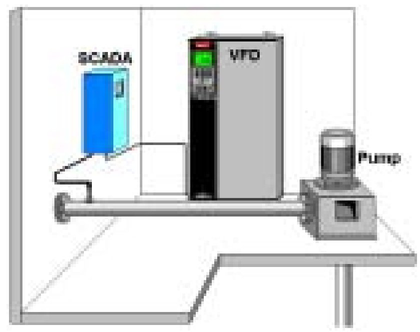
VFD 101
Intro Lesson
Variable Frequency Drives (VFD) Fundamentals



VFD controls water flow.

April 04

This introduction lesson reviews the reasons for using Variable Frequency Drives (VFD) in water and wastewater treatment. It specifically focuses on the opportunity to save energy and therefore money in the operation of pumps, blowers and fans. This lesson also covers the basic operation of an AC motor and what information is important when setting up a VFD. The objectives of this lesson are shown at the end of the post test.

The first part of this lesson is how a variable frequency drive (VFD) can save energy and therefore money. The word VFD is used in this lesson but other names are used for this same piece of electronic equipment, such as:

Adjustable Frequency Drive (AFD)

Variable Speed Drive

Adjustable Speed Drive

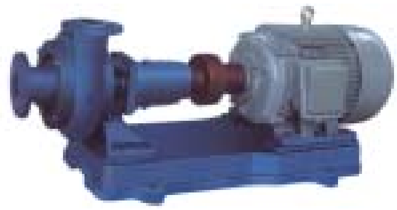
Inverter (to most motor manufacturers)

Frequency Converter (mainly in Europe)

or just simple Drives.

A Pre-test is given to determine your need for this lesson and a Post-test is given to determine the understanding of this information.

Why Control Flow?



- Water systems are designed for the “worst case” situations. Most of the time they have excess capacity.
- Controlling flow below its maximum
  - Saves energy
  - Improves system operation

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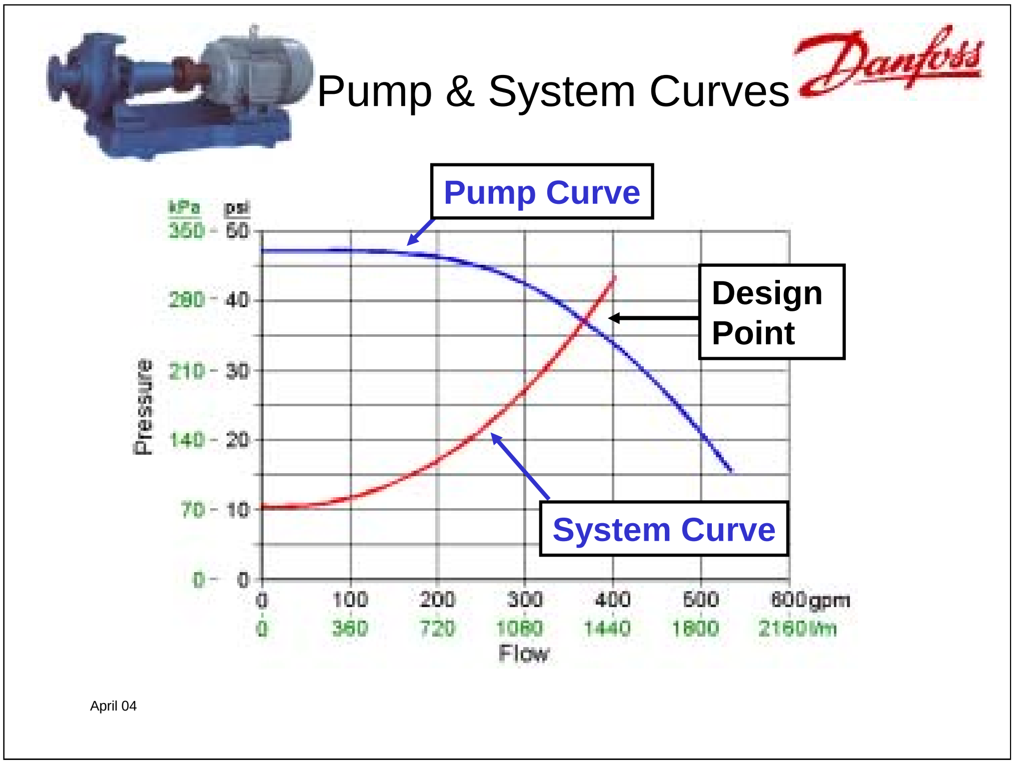
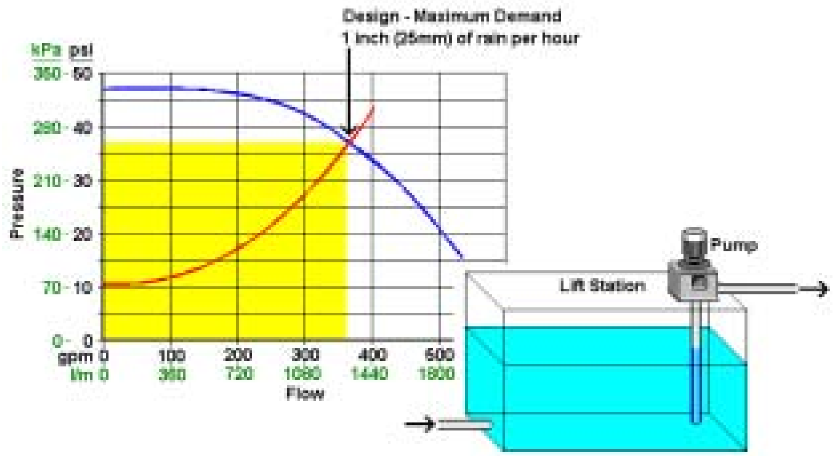
Using a pump as an example, it is sized for the worst possible condition, in other words at maximum load. The pump shown above has been sized for maximum flow which may only occur a few hours per year. The rest of the year the pump is oversized and has excess capacity. By controlling the flow, energy can be saved. Controlling the flow can also improve system operation which can make equipment run longer.



In the picture above, the Blue line shows the pump curve. Each pump manufacturer has a pump curve that shows the relationship between pressure and flow. As the flow increases, the pressure drops. The Red line shows the needs of a system, known as the system curve. Here as extra flow is needed, which causes resistance to increase. The pressure from the pump also increases to cause the water to flow through the pipes. Where they cross is known as the design point, which shows the maximum flow needed at the maximum demand. Selecting the proper pump also involves selecting the best pump efficiency and other issues but is not shown in the diagram above.

Lift Station Example



• Maximum Flow is capable of 360 gpm (1300 l/m)

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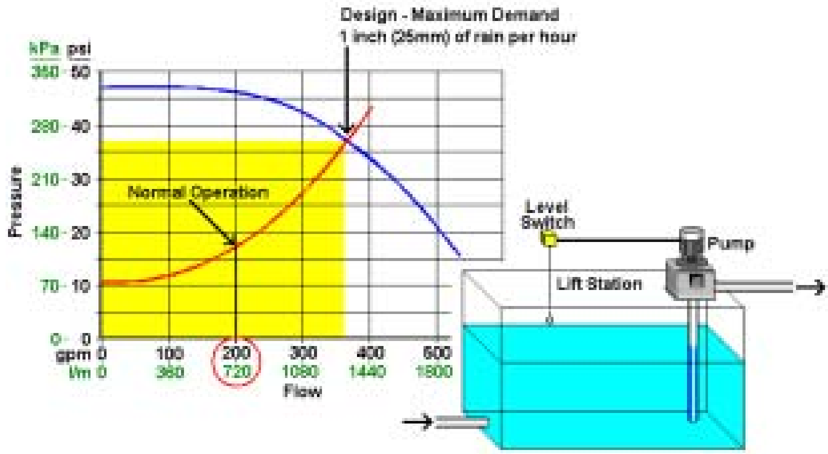
In the example above, a lift station is shown. The design point for this lift station is 1 inch (25mm) of rain per hour. Obviously it does not rain everyday especially at that rate, but the lift station must be designed to handle this demand in case it does happen. A pump curve is then selected which has the capability to handle this demand, in this example approximately 360 gpm (1300 l/m).

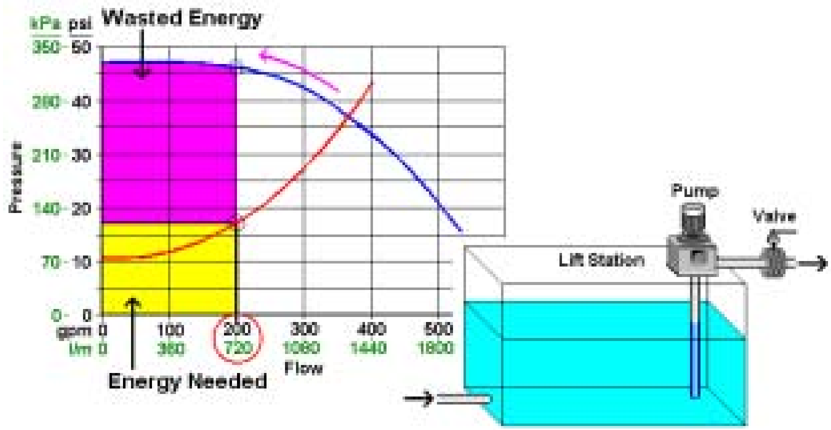
Design vs. Normal



- Normal Flow coming in stays around 200 gpm (720l/m)
- Cycle Pump ON and OFF

The design condition, or maximum flow is rarely needed. In fact normal operations requires perhaps only 200 gpm (720 l/m) to maintain the needs of the lift station. In order to achieve this level, a switch operates the pump cycling it ON then OFF to achieve this flow requirement. This constant cycling ON then OFF can cause excessive wear on the pump. Each time the pump starts, the amp draw is very large, perhaps 300% to 400% which can add to demand charges coming from the electric company.

Throttling Flow



- Use a valve to throttle the flow back to 200gpm (720 l/m)
- Pump rides up the pump curve – wasting energy

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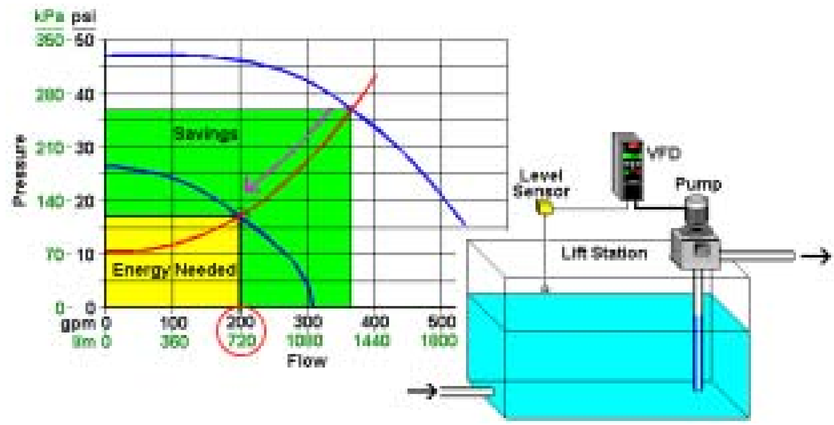
One way to control the flow to a normal level is to restrict it by using a throttling valve placed down stream from the pump. This restricts the flow so that 200 gpm (720 l/m) is pumped out and the pump runs relatively at the same speed. This saves on the wear caused by cycling the pump. The restricting valve causes the pump to ride up the pump curve, limiting the flow to 200 gpm (720 l/m), but increasing the pressure from 36 psi (250 kPa) to 46 psi (320 kPa). The system requires a much smaller amount of pressure and flow. The yellow block represents the amount of energy that is needed for the system. The purple block represents the amount of energy wasted.

Adjustable Speed



- Use a VFD to control the flow
- Pump rides down the system curve
- Saving energy

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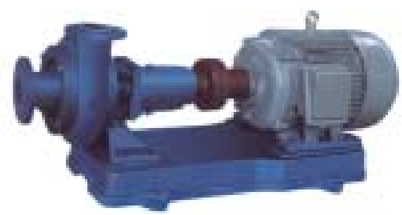
In the picture above, a level sensor is used to monitor the water level in the lift station. The pump is controlled by using a variable frequency drive to control the speed of the pump. This causes the pump curve, shown in blue, to be moved to a reduced location along the system curve. At the new pump location, both the flow and pressure are reduced. This reduces the amount of energy used which saves a considerable amount of money.

Why Adjustable Frequency Drive?

1. Energy Savings
2. Better System Control
3. Reduced Maintenance
4. Higher Efficiency
5. Easy Retrofit
6. Remote Mounting
7. Simple Control
8. Bypass capabilities



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The use of VFDs has been explained using pumps, but fans and blowers operating in very much the same way. Using a VFD on these applications can save considerable amounts of energy and causes a higher level of motor efficiency. By using VFDs the system can maintain a constant level or pressure without continuously cycling the pump or fan on and off. This allows for a better, tighter system control of a level or pressure, instead of cycling between a wide differential. The reduced cycling of the pump or fan also reduces maintenance not only on the fan or pump but other associated equipment such as check valves. VFDs are also soft-start devices, which have ramp time adjusts that allow for a slow start and slow stop eliminating the problem of water hammer.

An existing pump or fan can be easily retrofitted to use a VFD. If the motor is very old, perhaps 20 to 30 years old, an additional LC filter might be needed to protect the windings of the motor. Many VFDs can be run from their keypad which has a Hand-ON, Hand-OFF and Auto (HOA) settings, to check operation. If the VFD does run into problems, many come with auxiliary contacts to switch out the VFD and run power straight to the motor, allowing the pump or fan to run a full speed. This is known as a “bypass” capability.

How does an AC Motor Operate?

This part of the lesson covers AC motor operation and explains more terminology.

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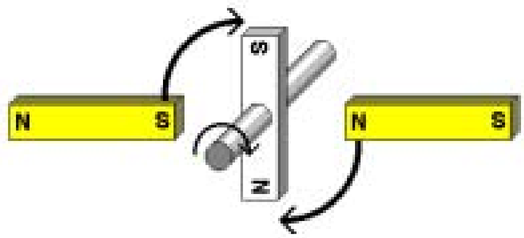
In one of the examples on a previous page, a pump was operated by an ON/OFF level switch. Obviously when power is applied, 240VAC, 380VAC or 460VAC, the motor runs. With no power, the motor stops. With the use of a variable frequency drive not only can the AC motor be started and stopped, but more sophisticated controls are accomplished.

A VFD can send a modulating signal to the motor, which allows a variety of speeds to be delivered not just an ON/OFF signal. This variety of speeds can be used to match the motor to a particular task, such as maintaining the correct speed to maintain a constant level in a lift station.

Some very small AC Motors, such as in the home, use single-phase motors. These single-phase motors require additional electric parts, such as a split capacitor, to move the magnetic field which causes the shaft to rotate. Because of these extra parts, single-phase motors do NOT operate correctly with a VFD, which only works with 3-phase motors.

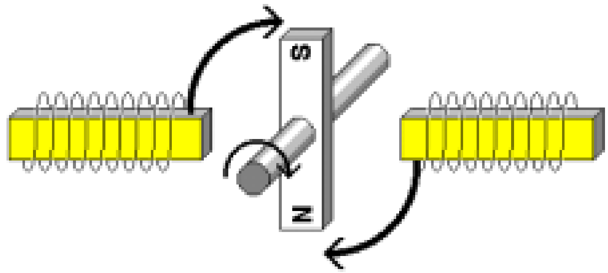
As background for the upcoming lessons, it is important that the operation of an AC motor is understood, which is covered in the pages that follow.

AC motor Operation



- AC motors use magnetic fields to produce rotation
- stationary magnets - Stator
- magnet in the middle rotates - Rotor

AC motors use magnetic fields to produce rotation. In the example above, there are 2 stationary magnets on the sides. These stationary sides, shown in yellow, are known as the **stator**. The magnet in the middle, in white, rotates and is known as the **rotor** or shaft. The magnet on the left repels the white magnet, south pushing against south. The magnet of the right also repels the other side, north against north. If the polarity of these three magnets does not change the rotor, ends up in a horizontal position, north to south and south to north, and stays there.



- Rotating magnetic fields causes rotation
- 60 Hz with 2 pole motor = 3600 rpm
- Synchronous speed is field speed
- Base speed is rpm from motor nameplate
- Difference is known as Slip

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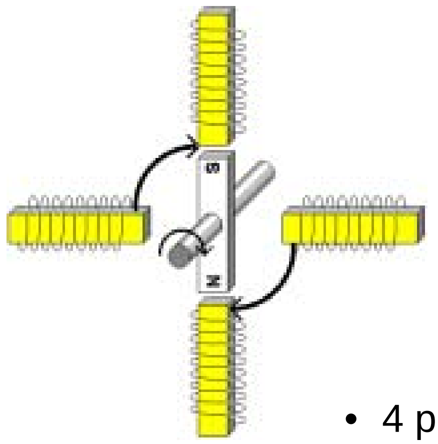
If the polarity of the stator is changing by inducing an AC current, the rotor continues to rotate trying to catch the magnetic field. For the motor shown here, if the frequency of the induced VAC is 60 Hz, the magnetic field rotates at 60 revolutions per second or 3600 revolutions per minute (rpm). In order to follow this, the rotor tries to rotate at 3600 rpm. The speed of the field is referred to as the motor's **synchronous** speed.

Base speed is the actual speed of the motor's rotor as designated by the nameplate information. In the vast majority of AC motors the base speed never quite matches the synchronous speed but is slightly behind it. These motors are known as **asynchronous** motors. This difference between the base and synchronous speed is known as **slip**. Example: if a 2-pole motor uses 60Hz the synchronous speed is 3600. The nameplate of this 2-pole motor shows a base speed of 3510 rpm, which means that it has a slip of 90 rpm. There are **synchronous** motors that have very special rotors that never slip, but these motors are far more expensive than asynchronous.



- 4 pole motor
- Sync speed is 1800 rpm
- Base speed is 1750, 1740, or perhaps 1725
- Very common

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Many ac induction motors that are connected to 60 Hz power have base speeds much lower than 3600 RPM. By changing the design of the motor, a lower base speed can be achieved. This induction motor shown above is the most commonly used.

The motor shown here is called a “4-pole” motor. It is wired so that the magnetic field rotates only one half of a revolution with a full cycle of induced ac power. The rotor therefore has to make 60 half-revolutions or 30 full revolutions, per second to keep up with the rotating magnetic field. The base speed of a 4-pole ac induction motor is 1800 rpm. These 4-pole motors are very common. Many nameplates have rpm listed as 1700, 1725 or 1750rpm. All of these are 4-pole motors, each with a different amount of slip. Motors that have nameplates of 1150 or 1175rpm are 6-pole motors. There is a formula that determines the speed of a motor shown on the next page.

Synchronous Speed Formula

$n = (120 \times f) / P$

- n= rpm
- f = frequency of Vac (60 Hz) and
- P = the number of pole pairs

Why 3 Phase Power?

- Necessary for large motors
- Lower current in each wire
- Motor operates more smoothly
- Rotation direction easily changed
- Eliminates the need for a starter circuit in the motor (example: split capacitor)

A formula to determine rpm based on the number of pole pairs is as follows, n = (120 x f) / P, where n= rpm, f = frequency of Vac (60 Hz) and P = the number of pole pairs. In this formula, the speed of the motor is directly related to the frequency. This is how the VFD, when it changes the frequency of the incoming power also changes the speed of the motor.

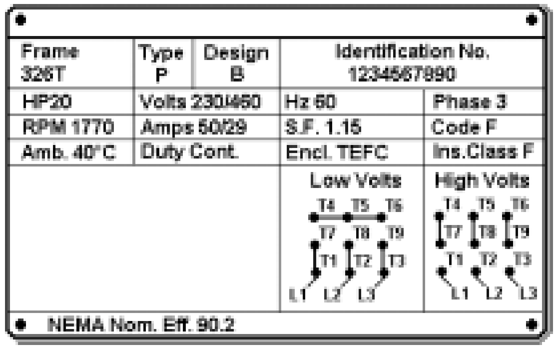
Up to this point, the motors that have been shown have been single - phase motors. This is done to simplify the drawings. It is important to point out that 3-phase motors are used with VFDs. There are reasons:

1) This eliminates the need for a starter circuit in the motor.

2) Current in each motor is reduced.

3) The motor operates more smoothly.

Motor Nameplate



Motor Plate

- Volts and amps
- RPM

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This section ends with a look at a motor nameplate. When using a VFD, information must be entered into the VFD to match the motor's nameplate. The entire nameplate is not discussed, but only the part that is necessary for the VFD.

The size of the motor comes first. It is a 20HP (Horsepower) motor, but for most VFDs, this must be converted into kW (kilowatts) The conversion is 0.75kW = 1Hp. In the nameplate above 20Hp is programmed into the VFD as 20Hp x 0.75 = 15kW. With motors from North America, they can be either 230 or 460Vac designated as 230/460. The wiring for each is shown in the lower right corner. The correct voltage of the motor must be put in the VFD. Next the motor frequency at full speed is entered which for North America is 60Hz, 50Hz for the rest of the world.

The correct current must also be entered which in this case is 50 amps at 230Vac or 29 amps at 460Vac. Next the speed of the motor is entered into the VFD, which in the example is 1770 rpm. Since the motor is slightly less than 1800rpm it can be determined that this is a 4-pole asynchronous motor. This is the information that is necessary for the VFD.

Some last notes about motors

North American Motor

Speed Range

Enclosures

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Some other notes that need to be mentioned.

Constant Torque Speed Range

Motors have a rating which is called constant torque speed-range which is given as a ratio, 20:1, 100:1 or 1000:1. This is an indication of how slow the motor can run before it overheats. A motor with a 1000:1 ratio is very good, which can run as slow as 1.8rpm without overheating. A 100:1 overheats when it reaches 18rpm and a 20:1 overheats when the speed is less than 90rpm. The larger the speed range ratio, the slower the motor can safely operate.

Enclosures

Enclosure types are indicated with letter codes. Here are a few:

TENV (Totally Enclosed Non-Ventilated)

TEFC (Totally Enclosed Fan-Cooled)

XPBC (Explosion Proof Blower-Cooled)

A Fan-cooled motor has an internal fan attached to the shaft. As the speed slows down, the cooling decreases. A Blower-cooled motor has an internal fan that is independent from the shaft. Blowers run at full speed all the time, so the blower is NOT effected by the speed of the shaft.

Some last notes about motors

European Motor

Service Factor

Inverter-Duty

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Service Factor

When motor manufacturer build ac induction motors, there is an item called Service Factor (S.F.). This is a rating of extra capacity. If a 10Hp ac motor has a Service Factor of 1.15, this means that the motor has the extra capacity to operate at 11.5Hp. Some motor manufacturers provide no extra for their motor, which means they have a Service Factor of 1.0. Other motor manufacturers are concerned with providing some extra so that their motors have a Service Factor of 1.15.

Inverter-Duty

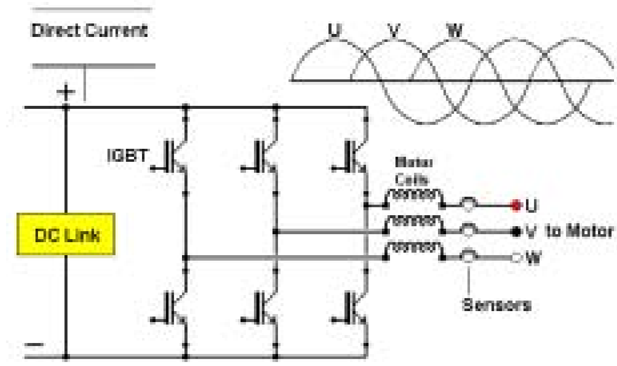
Some motors promote that they are Inverter-duty. This means that they are designed to operate with AFDs. If an AFD is used with an older motor, one that is not inverter-duty, the first winding has the potential to open, due to increased voltage and current surges.

This completes this lesson. Review the Post-Test to see how well you understand this information.

VFD 101

Lesson 3

Parts of a Variable Frequency Drive (VFD)



This lesson covers the parts that make up the Variable Frequency Drive (VFD) and describes the basic operation of each part.

Here is the basics outline for this lesson.

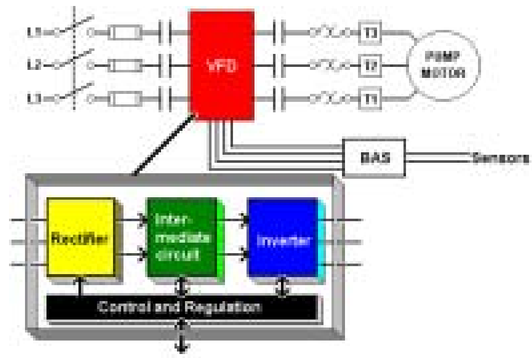
Outline:

Parts and Operations of a Drive

1. VFD part of a Larger System
2. Rectifier
3. Soft Charge Circuit
4. Intermediate Circuit (DC Link)
5. Brake Circuit
6. Inverter
7. Pulse Width Modulation
8. Control & Regulation Section

Note: Other names are used for this device, such as Adjustable Frequency Drive (AFD), Variable Speed Drive (ASD), Frequency Converter and Inverter, but Variable Frequency Drive (VFD) or just Drive is used throughout this lesson.

VFD 101
Lesson 3



This lesson covers the basic parts and operation of a Variable Frequency Drive (VFD). These parts are divided into 4 sections: Rectifier, Intermediate circuit (DC Link), Inverter and Control & Regulation.

1. VFD in a Larger System

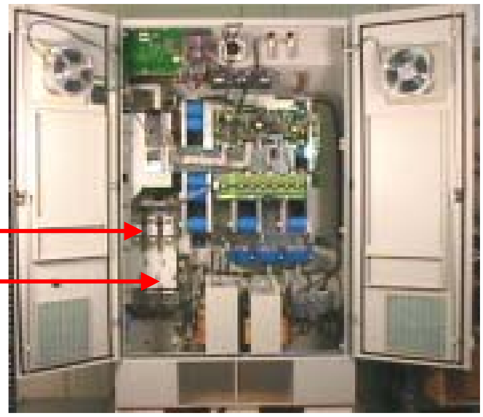
This section covers the parts and operation of the Variable Frequency Drive (VFD). It is important to keep in mind that the Drive is just one part of a system. In the diagram above, notice the disconnect switch, fuses, bypass switch, thermal overloads, BAS, etc. all play an important part in making an application work correctly.

Inside the VFD there are 4 major sections: rectifier, intermediate circuit (DC Link), inverter and control/regulation. This fourth section, control and regulation, interfaces with the other 3 sections.

In very general terms the operation of the drive is as follows. Power first goes into the rectifier, where the 3-phase AC is converted into a rippling DC voltage. The intermediate circuits then smoothes and holds the DC Voltage at a constant level or energy source for the inverter. The last section, the inverter, uses the DC voltage to pulse the motor with varying levels of voltage and current depending upon the control circuit. The pattern of the pulses going to the motor makes it appear similar to an AC sinusoidal waveform.

Each one of these sections is reviewed in some detail in the pages that follow.

To understand the parts of an VFD better, an example of a 450kW (600Hp) drive is used.



Fuses

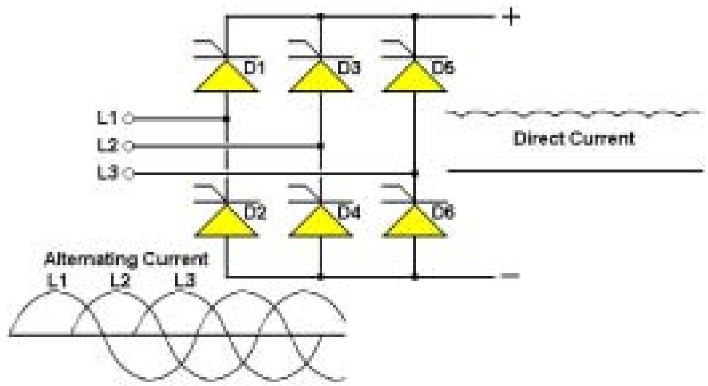
Disconnect

In the picture notice the fuses and disconnect switch.

As each part is explained pictures of these parts on a 450kW (600Hp) drive are displayed. This large drive is used in this lesson for the size of the parts are easy to identify.

One of the options for these large drives 315 – 450kW (350 – 600Hp) is to have fuses and a disconnect switch mounted inside the drive. With smaller size drives fuses and a disconnect are separate but are still part of the overall system as described on the previous page.

2) Rectifier Section



Its function is to change 3-phase AC into DC.

2. Rectifier

The 3-phase AC voltage goes into the rectifier section which is made up of a group of gated diodes (silicon rectifiers or SCRs). In most VFDs, these diodes are in a group of 6 as diagramed above. One VFD manufacturer has stressed that there should be more sets of diodes, 12, 18, even 24. Reasons for/against this are covered in lesson 5.

Diodes (D1 through D6) allow current to flow only in one direction when enabled by the gate signal. In this diagram, the AC power on L1 goes into Diodes D1 and D2. Because of the position of these diodes, current flow can only go up. The D1 diode conducts when the AC is positive and D2 conducts when the AC goes negative. This drives the top line (+) more positive and the bottom line (-) more negative. Diodes D3 and D4 convert L2 power to DC and Diodes D5 and D6 convert L3. A volt ohmmeter or VOM can be used to measure this DC voltage. In this type of circuit, the DC voltage is 1.35 times the AC line voltage.

If 240 Vac is coming in, 324 Vdc is generated.

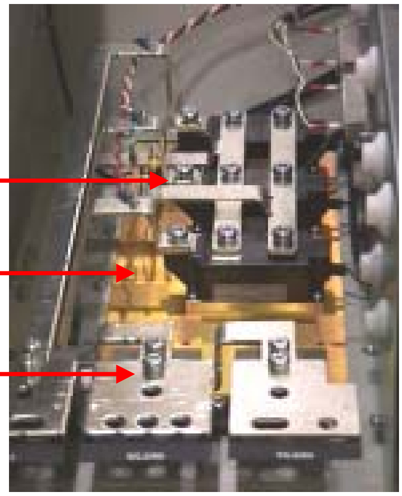
If 380 Vac is coming in, 513 Vdc is generated.

If 460 Vac is the line voltage, 621 Vdc is generated.

If 575 Vac is the line voltage, 776 Vdc is generated.

Because of line (power coming in) and load (power to the motor) changes, the DC Voltage level is constantly moving above and below this expected value.

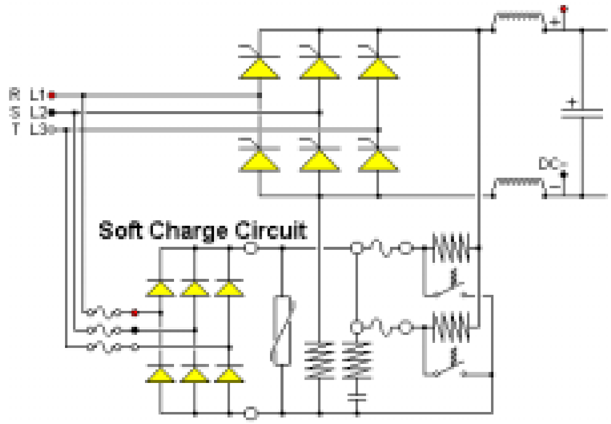
2) Rectifier Section



The Rectifier section contains terminals for incoming power, silicon rectifiers (SCR) and heatsinks

The picture above highlights the rectifier section of the drive. Six SCRs are used to change the incoming power from AC to DC. This rectification can generate a considerable amount of heat, so the SCRs are mounted onto a gold-colored heatsink. The fins of the heatsink are facing the other way inside a special ductwork where the air flow removes the heat. Four fans mounted across the top of this VFD pull the air across the heatsink. Remember that heat is the enemy both to the drive and to the motor. Any practice which makes either run cooler makes them last longer. Because of the high amperage (750A for this unit) there are bus bars connecting the rectifiers to the incoming power. Even the largest wire size is too small for this unit.

3) Soft Charge Circuit



On large drives, 22kW (30Hp) and larger, a soft charge circuit is added in helping charge the cap banks before main power is applied to the rectifier.

3. Soft Charge Circuit

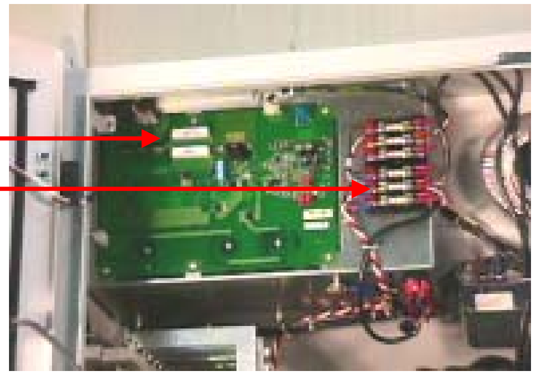
On larger drives, 22 – 450kW (30 – 600Hp), a part of the rectifier section is known as the soft charge circuit, which is used to power up the drive. With this circuit, when power is applied, the inrush of current is restricted going to the large capacitors in the DC Link, so that they may charge up slowly (within a couple of seconds). If this circuit was absent, line fuses would be blown every time the VFD was started. The soft charge circuit on some of the VFDs has a resistor or two in line with the current to slowly allow charging of the capacitors. This current resistor even has its own safety, a thermal switch, which shorts out if the current rush is too high in the soft charge circuit. The shorted thermal switch blows fuses on the soft charge circuit preventing the drive from starting.

Once main power is applied to the drive, the SCRs in the main rectifier section remain off. The much smaller rectifier section in the soft charge circuit starts, applying DC power through the current resistors charging up the capacitors in the DC Link. When these capacitors are charged to the DC voltage minimum value, the control section starts the firing of the SCRs in the main rectifier. Because of the amp draw through the current resistors in the soft charge circuit, time is needed to cool them off, so the 22 – 450kW (30 - 600 Hp) drives are limited to 2 start per minute.

3) Soft Charge Circuit

Soft Charge Circuit

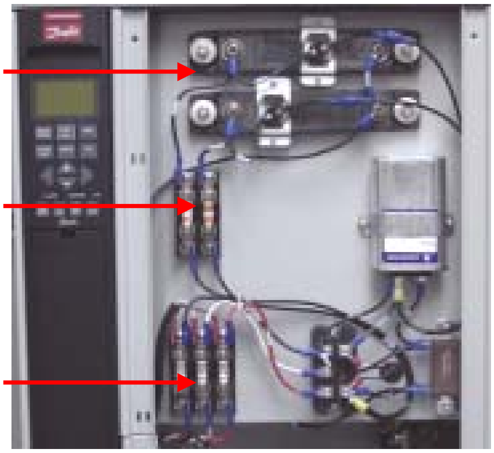
Soft Charge-
Snubber Fuses



Here is a picture of the soft charge circuit in the 450kW (600Hp) drive.

In the picture above, the soft charge circuit card is shown. This circuit card on the 450kW (600Hp) drive is in the upper left corner, just above the rectifier section. Notice that the soft charge fuses are just to the right of the circuit card. The soft charge circuit card on the 315-450kW (350-600Hp) drives uses small IGBTs instead of resistors to limit power going to the capacitors. This is referred to as an active soft charge.

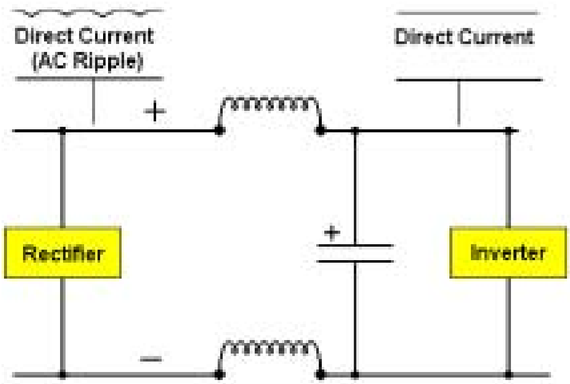
3) Soft Charge Circuit



Soft charge circuit in the 160kW (200Hp) drive.

On the 160kW (200Hp) drive, shown above, the soft charge circuit is exactly like the schematic diagram shown on the previous page. Notice the 2 large black current limiting resistors used to limit power going to the capacitors in the DC Link section.

4) Intermediate Circuit (DC Link)



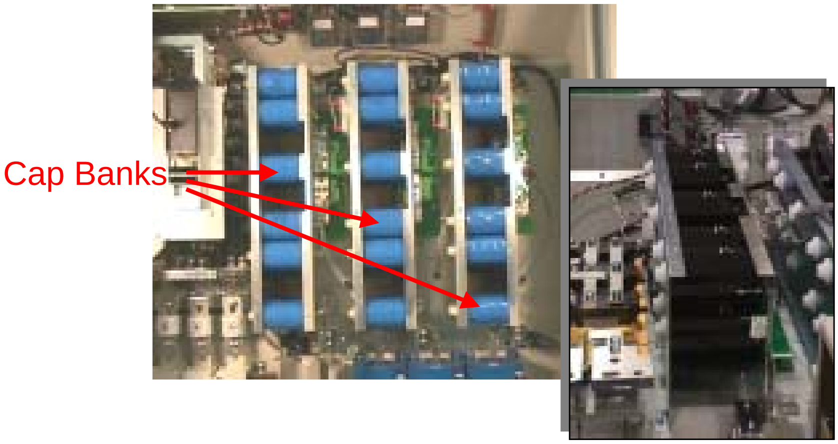
Using a large bank of capacitors and DC reactors the rippling DC voltage becomes more stable.

4. Intermediate Circuit (DC Link)

The Intermediate Circuit also known as a DC Link, can be seen as a power storage facility for the next section, the inverter section. There are 2 major components to the DC Link section, capacitors and coils. In the diagram above only one capacitor is shown but it is always a series of capacitors. With Danfoss VFDs, this intermediate section always uses DC coils also known as DC Line Reactors or DC chokes. For cost considerations, most other VFD manufacturers do not offer these DC Line Reactors as standard equipment. Danfoss regards these coils as essential for two main reasons; one is the ability to reduce harmonic noise (interference) by 40% and the other is the ability to ride through a temporary loss of power. This allows this drive to avoid numerous nuisance shut downs.

In the diagram above, notice that the rippled DC voltage coming in has now been filtered to a relatively constant voltage. Remember that this DC Link Voltage is 1.35 times the input voltage. The value of the DC Link voltage can be read from the display on the front of the drive. When ever working around the drive always be careful and give it a healthy respect. The largest drive produces 620Vdc at 750 A.

4) Intermediate Circuit (DC Link)

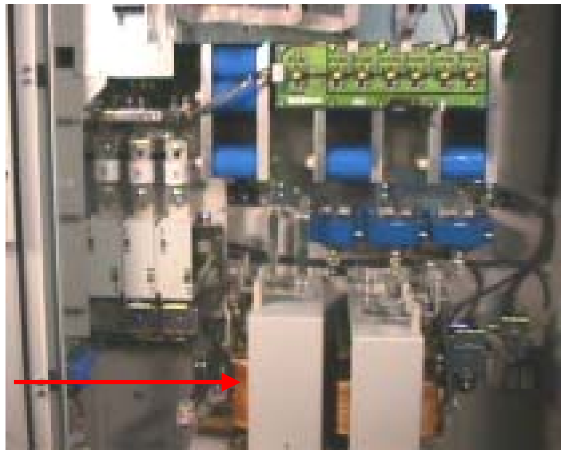


The blue capacitors banks (black on newer units) are a major part of the DC Link and store a great deal of energy.

When looking at a drive, some of the most striking components are the 2 devices that make up the DC link. The 3 banks of blue capacitors on the 450kW (600Hp) drive, shown on the left, are quite prominent. On newer units these blue capacitors have been replaced with black ones. They are in the center of the drive, just to the right of the rectifier section. There are 3 banks of 12 capacitors in each bank for a total of 36 capacitors. Capacitor numbers vary with each size of drive. This 3-bank arrangement is to allow for easier service. The plate on the right side of each capacitor bank has full voltage.

4) Intermediate Circuit (DC Link)

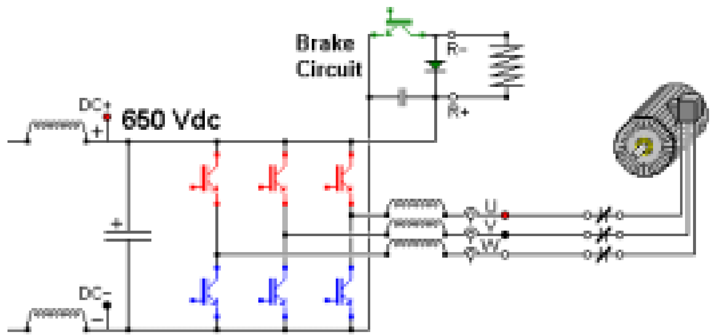
DC Reactors



There are 2 sets of coils shown above. The DC Link coils are always the ones with 2 terminals, shown here on the left.

In the picture above there are 2 sets of coils. The coils on the left at the bottom center of the drive, the ones that have 2 connections (DC +, DC -) are the DC Coils, also know as DC Reactors or DC Chokes. The other set of coils to the right, with 3 terminal connections, are discussed in the pages that follow.

5) Brake Circuit

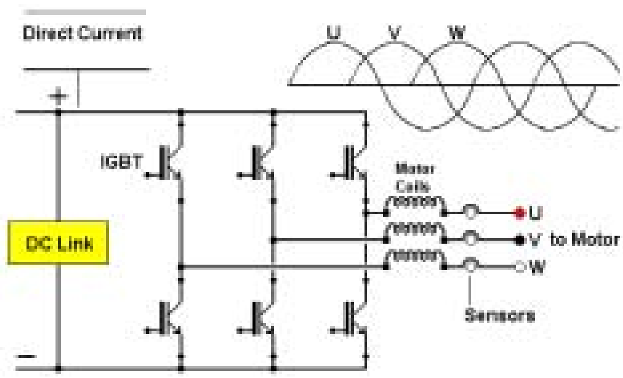


When drives are ordered with dynamic braking, the drive comes with Brake IGBTs. When the voltage gets too high on the DC Bus, the brake IGBT activates sending power to the brake resistor. This is NOT an option with HVAC drives.

<u>5) Brake Circuit</u>

This Brake Option, also known as Dynamic Braking, is used with devices that need to stop or change directions quickly, such as conveyors, hoists and centrifuges. On drives that have the brake option, an additional IGBT transistor is used to remove extra power coming back into the drive when the motor, which has a large inertia, is stopping or changing direction. The only HVAC related application that might use dynamic braking is for some fans for boiler combustion. This option is not required for the vast majority of HVAC applications.

6) Inverter Section



The Inverters take the voltage from the DC Bus and using Pulse Width Modulation (PWM) sends a signal which appears to the motor as an AC signal.

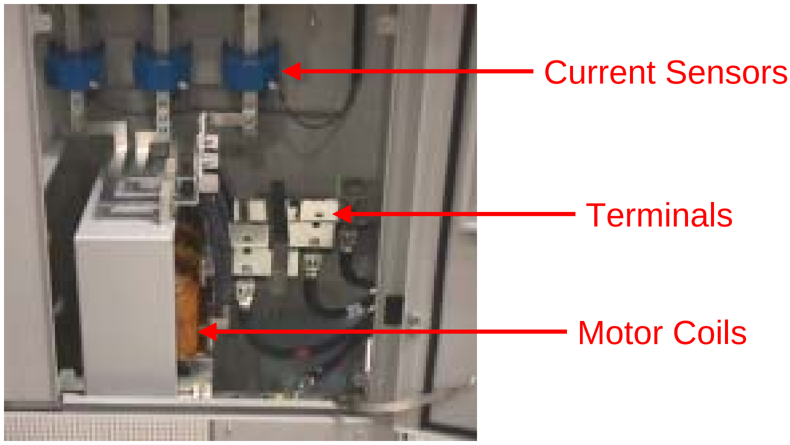
<u>6) Inverter</u>

The next part of the VFD is the Inverter section. This section takes the DC voltage from the intermediate section and, with the help of the control section, fires each set of IGBT (Insulated Gate Bipolar Transistors) to the U, V and W terminals of the motor. This firing of the IGBTs is known as Pulse Width Modulation (PWM) and is described in the next couple of slides.

Notice in the diagram above that sensors monitor the current going to each terminal of the 3-phase motor. Unlike some other manufacturers, Danfoss monitors all 3 phases continuously. There are some manufacturers, who in an attempt to cut costs, only have 2 sensors and guess on the output to the 3rd. There are others that only monitor the outputs when the first run command is given.

Another component that Danfoss insists on including are the motor coils on any drive larger than 18.5kW (25Hp). These coils smooth the waveform going to the motor. The smoother the waveform the less heat is generated at the motor and the longer the motor lasts. The standard distance used by Danfoss between its drive and the motor is 300m (1000 feet) using unshielded cable. There are other manufacturers that are limited to shorter distances 100m (330 feet) or less. Some end users have used distance as a sign of quality. The longer the distance, the better the drive.

6) Inverter Section



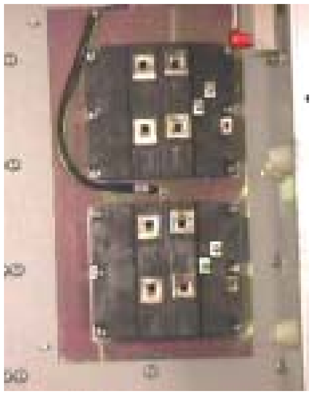
Motor coils, current sensors and motor terminals are located in the lower right corner of the 450kW (600Hp) drive.

The current sensors monitor the current going to the 3-phases of the motor. These sensors detect and alarm when a short circuit or grounded circuit is discovered. Some manufacturers only check for short circuits or grounding on the first run command, but Danfoss monitors for these faults all the time. This allows Danfoss to place a motor disconnect between the drive and the motor. If the motor is disconnected from the drive during operation, the drive might trip, but because of this constant monitoring, it suffers no damage.

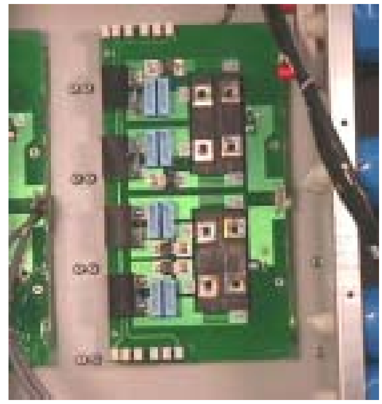
A disconnect switch between the motor and drive is not allowed by many other manufacturer. If a disconnect switch is used on a few drives, it causes severe damage – in other words the smoke is let out.

6) Inverter Section

IGBTs



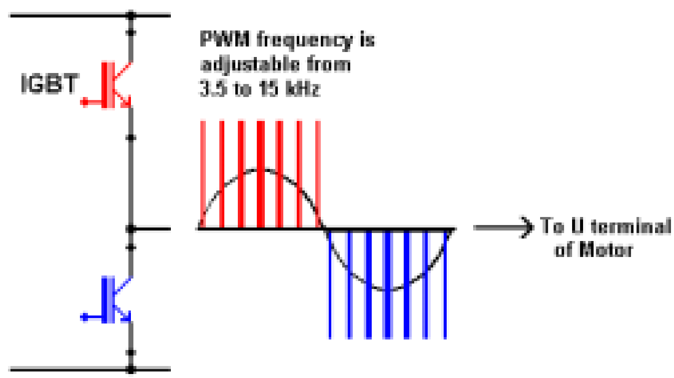
IGBT snubber card



The inverters, IGBTs and snubber card, are mounted on heatsinks under each of the 3 cap banks.

The IGBTs are mounted on the heatsinks behind the capacitors in the middle of the 450kW (600Hp) drive. The picture on the right shows two IGBTs with the circuit card which is used to help control them, know as a snubber card. The picture on the left shows the IGBTs without the snubber card. The correct mounting pattern for the 6 screws (done in a rotating manner) on each is critical, so that there is proper contact between the IGBT and the heatsink.

7) Pulse Width Modulation



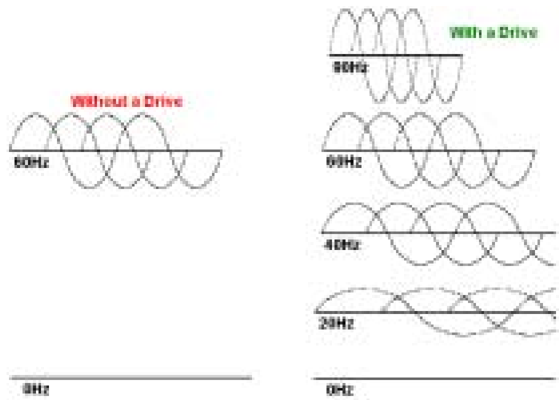
All manufacturers of drives use PWM, but there are differences when it comes to the shape of the pulses going to the motor.

7) Pulse Width Modulation

In the diagram above, a close up view of the waveform that goes to the motor shows the switching frequency of the IGBTs. The switching-pattern shown above is known as pulse width modulation or PWM. As the length of time is increased for the IGBT to be ON and then OFF, the motor responds to it as a sinusoidal waveform. The positive IGBT fires first in the diagram followed by its negative counterpart. Only one motor terminal (U) is shown but the same type of activity would appear on V and W.

In the diagram above only 7 pulses are shown on each side, but actually 1750 pulses or more should be shown. This PWM frequency can vary from 3.5KHz to 15 kHz, which means it is audible. It is also known as the **Carrier Frequency**, which is Variable by most VFD manufacturers. A low carrier frequency can have an annoying noise, but a higher carrier frequency generates more heat in the drive and motor. If the carrier frequency noise is too loud particularly with supply fans, LC filters can be placed between the VFD and motor and the noise stops at this filter.

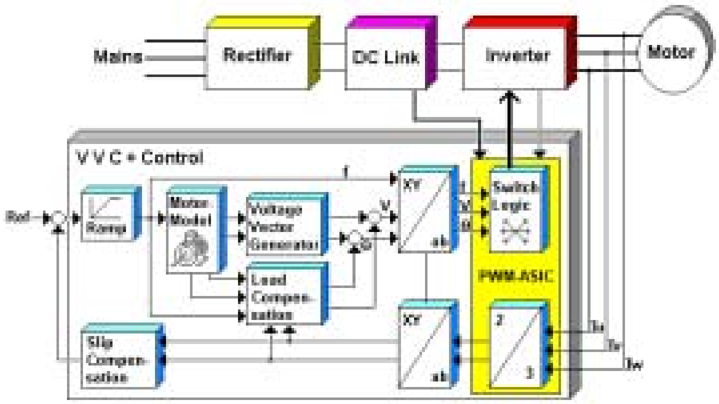
7) Pulse Width Modulation



Without a drive, the motor can go full speed or OFF; With a drive, the motor can go to a number of different speeds.

At first glance the function of a drive might look rather confusing. Taking 50Hz or 60Hz power input then changing it to DC only to change it back to look like AC to the motor. Due to the electronics in the drive, the DC voltage can be manipulated in a much easier and adaptable fashion. In the example, without the drive, the only signal the motor sees is ON (50Hz/60Hz) or OFF (0Hz). With a drive the motor can operate with 20Hz, 40Hz, 60Hz, 90Hz or any frequency in between, making it much more adaptable to any application.

8) Control & Regulation



The control and regulation section monitors the other 3 sections, making numerous calculations and adjustments to the outgoing signal.

<u>8) Control & Regulation Section</u>

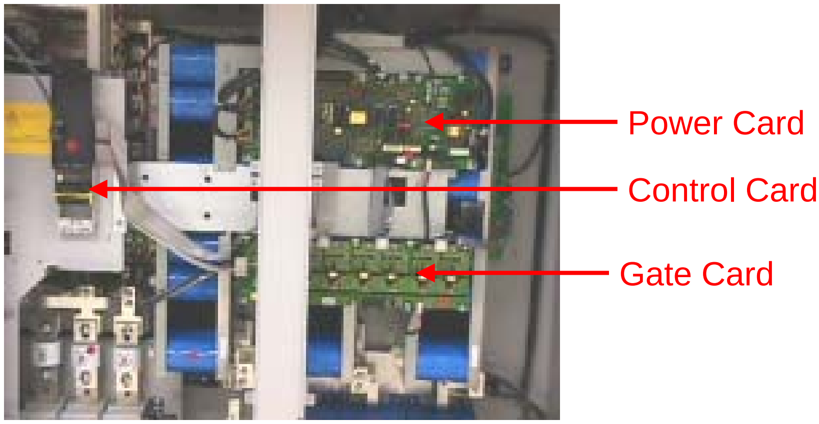
The control section coordinates and regulates signals inside the drive. This is where numerous calculations are completed to properly switch the IGBTs. This control section uses Vector technology, which separates the torque producing current from the magnetizing current. In the diagram above the current going to the AC motor is being monitored.

The Danfoss VLT 6000 has a special program, algorithm, called Automatic Motor Adaptation (AMA), which determines the electrical parameters for the connected motor while the motor is at a standstill, a feature introduced by Danfoss in 1996. Many competitors must decouple and spin the motor for tuning. Because the AMA measures the resistance and reactance of the motor's stator establishing a motor model, the magnetizing current can be calculated. This motor model is used to calculate the slip and load compensation.

The control section uses the frequency (f), voltage (V) and phase angle (theta) to control the inverter. This means that the torque producing current can be controlled more accurately. This robust sensor-less regulation scheme Voltage Vector Control (VVC+), which is patented by Danfoss, can compensate for rapid load changes.

In most HVAC applications where there is a minimum speed greater than 5Hz, the AMA feature is only a minor benefit. It is very important if used on motors spinning at 5Hz or less.

8) Control & Regulation

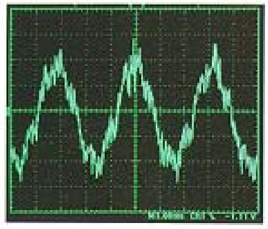


Three cards make up the control and regulation section, the control card, the power card and the gate card. On smaller units the power and gate cards are combined.

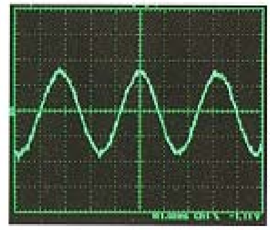
In the picture above, on the 450kW (600Hp) drive, 3 circuit cards make up the control and regulation section for the drive. These cards are mounted onto the frame used for the capacitor banks.

The Control Card is the same card used on all drives from 0.75 – 450kW (1 - 600Hp). The Local Keypad (LCP) fits into this control section. The LCP is used to program and monitor the drives operation. The next card is known as the power card, which is specific for a particular size of drives. It relays signals to the gate card, monitors the current from the current sensors, coordinates the fan operation and a number of other functions. The third is known as the gate card, whose major function is to send signals to the IGBTs. On smaller drives these last 2 circuit cards are together on one card.

Summary



Conventional PWM



Danfoss V V C +

The function of all the parts of the drive, Rectifier, DC Link, Inverter and Control/Regulation is to make a clean waveform to the motor.

The operation of the control and regulation section produces a very clean waveform going to the motor. The picture to the left shows an oscilloscope trace of a motor phase current provided by a conventional pulse width modulation system with harmonic elimination. To the right is the output from the Danfoss VVC+ system. The more sinusoidal the wave form going to the motor the easier it is on the motor and the less heat resulting in longer motor life.

Here are some of the advantages of the control and regulation program that is in the Danfoss drives.

<u>Advantages of Voltage Vector Control (VVC +)</u>

Up to 110% motor torque for 1 minute.

Automatic Energy Optimization

Flying Start

Sleep Function at minimum speed, Wake up speed on demand

PID LOOP with 4-20mA input and/or 0-10Vdc inputs

Fast system response to speed and load changes (3 ms updates)

Disconnect switch allowed between the drive and motor

Sensor calculation: Max of 2, Min of 2, Average of 2, etc.

Long Cable lengths (1000’ unshielded) between drive and motor.

This completes this lesson – Review Questions in Post-Test