logic in the regulator and the type of feedback from the motor. **Feedback** devices, such as **encoders** or **load cells**, are sensors on the motor, or on a process line, that monitor actual process performance. An example of a feedback device is a **tachometer** (tach), a device that monitors the actual speed of the motor. A tach can send a signal back to the drive telling it how fast the motor is actually running. The drive regulator can compare that signal to a set number programmed into the drive, and

determine if more or less voltage is needed at the motor to get the actual speed of the motor equal to the programmed speed. Because DC drives manipulate the voltage supplied to the motor, they are deemed **variable voltage control**. A drive using feedback sensors is said to have closed loop control.

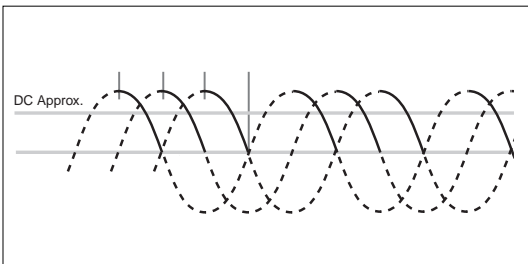
DC drives can control motor speed in two ways—by controlling the voltage supplied to the armature to obtain speeds below the base speed of the motor, or by reducing the current supplied to the field to obtain speeds above the motor's base speed.

AC Drives

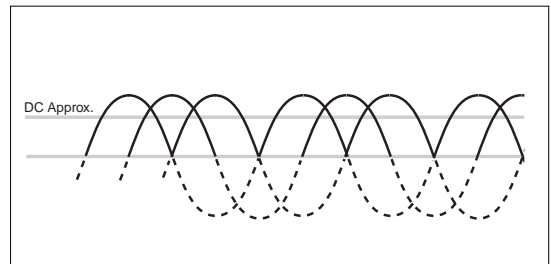
AC drives have three main components: A converter, a regulator, and an inverter. The converter in an AC drive is similar to that in the DC drive—it is used to convert AC power into DC power. While some AC drives use an SCR, most use a **diode rectifier** rather than an SCR. Diodes are similar to SCRs, but they do not have a gate and thus cannot be turned on or off. Hence, diode rectifiers are less expensive, but do not provide as tight of voltage control as an SCR.

DC drives can control motor speed in two ways—by controlling the voltage supplied to the armature to obtain speeds below the base speed of the motor, or by reducing the current supplied to the field to obtain speeds above the motor's base speed.

Diodes only allow the positive portion of AC power to be transmitted through the circuit. In an AC drive, the DC power will be converted back into a form of AC power, so the DC approximation does not need to be as accurate. Also, the level of DC voltage does not need to be controlled to control the motor speed.

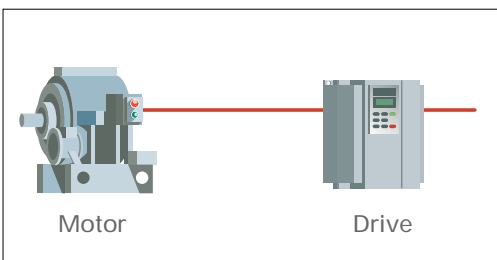


SCR

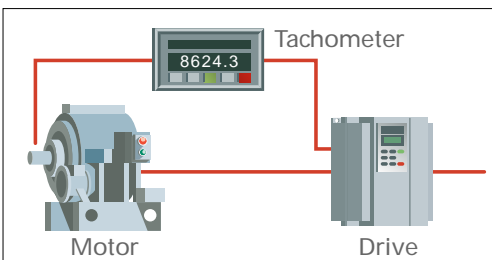


Diode Rectifier

AC drives also have regulators, which control the DC power before it is further transmitted. AC motors may have their speed and torque controlled as well, depending on the type of regulator. There are three main types of AC regulators. A **volts per hertz** regulator controls the ratio of voltage to frequency of AC



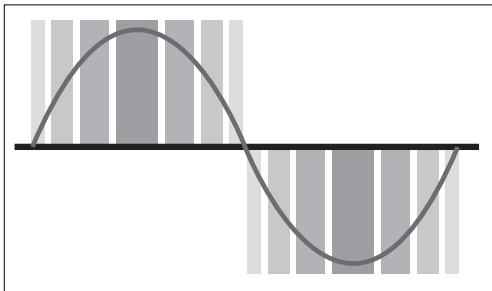
Open Loop Vector



Closed Loop Vector

power output to the motor. The speed of an AC motor depends on the frequency; thus the speed is controlled. A volts per hertz regulator does not use feedback devices. An **open loop vector** regulator also controls motor speed without feedback devices. However, it regulates the current output to the motor, and controls the rotor/shaft speed by controlling the frequency of the magnetic flux in the stator. This type of regulator may also be used to control the torque of a motor.

A **closed loop vector** regulator (also called **flux vector**) is similar to an open loop vector drive, but differs in that it uses feedback devices. The third component of an AC drive, the **inverter**, takes the regulated DC power and changes it back into a form of regulated (controlled) AC power. AC drives typically utilize an **Insulated Gate Bipolar Transistor (IGBT)** to invert power through a control strategy called **Pulse Width Modulation (PWM)**. IGBTs are capable of turning on and off very fast, allowing pulses of DC voltage to pass through to the motor. These pulses approximate an AC power supply.



PWM Power Approximating AC Power

BRAKING

Drives not only vary the speed at which motors operate, they also offer a means of braking a motor. If a motor is not connected to a drive or equipped with a mechanical brake, it will coast to a stop when the motor is shut off. Braking provides for a controlled form of stopping, whether it is coasting, gradual braking, or quickly halting the motor.

There are two means of braking with the use of drives: **Injection braking** and **Dynamic braking**. Injection braking is only applicable with AC drives and motors. To stop the motor, the drive sends DC current to the motor. Without the varying voltage and frequency in various phases, the magnetic field in the stator stops rotating. The rotor is attracted to the halted field and stops. Dynamic braking is used when the motor acts as a generator. Changes in the load may cause the motor to act as a generator rather than a motor. An example would be a conveyor belt that is sloped downward—as the weight is added to the belt, the load may pull the motor faster than it would normally operate. In dynamic braking, contactors, or other switching devices, create a circuit in the drive that directs power flow from the motor to resistors. Resistors dissipate power by converting it to heat. This form of controlling power flow slows down or stops the motor. **Regenerative braking** is a form of dynamic braking in which the power is dissipated back into the main AC line, rather than through resistors. This eliminates the wasting of power and also reduces the amount of heat created in the resistors.

Some applications require the motor to continue running when the drive has failed. Drives may be bypassed in these applications, or when they need to be maintained. **Bypassing** the drive means that control of the motor is switched from the drive to a starter. This switching is accomplished through contactors—one between the drive and the motor, and one between the motor and the starter. The electrical circuit has now been reconfigured so that power flows through the starter rather than through the drive. Drives can be bypassed manually (an operator can open and close the contacts), as in the case of maintenance, or automatically if the drive fails.

Injection braking is only applicable with AC drives and motors. To stop the motor, the drive sends DC current to the motor.

Dynamic braking is used when the motor acts as a generator.

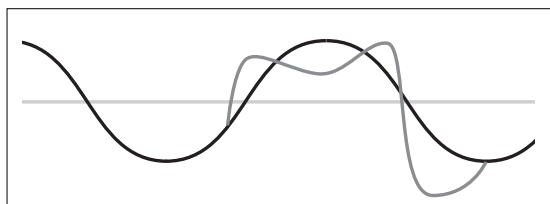
Bypassing the drive means that control of the motor is switched from the drive to a starter.

LINE CONSIDERATIONS

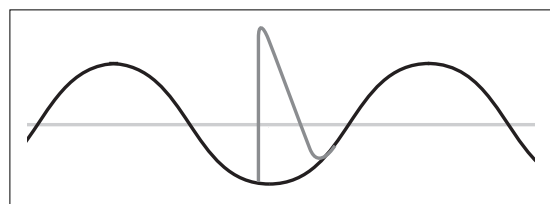
Both AC and DC drives create electrical noise that can affect the reliability and performance of the drive, motor, and AC power supply. The magnetic and electrical forces created within the drive cables can induce forces on other electrical devices in close proximity. The resulting disruptions in the power supply are referred to as **noise**. Noise disrupts the power in nearby cables, which can

cause overheating, reduced power factors, circuit breakers to trip, and malfunctions of other devices operating on the power supply. **Voltage spikes** are a type of noise caused by power surges when drives start up and shut off. Large quantities of voltage can suddenly be transmitted across the line when drives are used.

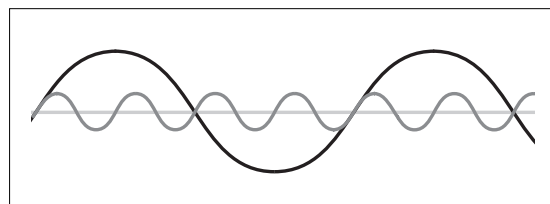
Harmonics are a special type of noise resulting from AC drives. Harmonics are sinusoidal waves with higher frequencies than the main power supply, and are transmitted back to the AC line.



Noise



Voltage Spikes



Harmonics

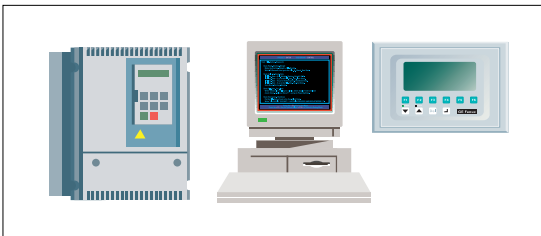
Drives may be built with special devices to reduce the amount of noise and harmonics created or transmitted. Devices that filter out noise are: Reactors, transformers, harmonic filters, isolation transformers, and 12 or 18 pulse drives.

Drives can be classified as 6, 12, or 18 pulse. The number of pulses is a reference to the number of conduction sequences available in the converter. Twelve and 18 pulse drives produce fewer harmonics than a 6 pulse drive, and the harmonics are at higher frequencies. **IEEE (Institute of Electrical and Electronic Engineers)** is another association that writes standards. IEEE 519 is a standard that defines acceptable levels of harmonics.

Both AC and DC drives create electrical noise that can affect the reliability and performance of the drive, motor, and AC power supply.

USER/OPERATOR INTERFACES

Drives offer a means of controlling a motor. A drive's **user interface** allows an operator to program control references to the drive/motor system, and to monitor motor and drive operating conditions. Interfaces include start/stop pushbuttons, keypads situated directly on the drive or in a remote location, PCs with drive compatible software, and programmable logic controllers (PLCs). PCs and PLCs are useful when multiple drive systems will be used at one time. They allow for multiple drives to be programmed quickly with the same control references, and also reduce the amount of wiring needed to link the systems together. They operate on a communications link or industrial network, which allows for high speed and quality process control.



Operator Interfaces

In most applications, drives are used to control motors in conjunction with other electrical equipment. For example, one motor may be used with a series of other motors in a continual process—the speed of one motor might be dependent upon another motor. If a sensor goes off, the motor might need to stop or slow down. Drives provide a means for developing a control logic based on the status of other devices. Drives also display the status of the motor and drive parameters, such as current and speed. These functions require input and output (I/O) connections within a drive.

There are two types of I/Os: Digital and Analog. **Digital I/Os** can be either on or off. Examples of digital I/Os would be a start button, fault signal, light, or photosensor. **Analog I/Os** may have a value within a set range. Examples of analog I/Os would be current level or current operating speed.

A drive's user interface allows an operator to program control references to the drive/motor system, and to monitor motor and drive operating conditions.

Drives provide a means for developing a control logic based on the status of other devices.

GLOSSARY

AC (Alternating Current)	A type of current in which the flow of electrons alternates back and forth as the voltage force alternates between pushing and pulling on electrons.
Analog I/O	A type of I/O which may have a value within a set range.
Armature	Another name for the rotor, and which is more commonly referred to in DC motors.
Bypassing	A means of switching control of the motor from the drive to a starter.
Closed Loop Vector Regulator	Also called flux vector, this regulator is similar to an open loop vector drive, but differs in that it uses feedback devices.
Constant Horsepower Load	Loads in applications where the amount of work to be done is independent of speed and torque, or that require constant tension.
Constant Torque Load	Loads in applications where the amount of force needed is independent of speed, and are the most common in industrial applications.
Converter	An electrical circuit that changes AC power to DC power.
Current	The actual flow, and strength of flow, of electrons.
DC (Direct Current)	A type of current in which electrons flow in one continual direction.
Digital I/O	A type of I/O which can be either on or off.
Diode Rectifier	Similar to SCRs, but diodes do not have a gate and thus cannot be controlled. Diodes only allow the positive portion of AC power to pass through the converter. Most AC drives use diodes.

Dynamic Braking	A means of braking when a motor acts as a generator and the drive dissipates the excess current.
Enclosure	An outer covering that protects electrical devices that comprise the control aspects of the drive.
Encoder	A type of feedback device.
Feedback Devices	Sensors on the motor, or on a process line, that monitor actual performance.
Field Test	A means of determining the nature of the load, if it is not obvious.
Frequency	A reference to how often AC changes direction, and is measured in units of hertz (or cycles per second).
Harmonics	A special type of noise resulting from AC drives: sinusoidal waves with higher frequencies than the main power supply, which are transmitted back to the AC line.
Horsepower	A reference to how much work the motor can do, or how much torque it can deliver over time.
IEC	The International Electro-technical Commission, which writes international standards for electrical devices.
IEEE	The Institute of Electrical and Electronic Engineers, which is an association that writes standards.
Injection Braking	A means of braking an AC motor by using an AC drive to send DC voltage to the motor.
Insulated Gate Bipolar Transistor (IGBT)	A transistor used in AC drives to generate AC power from DC power through a control strategy called Pulse Width Modulation (PWM).

GLOSSARY

Inverter	A component of an AC drive that takes the regulated DC power and changes it back into a form of regulated (controlled) AC power.
Load Cells	A type of feedback device.
Load	The equipment being driven by the motor.
NEMA	The National Electrical Manufacturers Association, which creates standards primarily followed in the USA.
Noise	Disruptions in a power or control system.
Open Loop Vector Regulator	A type of AC regulator that controls motor speed without feedback devices, regulates the current output to the motor, and controls the rotor/shaft speed by controlling the frequency of the magnetic flux in the stator.
Phases	A reference to how many currents (or voltage forces) are transmitted at one time.
Pulse Width Modulation (PWM)	A control strategy which uses Insulated Gate Bipolar Transistors to approximate an AC power supply by allowing variable amounts of DC voltage across the line.
Rated Current	The amount of current flowing through the drive/motor when under full load.
Regenerative Braking	A form of dynamic braking in which the power is dissipated back into the main AC line, rather than through resistors.
Regulator	The control portion of the drive that determines what voltage and current is supplied to the motor, and the circuit through which DC power is supplied to the motor.
Resistance	The “frictional” force in wires opposing the flow of current.

Rotor	The rotational part of a motor.
Shaft	The part of the rotor that extends outside of the motor case and connects to the equipment to be rotated.
Silicon Control Rectifier (SCR)	A gated diode that only allows current to pass through it when the current reaches a certain value, which turns on the SCR. DC drive converters typically use this device to transform AC current into a variable and tightly controlled form of DC current.
Stator	The stationary part of a motor.
Tachometer	A device that monitors the actual speed of the motor.
Torque	A reference to how much force the motor shaft exerts as it rotates.
User/Operator Interface	A means of allowing an operator to program control references to the drive/motor system, and to monitor motor and drive operating conditions.
Variable Torque Load	Loads in applications that exhibit both increases in torque and horsepower as speed increases.
Variable Voltage Control	A reference to DC drives because they manipulate the voltage supplied to the motor.
Voltage	The force that pushes or pulls electrons, causing them to flow.
Voltage Spikes	A type of noise in which large quantities are suddenly transmitted across the line.
Volts Per Hertz Regulator	A type of AC regulator which controls the frequency of AC power output to the motor, and does not use feedback devices.

DRIVE BASICS 0 QUIZ

The following pages contain our Drive Basics 0 multiple choice quiz.

Please detach, complete, and return the quiz via fax or mail to:

Don Davis

Product Manager

GE Fuji Drives USA, Inc.

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The quiz must be completed and returned if you wish to receive future books and updates.

Name _____

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Please circle one answer for each question.

1. A load may be classified as:
 - a) constant horsepower
 - b) constant torque
 - c) variable torque
 - d) a, b, or c

2. The inner electrical components of a DC drive form the following two main components:
 - a) a converter and a regulator
 - b) an inverter and a braking unit
 - c) an encoder and processing logic
 - d) load cells and IGBTs

3. A silicon control rectifier (SCR) or diode rectifier is used in drives to:
 - a) stop the motor
 - b) maintain constant torque
 - c) vary the number of phases supplied to the motor
 - d) convert AC power into DC power

4. Drive enclosures:
 - a) provide cooling to the motor
 - b) are defined by NEMA or IEC standards
 - c) protect the drive from the operating environment
 - d) both b and c

5. Feedback devices are used to:
 - a) transform DC power into AC power
 - b) tell the drive about the status of the actual motor/process
 - c) load cells
 - d) control the frequency supplied to AC motors

6. Drives can control DC motor speed by:
- a) varying the frequency of power supplied to the motor
 - b) regulating the flux vector
 - c) controlling the amount of voltage supplied to the armature, or the amount of current supplied to the stator field
 - d) using IGBTs to change AC power into DC power
7. IGBTs are used in AC drives to:
- a) control the amount of resistance used to stop the motor
 - b) program set points into the drive
 - c) approximate an AC sine wave through the process of pulse width modulation (PWM)
 - d) they are not used in AC drives
8. Harmonics are:
- a) a musical sound created by the drive
 - b) a type of noise created by the drive, which affects the power supply in an adverse way
 - c) forms of regenerative braking
 - d) a means of bypassing the drive in case of failure
9. The three main types of AC drive regulators are:
- a) volts per hertz, open loop vector, and flux vector
 - b) diode rectifiers, SCRs, and IGBTs
 - c) constant torque, variable speed, and variable HP
 - d) converter, inverter, and IGBTs
10. Drives may have the following two types of input or output connections to control a process:
- a) 6 and 12 pulse
 - b) digital and analog
 - c) logical and harmonic
 - d) external and internal