101 BASICS SERIES

LEARNING MODULE 20:
ADJUSTABLE FREQUENCY DRIVES

Cutler-Hammer

EATON

WELCOME

Welcome to Module 20, which is about *adjustable frequency drives*. An adjustable frequency drive is a device used to control the speed, *torque*, *horsepower* and direction of an *AC* motor.

FIGURE 1. TYPICAL ADJUSTABLE FREQUENCY DRIVES

Like the other modules in this series, this one presents small, manageable sections of new material followed by a series of questions about that material. Study the material carefully then answer the questions without referring back to what you've just read. You are the best judge of how well you grasp the material. Review the material as often as you think necessary. The most important thing is establishing a solid foundation to build on as you move from topic to topic and module to module.

A Note on Font Styles

Key points are in bold.

Glossary items are italicized and underlined the first time they appear.

Viewing the Glossary

You may view definitions of glossary items by clicking on terms and words that are underlined and italicized in the text. You may also browse the Glossary by clicking on the Glossary bookmark in the left-hand margin.

WHAT YOU WILL LEARN

We'll **step through each of these topics** in detail:

IMPORTANCE OF MOTOR SPEED CONTROL

Motor speed control is important in many applications. It allows for precise control of the application. This allows the same equipment to be used for multiple products or processes.

Here are some examples of the uses of motor speed control:

- Stamping Machine – pressure exerted by the stamping head.
- Cooling Tower – temperature of the cooling source, such as water.
- Polishing Machine – speed of the rotating polishing head.
- Commercial Bakery – speed at which conveyors move a batch through the oven.

As you may recall from Module 16, Basics of Motors and Motor Control, all AC motors have a synchronous speed. This is the speed at which the motor is designed to run.

Suppose you have a motor connected to a conveyor belt application, and you want to slow the conveyor speed. What can you do? The motor is built to run at only one speed. The answer is you find a way to change the motor's speed.

How Can Motor Speed Be Controlled?

Many methods for controlling the speed of a motor are in use today. The list that follows is neither detailed nor complete, but will serve to give you an idea of the variety of methods available.

- Electrical Methods – **The motor speed is actually changed electrically.**
    - Adjustable *Voltage* – changing the DC input voltage changes the DC motor's speed.
    - Adjustable *Frequency* – changing the input frequency changes the AC motor's speed.
    - Eddy Current – changing the strength of the magnetic field changes the AC motor's speed.
- Mechanical Methods – **The motor speed stays constant**, and is converted to the desired speed, using gears, sheaves, clutches or other mechanical means.

WHAT DOES AN ADJUSTABLE FREQUENCY DRIVE DO?

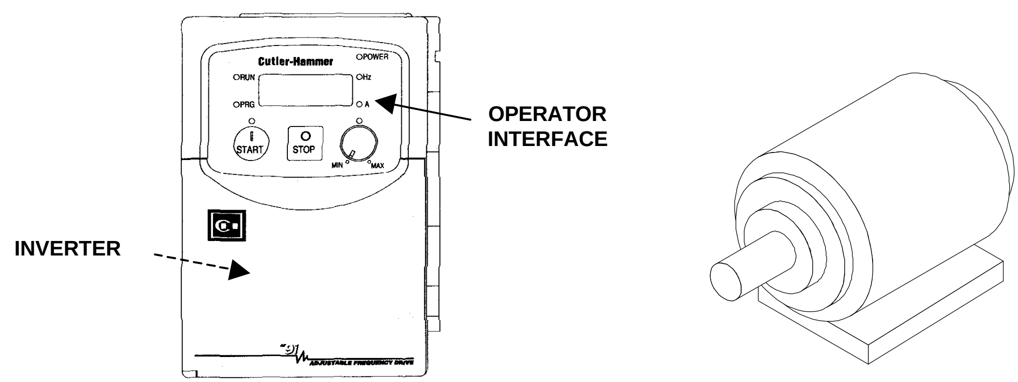
The adjustable frequency drive is an electrical device used for controlling the speed of a motor, by which we specifically mean an **AC motor.**

An adjustable frequency drive (or AF drive) **is a device used to convert *three phase*, 60Hz input power into an adjustable frequency and voltage source.** This source is then used to power a motor.

The AF drive allows for control of the motor's speed by controlling the frequency of the power fed to the motor. We will see how frequency affects motor speed later in this module.

The AF drive system is very simple. It consists of only three components:

- AC Motor – Usually, a NEMA Design B, squirrel cage induction, 3-*phase* motor
- Motor Control Section (also called the *Inverter* section)
- Operator Interface



OPERATOR INTERFACE AND INVERTER SECTION

AC MOTOR

FIGURE 2. TYPICAL ADJUSTABLE FREQUENCY DRIVE COMPONENTS

The **operator control** allows the operator to command the motor to function as desired, through the use of motor control inputs and outputs.

The **motor control section** controls the motor's speed by converting utility power into adjustable frequency power.

The **AC motor** drives the device (fan, pump, etc.) by converting the electrical power to mechanical power.

WHY USE AN ADJUSTABLE FREQUENCY DRIVE?

There are a number of excellent reasons for choosing an AF drive over other methods for motor speed control. These include:

- Versatility
- Energy Savings
- Performance
- Reliability
- Size
- Future

Let's discuss each of these reasons in a little more detail.

Versatility

An AF drive is very versatile. It provides many expanded functions that other motor speed control methods do not offer, such as self-diagnostics, current status display, multiple-use programmability, and more precise speed control.

Energy Savings

Cost is a natural concern for many customers. Since the AF drive allows for precise control of the amount of energy going to the motor, **cost savings on energy can be realized.** It also helps reduce peak energy demand problems in the plant by ramping up the power drawn by the motor.

Furthermore, the circuitry in the AF drive is designed to maximize the energy put through the unit. In other words, **very little of the costly electricity fed into an AF drive is wasted as heat.**

Performance

The operator interface is simple to operate. Any required changes to the drive settings can be made quickly by the operator, and go into effect instantly.

The AF drive responds rapidly to changes in the motor's load, maintaining the requested speed, even when the load change is abrupt.

The tolerance for speed variance from the operator's setpoint is very small as well, assuring precise operation.

Reliability

AF drives are very reliable products. **Because the unit is solid state, there are no moving parts to fail**, apart from the cooling fan. In fact, the mean time between failures has been calculated at over 90,000 hours for some AF drives.

Because the drive controls are integrated into the drive "box," **no external control system is required.** This is one less thing to maintain.

Nuisance tripping is avoided by the built-in protective circuitry. And the trip parameters are easily adjustable.

Size

The AF drive is lighter and smaller than most other methods of motor speed control.

Future

Continuing improvements in digital logic and microprocessor technology will mean more features at a lower cost.

Currently, the AF drive generates a certain amount of heat. Depending on the application, this may need to be taken into consideration when choosing an enclosure. As the power conversion circuitry in the AF drive continues to improve, less and less of the electricity handled by the drive will be wasted as heat. This means drive heat generation will become less of an issue.

TYPICAL ADJUSTABLE FREQUENCY DRIVE APPLICATIONS

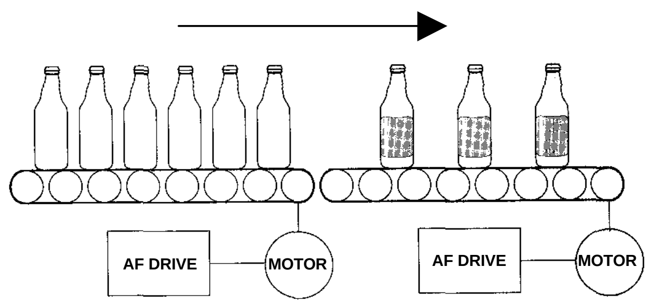
Here are some typical adjustable frequency drive applications:

- Conveyors, belts, chains, screws, and bulk and packaged material handlers
- Fans, blowers, compressors and pumps
- Machine tools, grinders, lathes and stamping presses
- Custom machinery, labelers, packaging machines, bottle washers, wire drawing, textiles, etc.
- Extruders
- Process machinery, kilns, grinders, blenders and agitators.

IN THE WORKPLACE

Using AF drives on this beverage bottling conveyor allows the operator to run different sections of the conveyor at different speeds. The bottles may be bunched close together for filling, and then spread out for labeling.

For this application, two motors and two drives would be required. One motor would run the filling section at a given speed, and a second motor would run the labeling section slightly faster, spreading the bottles out.



BEVERAGE BOTTLING LINE

REVIEW 1

Answer the following questions without referring to the material just presented. Begin the next section when you are confident that you understand what you've already read.

1. An adjustable frequency drive is a device used to convert standard 3 phase, 60Hz input power into an adjustable _________ and _________ source.
2. In terms of reliability, the only moving part of the AF Drive that can fail is the _________ ____.
3. Describe how an AF drive is used with an office building's air-conditioning system. Why is an AF drive useful for this sort of application?
4. Think of three applications (other than those mentioned in this section) that would benefit from the use of an AF drive.

   Application #1 ____

   Description of the benefit of using an AF drive with this application:

   Application #2 ____

   Description of the benefit of using an AF drive with this application:

   Application #3 ____

   Description of the benefit of using an AF drive with this application:

HOW DOES IT WORK?

Motor Concepts

So far in this training module, we have discussed what an adjustable frequency drive is, and why it is useful. What we have yet to do is discuss how an AF drive works. We will devote this section to discussing precisely that. To do this, we need to define a few concepts critical to understanding how an AF drive and a motor work.

Let's look first at some motor concepts:

- Synchronous Speed
- Horsepower and Torque

Synchronous Speed

As you may recall from Module 16, Basics of Motors and Motor Control, a motor is designed to run at what is called its *synchronous speed*.

Synchronous speed is determined by the number of poles that the motor has, and the frequency of the current being supplied to it. The equation for determining the synchronous speed of a motor is:

$$N = 120f/P$$

Where:
N = the **synchronous speed** of the motor in revolutions per minute (RPM)
f = the **frequency of the current** supplied to the motor in Hertz (Hz)
P = the **number of poles** the motor has

The typical frequency supplied is 60 Hertz, and the "typical" motor has 4 poles. Plugging these numbers into the equation, we find:

$$N = (120 \times 60) / 4 = 1800$$

Now you can see why the "typical" motor runs at 1800 rpm.

You can also see clearly that changing the frequency of the current has a direct effect on the motor's speed. Suppose we wanted to run this "typical" motor at only 1200 rpm. Calculate the frequency setting for the AF drive by solving for f.

$$1200 = 120f/4$$
$$4800 = 120f$$
$$40 = f$$

So, you would have to adjust the frequency of the current to 40 Hz to run the motor at 1200 rpm.

Horsepower and Torque

Horsepower is the unit of measurement for the amount of work a motor can do. All motors are rated according to the number of horsepower they can provide. This is called, appropriately enough, the motor's Horsepower Rating.

Torque is a measurement of rotational force – in this case, the rotational force required to turn the input shaft of the machine the motor is driving.

By using a speed control device such as an AF drive, it is possible to get a motor to provide a different amount of horsepower. Consider the formulas below:

$$HP = (T \times N)/5252 \qquad T = 5252HP/N \qquad N = 5252HP/T$$

Where:
HP = the **horsepower** provided by the motor
T = the **torque** of the motor in foot-pounds
N = the **synchronous speed** of the motor in rpm

Suppose you had a four-pole motor that runs at 1800 rpm on 60 Hertz. The motor is rated at 5 horsepower. How much torque does this motor generate when it reaches full speed?

Simply plug the numbers into the formula:

$$T = 5252HP/N$$

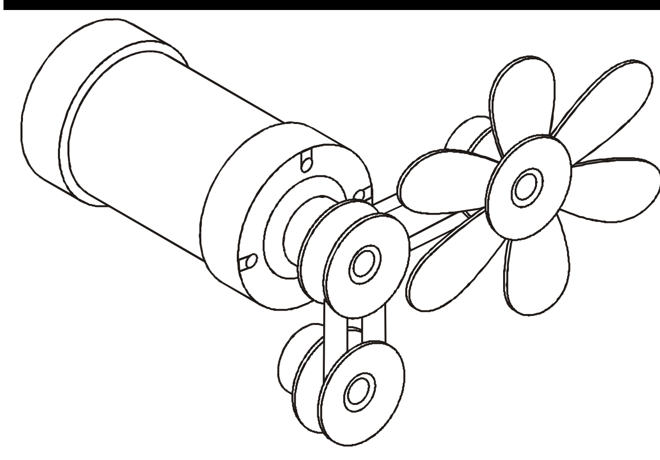
$$T = (5252 \times 5) / 1800$$

This motor generates about 14.5 foot-pounds of torque.

IN THE WORKPLACE

The fan pictured here is used to cool a motor. When the motor is run at a higher speed, it requires more cooling. This means the fan needs to turn faster.

This can be accomplished with an adjustable frequency drive. Increasing the frequency of the current sent to the fan increases the rate at which the fan turns.



COOLING FAN

HOW DOES IT WORK?

The most common control for an AC motor is the motor starter. The starter connects the motor directly to the utility power supply, and operates the motor at its rated speed continuously.

The AF drive, on the other hand, **converts the utility power to adjustable frequency and voltage.** This allows for control of the motor's speed.

Drive Concepts

Now, we will take a look at some concepts that are important to understanding how the AF drive operates.

- Pulse Width Modulation
- Power Factor
- Impedance
- Harmonics

Pulse Width Modulation

As we mentioned earlier, an AF drive is a device used to convert 3 phase, 60Hz input power into an adjustable frequency and voltage source. However, we didn't explain how this is done.

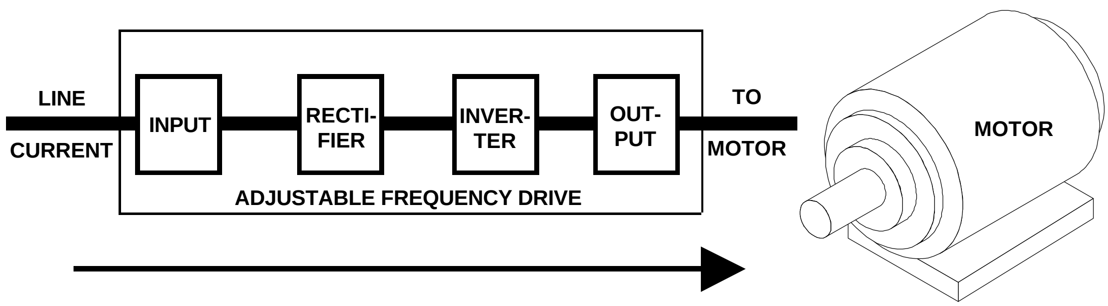


FIGURE 3. CURRENT PATH FROM LINE TO MOTOR

The drawing above illustrates the path the current takes through the AF drive to the motor. When the line current first enters the AF drive, it passes into the *rectifier*, **which converts the incoming AC current to DC current**.

Before being sent to the motor, the current enters the inverter. **The inverter converts the DC current into a "synthetic" AC current, which is then fed to the motor.** Let's look at how the inverter does this.

Pulse Width Modulation (continued)

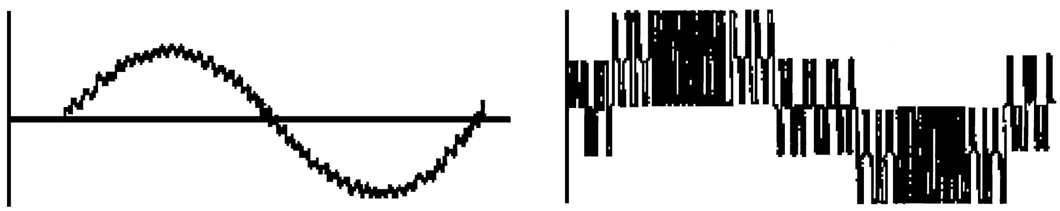
There are three common inverter types in use today. They are:

- Pulse width modulation (PWM)
- Current source inverter (CSI)
- Variable voltage inverter (VVI)

Eaton/Cutler-Hammer AF drives use the first type of inverter, the *pulse width modulation* (or PWM) inverter. (We will not take time here to explain how the other two inverters work, as they are older technology, and no longer commonly used.)

AC current is represented by a sine wave. One full sine wave is called a cycle. **The frequency of the current is the number of cycles that pass a given point in one second, and is termed Hertz** (or Hz). Line current frequency in North America is 60 Hertz.

As shown in figure 4, the PWM inverter takes the DC current from the rectifier and switches it on and off very quickly, approximating a sine wave.



AC LINE CURRENT WAVEFORM **"SYNTHETIC" AC PWM OUTPUT WAVEFORM**

FIGURE 4. LINE CURENT VS. SYNTHETIC AC CURRENT SINE WAVES

By simply speeding up or slowing down the rate at which the current is switched on and off, the AF drive can create a "synthetic" AC waveform with any frequency.

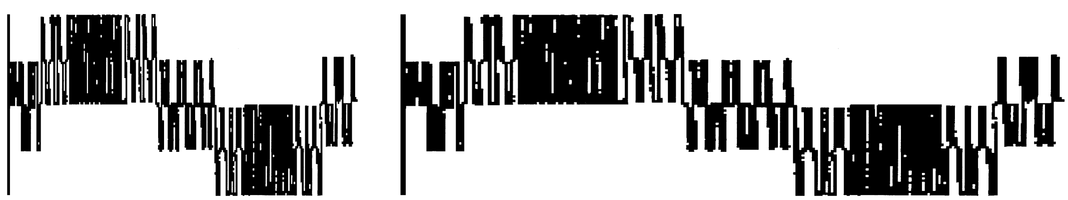


FIGURE 5. SYNTHETIC AC CURRENT CAN BE PRODUCED AT ANY FREQUENCY

Pulse Width Modulation (continued)

A device called an *integrated gate bipolar transistor* (IGBT) has been developed to switch the current six times faster than the previous generation of AF drives. It switches literally thousands of times each second. The results of using IGBT technology include:

- A refined synthetic AC sine wave which more closely matches the natural AC sine wave
- Less audible motor noise
- Less heat generated due to the closer match with the "natural" sine wave
- A smaller heat dissipation device (called a heat sink) is required within the AF drive

Power Factor

Earlier in this module, we mentioned that energy (utility power) cost is a primary concern of the customer. One attribute which affects the cost of power is a load's *power factor*. Utility companies often add a charge if the power factor is lower than their specified level. **The power factor is the ratio of the power in to the power out of a device.** Specifically, it is a ratio of the input kilowatts (KW) to the input kilovolt-amperes (KVA) being drawn by a load.

Ideally, a power factor of 1.00 (called "unity") is desired. But most electric loads are not at unity power factor. In fact, power factor value can be positive or negative.

Capacitors are often used to correct system-wide power factors to near unity. However, *capacitors* should be used with extreme caution on power systems with AF drives. If they are not applied correctly, there is a high potential for capacitor failure. **Capacitors must never be used on an AF drive output.**

The current being drawn by the drive (from the utility) contains harmonics, which we will discuss on the next page. Harmonics cause the KVA to increase, leading to a lower system power factor. The power factor determined by taking harmonics into consideration is called *total power factor*.

The most typical power factor specified by most AF drive manufacturers is called *displacement power factor*. **Displacement power factor is the ratio of the input KW to the input KVA, neglecting any harmonics.**

Of the three inverter types, the pulse width modulation (PWM) type provides the highest displacement power factor, about 0.95. Additionally, **the PWM inverter has the same displacement power factor at any AF drive frequency setting**. This is not true for the other two AF drive types (CSI and VVI).

The AF drive's displacement power factor is not affected by the motor's speed or load. However, the total power factor is affected by these conditions.

Impedance

Impedance is the apparent opposition to the flow of current though an AC electrical circuit, **a force that hinders the flow of current.**

AF drives have a minimum impedance requirement. This minimum impedance protects the AF drive against damage from any brief line voltage surges.

You may need to add a line reactor – a device that works against the current flow – to provide sufficient impedance.

AF drives also have a maximum impedance limit. If the impedance exceeds the maximum allowed, it is possible that the AF drive's full rated output may not be delivered to the motor.

Harmonics

Harmonics are certain frequencies at which unwanted and unusable voltages and currents are introduced into the system. Harmonics are produced by all non-linear electrical loads. A non-linear load is a load that pulls current from the line in a non-linear fashion, switching current on and off. The AF drive is a non-linear electrical load, as are computers, printers, copy machines, uninterruptable power supplies, and fluorescent lighting ballasts.

Harmonic frequencies are multiples of the fundamental frequency. In North America, where the *fundamental frequency* is 60 Hz, harmonics would be at 120 Hz, 180 Hz, and so on. The system sees these additional waveforms as "noise" on the line, which has a negative effect on the quality of the power.

Harmonics can cause equipment malfunction, data distortion, transformer and motor insulation failure, and nuisance tripping of breakers.

We will look at what can be done about harmonics a little later in this module.

HOW DOES IT WORK?

Operator Interface Concepts

Now, let's look at some concepts relating to the operator interface.

- Operator control
- *Remote speed control signal*

Operator Control

The most basic requirements of operator control are the ability to start, stop, change speeds and reverse directions of the AF drive. Operator command functions are usually desired in both manual and automatic modes.

Higher control functions, such as feedback to the control station, are often desired. Fully digital AF drives have all the standard control features mentioned above, plus flexible features to meet the needs of specialized application needs, much like a Programmable Logic Controller (PLC) would.

In addition to communicating easily with human operators, the AF drive should also interface with computer-controlled automation systems. Inputs on the operator control unit monitor system elements, such as motor temperature and critical interlocks, and can shut down the AF drive if necessary. Inputs are also used to switch the start and stop commands between the manual and automatic modes.

Control Signals

Control signals communicate information between components. They are grouped as inputs (signals coming into the AF drive) and outputs (signals leaving the AF drive). Inputs from the motor include current speed, direction, rate of acceleration, overload warnings and so on. Outputs to the motor include requests to start, stop, accelerate, maintain a preset speed, jog the load and so on.

Speed reference commands can be sent manually or automatically. Manual speed input types include door-mounted speed potentiometers and digital keypads. Automatic speed input types include customer-supplied instrument signals and pneumatic sensors.

Input and output signals can be analog or digital. Every manufacturer in the industry offers three standard analog signals: current, voltage and pneumatic. However, digital signals are preferred, as they are more reliable and exacting. Only a few manufacturers (including Eaton/Cutler-Hammer) can provide digital signals.

IN SUMMARY

As you can see, adjustable frequency drives are fairly complex in their function. And explaining their function has required us to look at a lot of underlying engineering concepts.

Let's take a moment to sum up what we have covered in this section.

An AC induction motor is designed to run at a **synchronous speed**. This is determined by the number of poles that the motor has, and the frequency of the current being supplied to it. Changing the frequency of the current changes the motor's speed.

Horsepower is the unit used for measuring the amount of work a motor can do. By using an AF drive, a motor can provide a variable amount of horsepower.

When the line current first enters the AF drive, it passes into the **rectifier, which converts the incoming AC current to DC current**. It then enters the inverter. The **inverter converts the DC current into a "synthetic" AC current**, by switching it on and off very quickly, **approximating an AC sine wave**. By simply speeding up or slowing down the rate at which the current is switched on and off, the AF drive can create a "synthetic" AC current with any desired frequency.

Total power factor includes the effects of harmonics, while displacement power factor excludes harmonics.

Impedance is a force that restricts the flow of AC current. AF drives have a minimum and a maximum impedance requirement. Keeping the impedance between the minimum and maximum:

- Reduces the peak charging currents allowed into the rectifier
- Protects the AF drive against damage from any brief line voltage surges
- Allows the AF drive's full rated output to be delivered to the motor

Harmonics are frequencies at which unwanted and unusable voltages and currents are introduced into the system. The system sees these additional waveforms as "noise" on the line, which has a negative effect on the quality of the power. Harmonics can cause equipment malfunction, data distortion, transformer and motor insulation failure, and nuisance tripping of breakers.

The operator interface controls allow the worker to start, stop and change the speed of the AF drive. Higher control functions, such as feedback to the control station, are often desired.

Control signals can be sent manually or automatically, and can be produced by analog or digital means. **Digital control signals are preferred**, as they are more reliable and exacting.

REVIEW 2

Answer the following questions without referring to the material just presented. Begin the next section when you are confident that you understand what you've already read.

1. The synchronous speed of a motor is determined by the number of ______ that the motor has, and the _________ of the current being supplied to it.

2. The equation for determining synchronous speed is: N = 120 x F / P. Suppose you had an AC motor with 8 poles running at 60 Hz. What would be the motor's synchronous speed?

   _________ RPM

3. Suppose your application called for running the motor described above at 600 rpm. The AF drive attached to the motor would need to be reset to provide how many Hertz?

   _________ Hz

4. Suppose you had a 3 horsepower, 4 pole motor running at 60 Hz. How much torque is the motor capable of producing?

   _________ foot-pounds of torque.

5. The device in the AF drive which converts the incoming AC line current to DC is the ___________.

6. Name 2 of the benefits of using IGBTs in an AF drive.

   ____

   ____

7. The ratio of the AF drive's KW input to KVA input is called its __________ ___________.

8. Keeping the impedance between the minimum and maximum allows for these three desirable effects:

   - ____
   - ____
   - ____

CONCERNS WITH USING ADJUSTABLE FREQUENCY DRIVES

We have looked at how adjustable frequency drives work, and why they are so useful. We have also discussed their advantages over other speed regulation methods. However, do not assume that the AF drive is foolproof. There are a number of issues you need to consider. These are:

- Heat Issues
- Output Filtering
- Harmonics

If these issues are ignored while planning the implementation, problems can arise in application.

Heat Issues

As we have discussed previously, an AF drive generates a certain amount of heat. This heat generation is taken into consideration in sizing the drive's cooling fan, particularly if the AF drive is in an enclosed space.

Likewise, you need to be aware of heat issues in the customer's application. All the other components in the system also generate heat that must be dissipated. And the ambient temperature of the operating environment needs to be considered as well.

A motor will run at a higher temperature when operating on an adjustable frequency drive than it will operating on line current. Why is this?

- Slowing the speed of the motor results in an equal slowing of the motor's cooling fan. Heat dissipation may be hampered when running the motor below its designed speed.
- As we mentioned earlier, harmonics waste power. This power is lost as heat. AF drives are affected by harmonics, so more heat is generated and must be dissipated.

For these reasons, look closely at the customer's application to be sure that heat problems won't cause insulation failure, or, worse, burn up the motor. You may need to recommend a larger motor and/or a larger enclosure, or a separate cooling system for the customer's application.

Output Filtering

When the motor is located far away from the AF drive, a protection issue arises. (This distance varies by drive model. Consult your catalog for specific information.) The long cable connecting the drive to the motor could potentially produce frequent, repetitive voltage surges. These surges could eventually cause insulation failure and destroy the motor.

When the cable length for the application exceeds the acceptable length in the product catalog, you will need to add an *output filter* (also called a dv/dt *filter*) to the circuit. The output filter will catch voltage surges before they can damage the motor.

Harmonics

As we mentioned, harmonics are produced by all non-linear electrical loads, including AF drives. What can be done about harmonics to protect a customer's equipment and computer systems?

- A trap filter can be added to the system to catch each harmonic frequency and take it to ground. The equipment is protected from damage.

  The disadvantage to using this method is that the trap filter can serve as a "magnet" for all harmonics on the electrical grid. This means that your customer's other machines – or even a neighbor's machines – can use (and burn up) your customer's trap filter.

- A *line reactor* can be added to lessen the problem. This is a device which adds impedance to the line to keep the impedance between the minimum and maximum allowed values. Risk of equipment damage is minimized.

- A "Clean Power" rectifier can be used. This is rather expensive, but where the other two methods "clean up" the harmonics, this method prevents harmonics from ever occurring.

HELPING THE CUSTOMER

Factors to Consider

When helping a customer select an adjustable frequency drive for an application, there are a large number of factors that you must take into consideration. Let's look at each one briefly.

- **Consider the application itself**
  High-torque, large inertia, quick ramp-up applications are not recommended for use with an AF drive.

- **Load type, power and torque**
  How large is the load? How much torque is required to get it moving? Is it a constant torque or variable torque application?

- **Motor type, full load amps and horsepower**
  What type of motor is it? What is the motor's full load amps and horsepower? Get the brand and model number of the motor so you know exactly what you are dealing with.

- **Speed range needed**
  What range of motor speeds does the customer want available to him?

- **Speed regulation needed**
  How precise does the speed setting need to be?

- **Control response**
  How quickly should the control respond to changes in the load, or changes in operational settings?

- **Efficiency**
  Higher efficiency means lower energy costs.

- **Overload capacity**
  What class (10, 20) of overload protection is required for the application?

- **Reliability**
  We can assume the customer would like the unit to fail as little as possible, of course. How critical is it to avoid nuisance tripping? How important is it to be able to adjust the trip settings?

- **Physical size of the unit**
  How much physical space is available at the application site for a motor speed control unit?

- **Audible noise**
  Does the customer have any concerns related to audible noise produced by the motor or speed control unit?

- **Harmonics**
  Does the customer have any concerns regarding harmonics on the line? Take into consideration the entire system of which the drive is a part.

Factors to Consider (continued)

- **Enclosure type**
  Does the customer have any special needs relating to the application's environment? Choose a NEMA enclosure type to match.

- **Location**
  Is the distance between the motor and the AF drive a problem? Check in the product catalog. An output filter may be necessary.

- **Cost**
  Customers want the least expensive product that will meet all the application's requirements. As you explain the cost of a particular unit, be sure to put it in terms of the total cost to the customer. What may seem like a high initial cost may in fact save the customer a lot of money over the life of the unit. Energy cost savings, reduced downtime because of on-board diagnostics, and the like can be presented as returns on the investment in the device.

Application Checklist

Here is a good checklist to use when helping a customer decide which type of AF Drive is best for the application.

MOTOR

New ____ Existing ___ Hp ____ Base Speed _____ Voltage _____

FLA ____ LRA ___ NEMA Design ____ Gearbox/Pulley Ratio _____

Hz _____ Service Factor _____

LOAD

Application: ____

Load Type: Constant Torque _____ Variable Torque ____Constant HP _____

Load inertia reflected to motor: _____________ $lb.ft^2$

Required breakaway torque from motor: ___________ ft-lb.

Running load on motor: ___________ ft-lb.

Peak torque (above 100% running): __________ ft-lb.

Shortest/Longest accel time: _____ / _____ sec. up to ____ Hz from stop

Shortest/Longest decel time: _____ / _____ sec. down to ____ Hz from max. speed

Operating speed range: ______ Hz to _____ Hz

Time for motor/load to coast to stop: _____ seconds.

Application Checklist continued

AF drive

Source of start/stop commands: I/O terminals ____ Keypad ____ Other ______

Source of speed adjustment: ________________________________

Other operating requirements: _______________________________

Will the motor ever be spinning when the AF Drive is started? Yes___ No ____

How far apart are the motor and the AF Drive? _________ feet

Is the load considered high-inertia? Yes___ No ____

Is the load considered hard to start? Yes___ No ____

Options desired: Multiple operators ______ Output Signals ______

Power Options _________________________________

Other ____

Other requirements or conditions: ________________________

POWER SUPPLY

Supply transformer: ______ KVA, or short circuit current at drive input _____ amps

Total Horsepower of all drives connected to supply transformer/feeder _______ Hp

Is a drive transformer of line reactor desired? (May be required) ________

Any harmonic requirements? Y/N % Voltage THD ____ % Current THD ____

Total non-drive load connected to the drive's feeder: ________ amps

SERVICE

Start-Up Assistance: ____________ Customer Training:__________

Preventive Maintenance: _________ Spare Parts: ________

ADDITIONAL ISSUES – Answer Yes or No

_____ Will the AF Drive operate multiple motors?

_____ Will the power supply source ever be switched with the AF Drive running?

_____ Is starting or stopping time critical?

_____ Are there any peak torques or impact loads?

_____ Will user-supplied contactors be used on the input or output of the AF Drive?

Recommending a Product to the Customer

Using all the information gathered here, consult your product catalogs to make a recommendation to the customer.

It is possible that you may have to suggest more than one product, as you may not find a perfect match for all the application's requirements.

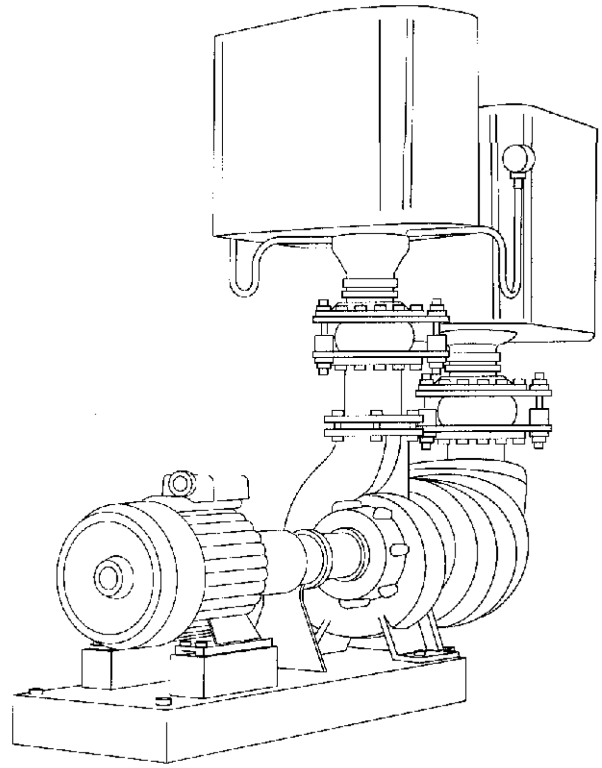
IN THE WORKPLACE

The centrifugal pump on a chilled water system, shown here, is an ideal candidate for use with an adjustable frequency drive.

As the pump turns faster, it moves more water, and it requires more torque.

This application also requires water flow through the pump to be regulated.

You will need to work with the customer to select an adjustable frequency drive for an application such as this, taking into consideration the factors mentioned above.



TYPICAL PUMP ON A CHILLED WATER SYSTEM

NORMALLY SPECIFIED FEATURES

There are four features that the customer will generally specify when looking into an adjustable frequency drive. These are:

- *Bypass*
- Line Reactor
- Control Signal
- Output Filter

Let's take a brief look at each feature.

Bypass

Adding a bypass to the AF drive allows the motor to be transferred via a set of contactors to the utility line, to allow maintenance to be done on the drive.

There are two bypass types available:

- Manually operated
- Automatically transferred

Line Reactor

The customer may specify a line reactor for the application.

Get all the pertinent information from the customer and from the product catalog. Then, refer to the section on impedance (earlier in this module) to determine whether a line reactor is needed for the customer's application.

Control Signals

The customer may specify a control signal type or types for the application. Determine the customer's requirements and decide whether analog or digital inputs and outputs are more appropriate.

Output Filter

When the cable length for an application exceeds the acceptable length in the product catalog, you will need to add an output filter (also called a "dv/dt" filter) to the circuit. The output filter will reduce the *voltage transients* before they can damage the motor.

The customer may specify the need for an output filter if the cable length is excessive, but may not be aware of this requirement. In any case, you should verify whether an output filter is needed for the customer's application.

REVIEW 3

Answer the following questions without referring to the material just presented.

1. What two motor heat issues crop up when running a motor with an AF drive?

   ____

   ____

2. The output filter works to protect the motor by:
   ____.

3. Name four of the factors that you must take into consideration when choosing an AF drive to suit a customer's application.

   ____

   ____

   ____

   ____

4. Name two methods for dealing with harmonics.

   ____

   ____

GLOSSARY

AC
Alternating current.

Adjustable Frequency Drive
An electrical device used for controlling the speed of an AC motor. Also called AF Drive.

Bypass
A device added to an AF drive which allows the motor power to be transferred via a set of contactors. This is useful in case of a drive failure, or if maintenance is being done on the drive.

Capacitor
A device that consists of two conductors separated by an insulator. It is used to store electricity.

Displacement Power Factor
The ratio of input KW to input KVA of the AF drive, excluding harmonics.

Filter
A component for smoothing the DC current in an AF drive.

Frequency
The number of cycles per second made by an alternating electrical current. The unit of measure is the Hertz.

Fundamental Frequency
The frequency of line current. In North America, this is 60 Hertz.

Harmonics
Certain frequencies; specifically, multiples of the fundamental frequency, at which unwanted and unusable voltages and currents are introduced into the system.

Horsepower
Unit of measurement used for describing the amount of work a motor can do.

Impedance
The apparent opposition to the flow of current though an AC electrical circuit; a force that literally impedes the flow of current.

Integrated Gate Bipolar Transistor
A device used to switch the DC current in the inverter section of an AF drive.

Inverter
The section of the AF drive which converts DC current into a “synthetic” AC current, which is then fed to the motor.

Line Reactor
A device which adds impedance to the line to keep the impedance between the minimum and maximum allowed values for a particular piece of electric equipment, such as an AF drive.

Output Filter	When the cable length for the application exceeds the acceptable length, adding this device to the circuit protects motor from voltage surges. Also called a DV/DT Filter.
Phase	The relationship between the current and voltage in an AC circuit, with respect to their angular displacement.
Power Factor	A blanket term, used to describe various measurements of the percentage of the input current available after passing through the system. See Total Power Factor, Displacement Power Factor.
Pulse Width Modulation	A type of inverter which takes the DC current from the rectifier and switches it on and off very quickly, approximating a sine wave.
Rectifier	A device which converts the incoming AC current to DC.
Remote Speed Control Signal	This signal is used to control the speed of the drive remotely, from a control panel not located directly on the drive.
Synchronous Speed	A motor's design speed, determined by the number of poles that the motor has, and the frequency of the current being supplied to it.
Three-Phase	A type of AC power where three AC currents are introduced at 120° variances.
Torque	A measurement of rotational force.
Total Power Factor	The ratio of the input KW to input KVA of the AF drive, including harmonics.
Voltage	Electrical potential difference. The unit of measure is the Volt.
Voltage Transient	Technical term for an unexpected and undesirable voltage surge in a circuit.

REVIEW 1 ANSWERS

1. frequency, voltage
2. cooling fan
3. many possible answers
4. many possible answers

REVIEW 2 ANSWERS

1. poles, frequency
2. 900 RPM
3. 40 Hz
4. 8.75 foot-pounds of torque
5. rectifier
6. Ane two of the following:
   Refined synthetic AC sine wave, more closely matching natural AC sine wave
   Less audible motor noise
   Less heat generated due to the closer match with the “natural” sine wave
   Smaller heat sink required
7. power factor
8. Reduces the peak charging currents allowed into the rectifier, protects the AF drive against damage from any brief line voltage surges, and allows the AF drive’s full rated output to be delivered to the motor

REVIEW 3 ANSWERS

1. Answer should basically say: “1. Slowing the speed of the motor results in an equal slowing of the motor’s cooling fan. 2. Harmonics waste power. This power is lost as heat. AF drives are affected by harmonics, so more heat is generated and must be dissipated.”

2. reducing voltage transients before they can damage the motor

3. Ane four of the following:
   Load type, power and torque
   Motor type, full load amps and horsepower
   Speed range needed
   Speed regulation needed
   Control response
   Efficiency
   Overload capacity
   Reliability
   Physical size of the unit
   Audible noise
   Harmonics
   Location
   Cost

4. Ane two of the following:
   Trap filter
   Line reactor
   Clean power rectifier

Cutler-Hammer
Milwaukee, Wisconsin U.S.A.

Publication No. TR.08.03.T.E
February 1999
Printed in U.S.A. (GSP)

101 Basics Series and 201 Advanced Series are trademarks of Cutler-Hammer University, Cutler-Hammer and Eaton Corp.
©1999, Eaton Corp.