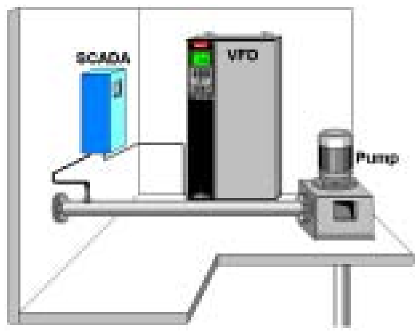
VFD 101

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

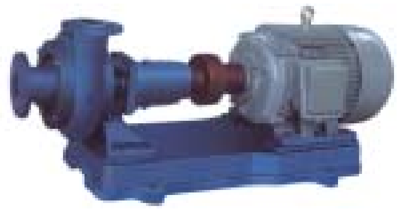
Inverter (to most motor manufacturers)

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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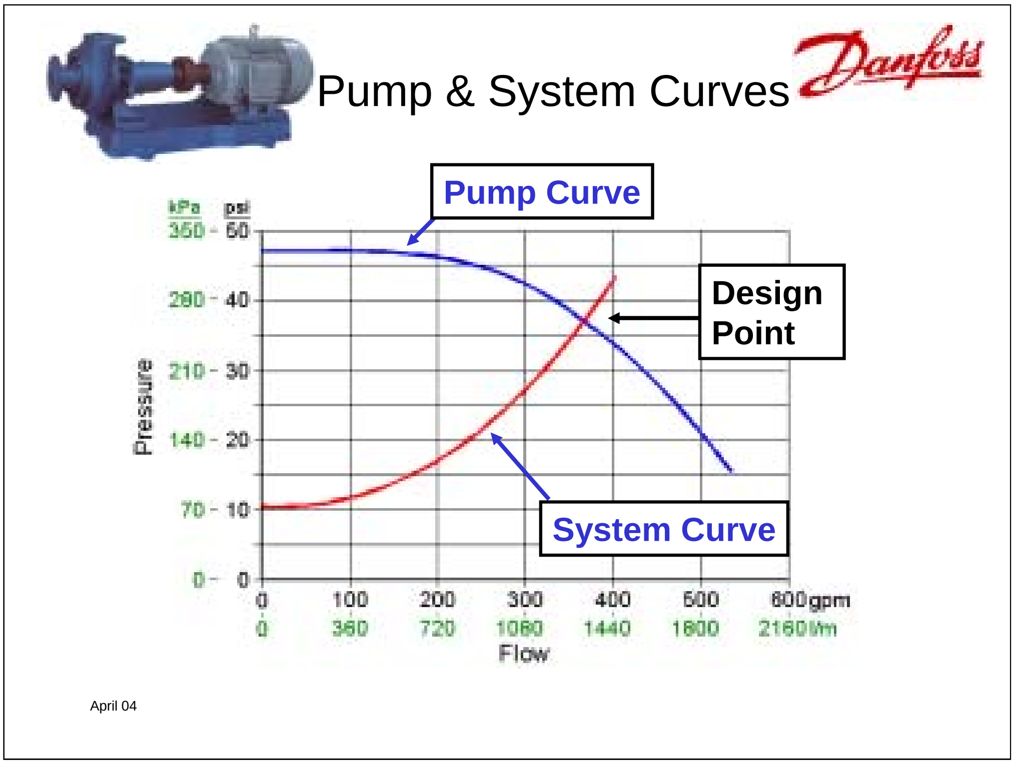
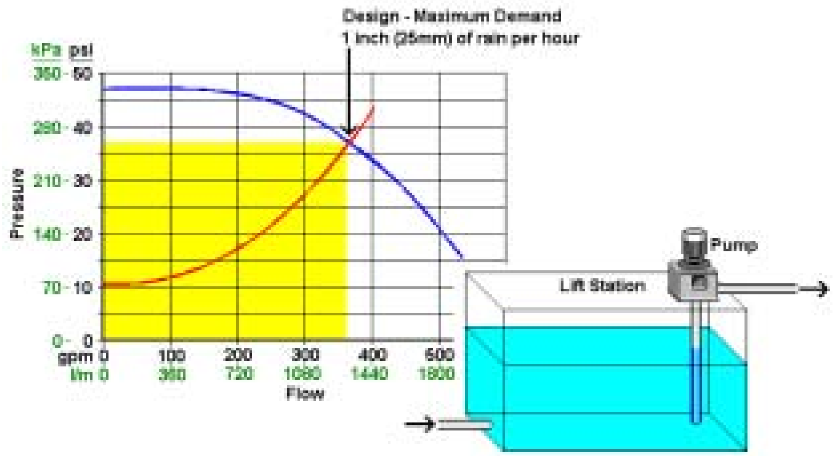
Using a pump as an example, it is sized for the worst possible condition, in other words at maximum load. The pump shown above has been sized for maximum flow which may only occur a few hours per year. The rest of the year the pump is oversized and has excess capacity. By controlling the flow, energy 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.

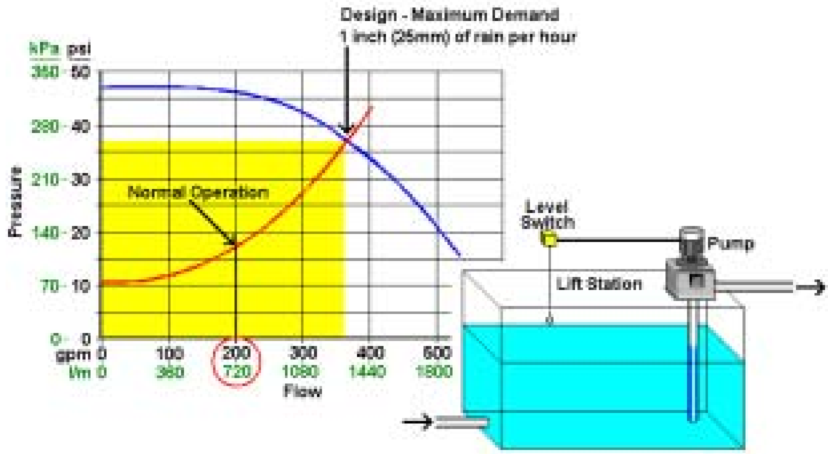
Lift Station Example



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

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

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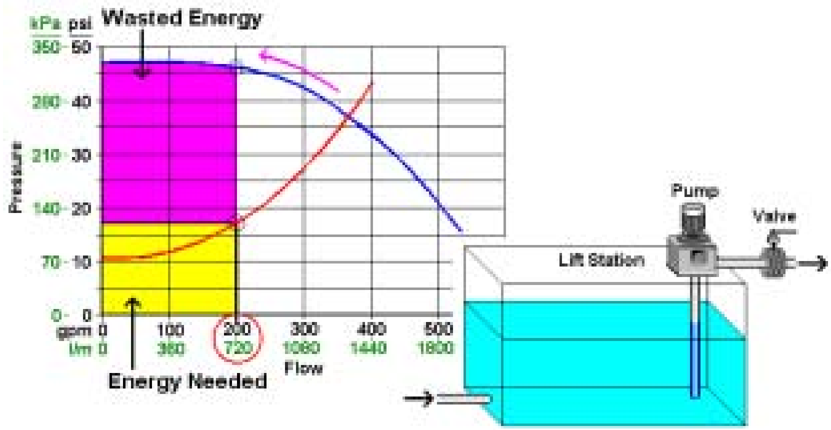
The design condition, or maximum flow is rarely needed. In fact normal operations requires perhaps only 200 gpm (720 l/m) to maintain the needs of the lift station. In order to achieve this level, a switch operates the pump cycling it ON then OFF to achieve this flow requirement. This constant cycling 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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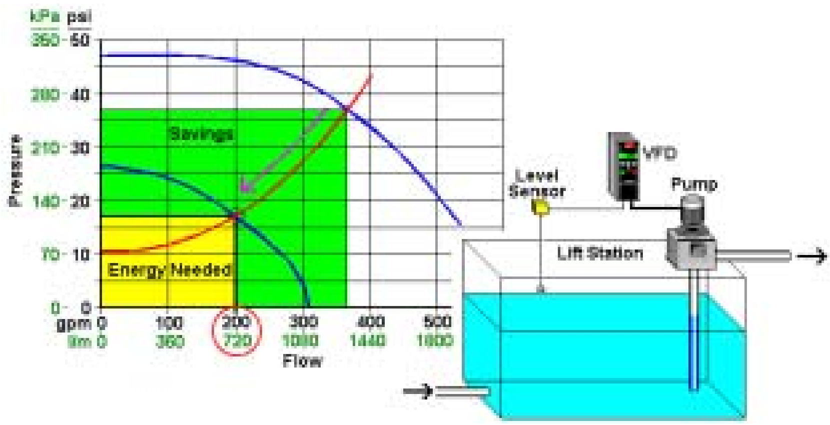
One way to control the flow to a normal level is to restrict it by using a throttling valve placed down stream from the pump. This restricts the flow so that 200 gpm (720 l/m) is pumped out and the pump runs relatively at the same speed. This saves on the wear caused by cycling the pump. The restricting 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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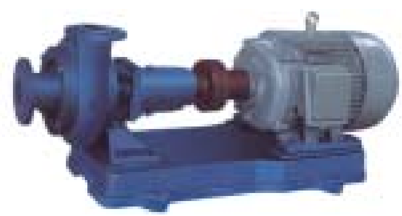
In the picture above, a level sensor is used to monitor the water level in the lift station. The pump is controlled by using a variable frequency drive to control the speed of the pump. This causes the pump curve, shown in blue, to be moved to a reduced location along the system curve. At the new pump 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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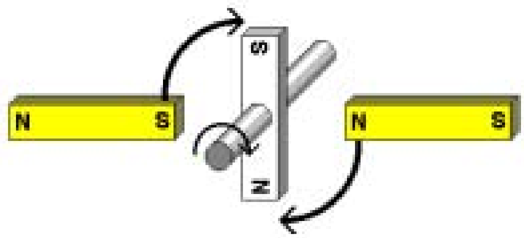
In one of the examples on a previous page, a pump was operated by an ON/OFF level switch. Obviously when power is applied, 240VAC, 380VAC or 460VAC, the motor runs. With no power, the motor stops. With the use of a variable frequency drive not only can the AC motor be started and stopped, but more sophisticated 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

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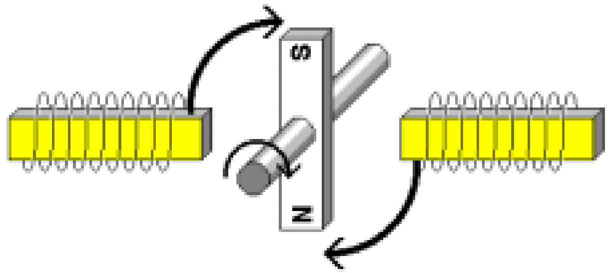
AC motors use magnetic fields to produce rotation. In the example above, there are 2 stationary magnets on the sides. These stationary sides, shown in yellow, are known as the **stator**. The magnet in the middle, in white, rotates and is known as the **rotor** or shaft. The magnet on the left repels 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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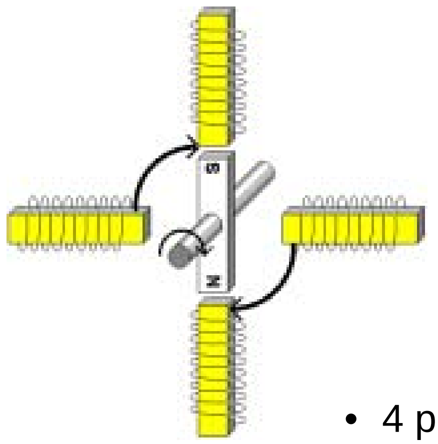
If the polarity of the stator is changing by inducing an AC current, the rotor continues to rotate trying to catch the magnetic field. For the motor shown here, if the frequency of the induced VAC is 60 Hz, the magnetic field rotates at 60 revolutions per second or 3600 revolutions per minute (rpm). 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)

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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.

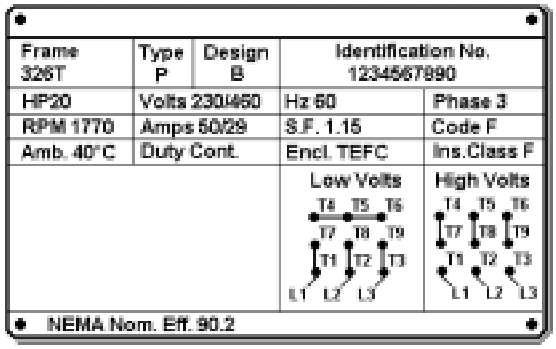
Up to this point, the motors that have been shown have been single - phase motors. This is done to simplify the drawings. It is important to point out that 3-phase motors are used with VFDs. There are reasons:

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.