Drives 101

Lesson 4

Application Terminology for an AFD

Screw Compressor
AFD must be CT or VT?

This lesson covers the application terminology associated with an Adjustable Frequency Drive (AFD) and describes each term in detail.

When applying an Adjustable Frequency Drive (AFD) to a particular application, a number of terms are involved. This lesson attempts to clarify most of those terms.

Here is the basics outline for this lesson.

Outline: **Application Terminology**

1. Application Curves
2. Starting Torque
3. Open or Closed Loop
4. Closed Loop and PID
5. Different Types of AFDs

Outline

Application Terminology

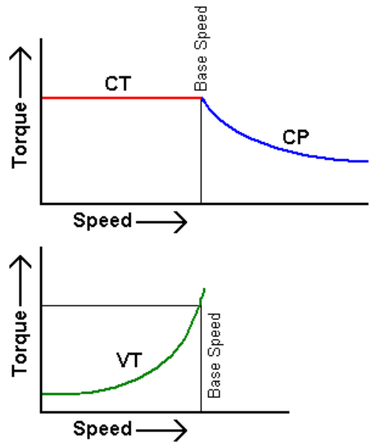
1. Application Curves – CT, CP, VT
2. Starting Torque – HO, Breakaway, NO
3. Open or Closed Loops
4. Closed Loop & PID – Action, Setpoint, Offset, Proportional, Integral, Derivative
5. Different Types of AFDs

This module covers some of the application terminology used with adjustable frequency drives (AFD). This terminology becomes very important for selecting the correct AFD and programming the correct settings needed for an application.

Applications include terms such as Constant Torque (CT), Constant Power (CP) and Variable Torque (VT). Starting Torque is also covered, which uses High Overload (HO), Breakaway Torque, and Normal Overload (NO). Terms such as speed open loop, speed closed loop and process closed loop are also covered. Terms in the process closed loop, also explore action, setpoint and PID terminology.

The last part covers a summary of the different types of AFDs. It shows the Volts/Hz, Voltage Vector, Flux Vector as they compare to a DC Servo in terms of response, accuracy and speed range. A more detailed explanation of each type is scheduled for a later lesson.

1. Application Torque Curves



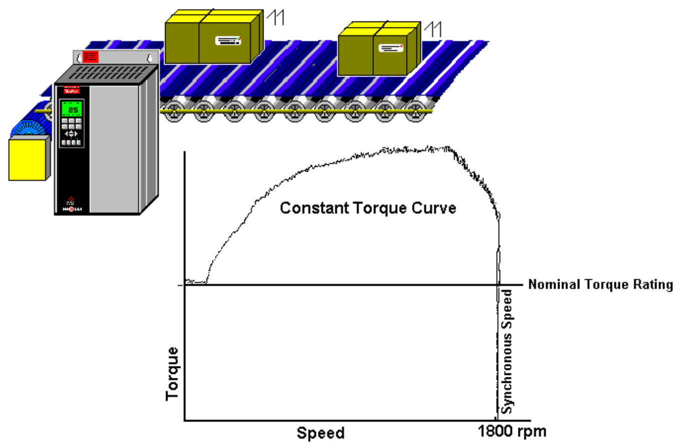
This part of the lesson covers the application terminology associated with an AFD, starting with application torque curves.

AFD Application Terminology

1. **Application Torque Curves**
   a) Constant Torque (CT)
   b) Constant Power (CP)
   c) Variable Torque (VT)

2. Starting Torque
3. Open or Closed Loop
4. Closed Loop & PID
5. Different Types of AFDs

1. a) Constant Torque (CT)



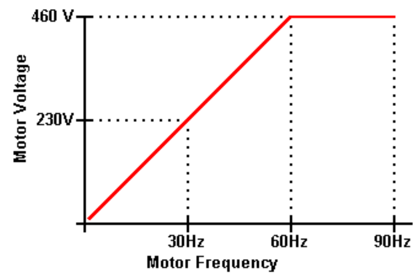
- CT applications are the majority of applications
- Torque stays relatively constant from 5Hz to 60Hz.
- AC motors have low torque at slow speeds.

The graph above shows Torque in relationship to Speed. This graph was made when the AFD and loaded motor, were running at Synchronous Speed, 60 Hz, 1800 rpm on a 4-pole 3-phase AC motor. The speed of the AFD was slowly turned down to 0 Hz. Notice that the torque drops down to its nominal rating on an AC induction motor at the lower speeds, 5Hz or less.

<u>Constant Torque</u> applications require a constant level of torque throughout a process regardless of different speeds. The vast majority of applications for an AFD are constant torque. Any applications that involve conveyors, mixers, elevators, feeders, hoists, bottling machines, screw compressors, and numerous others, are constant torque.

In the example above constant torque must be maintained on the conveyor. Notice that the torque curve drops when the speed is reduce below a minimum speed of about 5Hz. To compensate for this drop, some AFDs can perform "motor tuning" which matches the AFD settings to a particular motor. This "tuning" allows for more precise calculations by the AFD giving more torque throughout the CT curve, but particularly noticeable is the torque boost at those slow speeds from 1 to 10Hz.

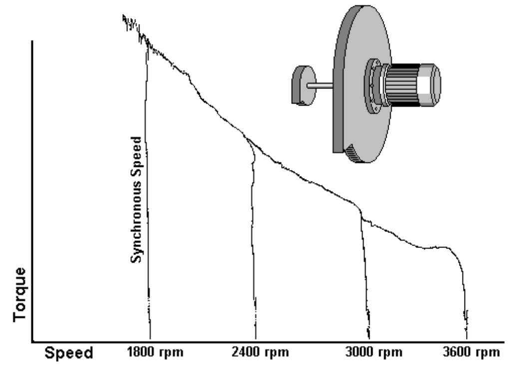
Volts per Hertz Chart



- In order to keep a constant torque which is directly related to current, the voltage going from the AFD to the motor is increased as the speed increases. In the example above on a 460Vac motor, 460 Volts is only sent to the motor when the speed reaches 60Hz.

Constant Torque is achieved because the AFD is increasing the voltage to the motor as it increases the speed. This is displayed by the **Volts/Hz chart** shown above. In this chart, when the AFD sends a signal of 30Hz, it is also sending a 230V signal to the motor. When the AFD sends a 60Hz signal, the voltage is at 460V. This relationship keeps the current and in turn the torque to the motor relatively constant. The changes seen in the motor current are based on the load. Notice that when the speed reaches 60Hz, base speed, the voltage going to the motor from the AFD can not go higher, it has reached its limit, in the example above 460V. If the speed is increased above base speed, to say 90Hz, the voltage from the AFD stays at 460V, but the current and torque drop. This Volts/Hz chart is different with motors that use different voltages.

1. b) Constant Power (CP)

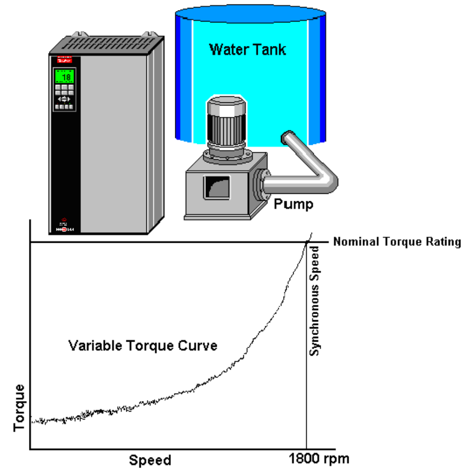


- CP applications are rare for the AFD.
- CP applications are always above base speed.
- Torque drops significantly above base speed (60Hz).

Constant Power applications are always run at speeds above base speed, 60Hz and higher. On a Constant Torque Curve, the area above base speed is known as the Constant Power Curve. The few applications that require these high speeds are typically saws, and grinders.

In the example above, notice that the torque curve drops off above 60Hz (1800rpm). It is at this point that the voltage being sent to the motor can NOT be increased, it has hit its maximum limit. As the drive continues to increase the speed, and with the voltage staying the same, the current to the motor starts to drop off, which means that the torque drops as well.

1. c) Variable Torque (VT)



- VT applications save a great deal of energy
- Used with centrifugal pumps and centrifugal fans.

<u>Variable Torque</u> (VT) applications almost always involve centrifugal pumps or centrifugal fans. The torque required to operate a pump or fan is very low until it starts to approach its base speed, 60Hz. There are formulas that show the relationship of power to rpm. Ideally, assuming no friction losses, the pump at half the speed only requires 1/8 the power. AFDs on VT applications save a great deal of energy and money. Once above base speed, a fan or pump requires a considerable amount of power, so they are rarely run above 60Hz.

A point of clarification between Synchronous speed and base speed is useful.

Synchronous speed, in an induction motor, is the RPM of the <u>magnetic field</u> when the motor reaches its nameplate voltage and frequency. The formula for synchronous speed is as follows:

Synchronous speed = (Motor frequency) * 120 / (# poles)

Example: 60Hz * 120 / 4 poles = 1800RPM

Base Speed is the speed in rpm that results when the motor is at its nameplate voltage, frequency and current. Most Asynchronous 4-pole induction motors using 60Hz have a base speed between 1725 to 1770rpm.

2. Starting Torque

Centrifuge

This part of the lesson covers the application terminology associated with starting torque.

Outline:

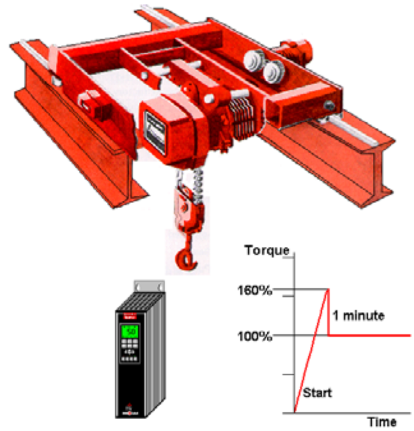
AFD Application Terminology

1. Application Torque Curves

2. **Starting Torque**
   a) High Overload (HO)
   b) Breakaway Torque
   c) Normal Overload (NO)

3. Open or Closed Loop
4. Closed Loop & PID
5. Different Types of AFDs

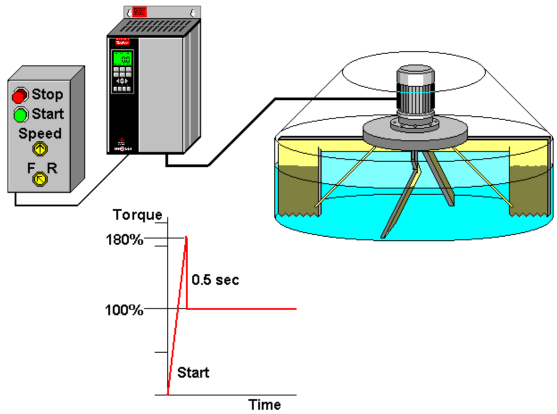
2. a) High Overload (HO)



- High Overload allows 160% starting current for 1 min.
- Most CT applications require High Overload.
- If drive exceeds 160% or 1 minute, AFD trips.

High Overload (160%) is used to apply the torque to start a load. The inertia to start a centrifuge, or in the example above a hoist requires a great deal of starting torque. It can be as high as 160% of the current for 1 minute. Once started the torque drops back to 100% or less. If the load does not move and the drive exceeds 160% or exceeds 1 minute, the drive trips, which means that the AFD does not move the motor. This trip gives an Over-current or Torque Limit alarm and for protection sake a reset button must be pressed to clear the alarm and restart the AFD. Some AFDs have a High Overload limit of 150% for 1 minute.

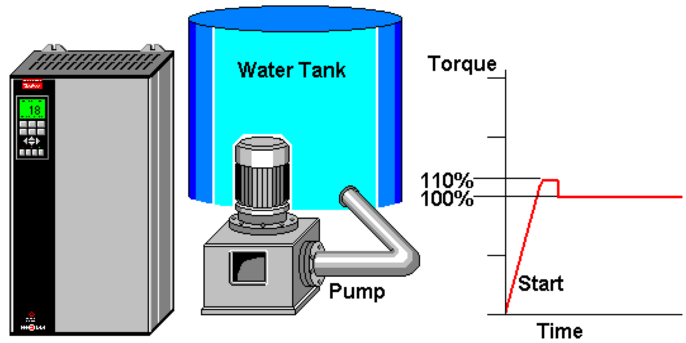
2. b) Breakaway Torque



- High Overload has a breakaway torque that allows 180% starting current for 0.5 seconds.
- If drive exceeds 180% or 0.5 seconds, AFD trips.

Breakaway Torque (180%) also known as Starting Torque, usually refers to the first 0.5 seconds after start. In the example a mixer has a very thick substance, perhaps a batch of adhesive. When the AFD starts to turn the motor the resistance of the substance is very high. The AFD increases the current output up to 180% for half a second to get the mixer started. Once it starts, the AFD continues at the High Overload setting of 160% for 1 minute. If it does not move, the AFD trips for protection of the AFD, motor and mixer.

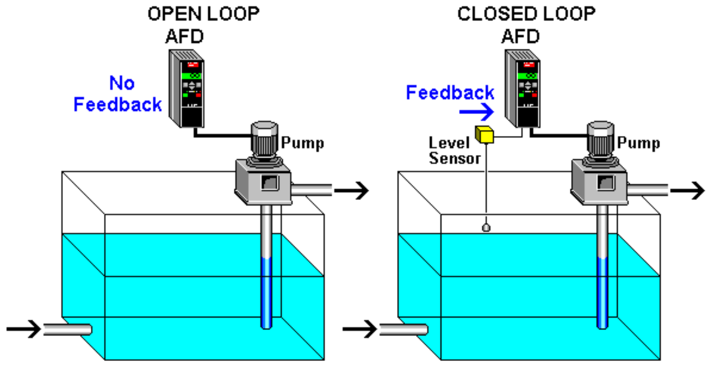
2. c) Normal Overload (NO)



- Normal Overload has a starting torque that allows 110% starting current for 1 minute.
- Most VT applications require Normal Overload.
- VT AFDs are sized differently – 200Hp for CT; 250Hp for VT

<u>Normal Overload (110%)</u> is almost always used with VT applications basically with centrifugal fans and pumps. When a centrifugal pump is started it takes very little starting torque to turn the impeller against water, so the 110% limit is adequate. If the 110% for 1 minute is exceeded, again the AFD trips. Since the current output on starting is less for VT applications, smaller AFDs can operate slightly larger motors. If a 200Hp AFD which is normally Constant Torque (CT) has a VT setting, the AFD could be used to operate a 250Hp motor with little difficulty.

3. Open or Closed Loop



- All applications fall into 2 categories, Open Loop or Closed Loop
- Closed loop has additional settings which include controller action, setpoint, and PID settings

Outline:

AFD Application Terminology

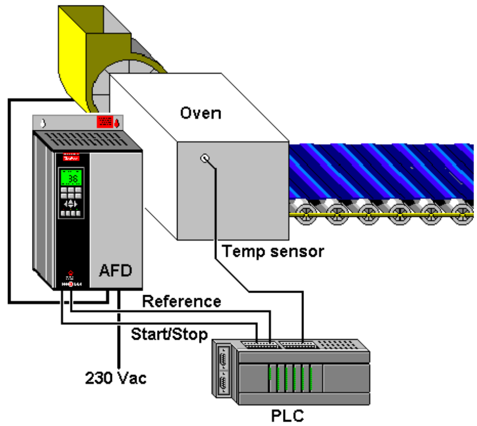
1. Application Torque Curves
2. Starting Torque
3. Open or Closed Loop
   a) Open Loop
   b) Closed Loop
4. Closed Loop & PID
5. Different Types of AFDs

A quick definition for Open and Closed Loop is shown here.

Open Loop control does NOT have a direct feedback signal.

Closed Loop has a direct feedback signal coming into the AFD.

3. a) Open Loop



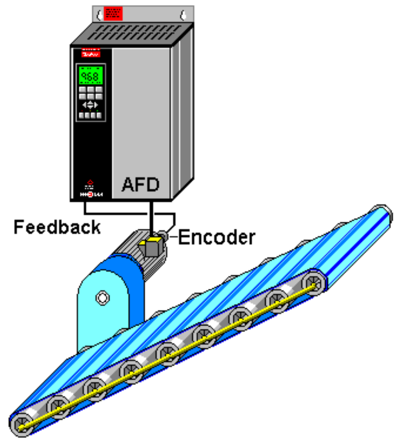
- The AFD is programmed for open loop, because there is NO feedback signal going to the AFD – but the system using the PLC is a closed loop system.

Speed Open Loop control does NOT have a direct feedback signal.

In the example above, a temperature sensor is wired to a Programmable Logic Controller (PLC). The closed loop inside the PLC calculates a reference signal. This reference signal is sent to the AFD, which in turn controls the motor and fan. In this example the AFD is programmed for Speed Open Loop. It receives a reference command from the PLC controlling the temperature in the oven. Because the feedback signal, temperature, goes to the PLC, a closed loop must be setup in the PLC to control the oven. The PLC then sends a reference signal to the AFD for proper modulation of the fan. If the temperature sensor were wired directly into the AFD, then the drive would need to be programmed for Process Closed Loop in order to have proper control of the fan.

The system is a closed loop system because it senses its own action, but the AFD is programmed for speed open loop.

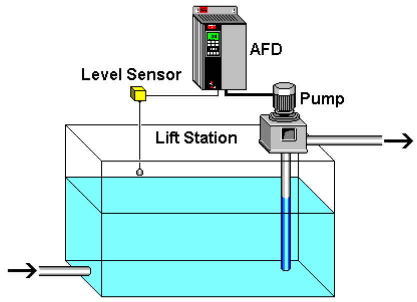
3. b) Speed Closed Loop



Speed Closed Loop requires an encoder to feedback the RPM signal to the AFD letting it know the speed of the motor.

Speed Closed Loop has feedback coming from an encoder which gives a fixed number of pulses (example: 4096) every time the motor makes one revolution. This rating is known as PPR or pulses per revolution. The speed closed loop configuration for the AFD monitors the encoder to match the speed reference or setpoint, perhaps 950rpm. A proportional gain setting is used for modulation, an integral setting and perhaps a derivative setting. These terms are covered later in this lesson. In some AFDs, the default settings are adequate for proper control of speed.

4) Process Closed Loop



- Sensor monitors the feedback signal.
- Controller, the AFD, gives the sensor a desired value, action and PID settings and calculates a response.
- Controlled Device, the pump, responds to the signal from the controller, increasing or decreasing in speed.

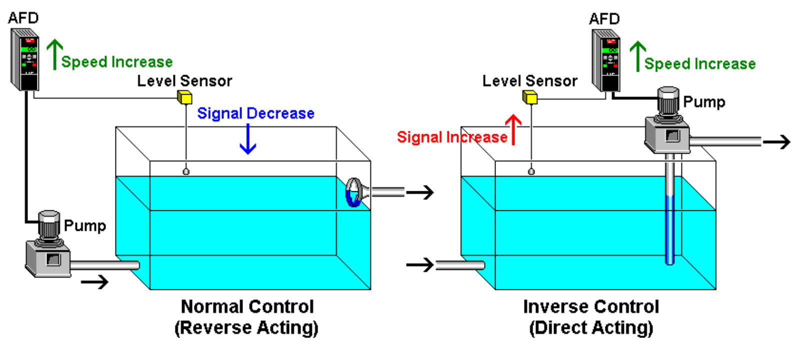
Process Closed Loop is where the controller inside the AFD can be used to modulate the speed of a motor to maintain a process. It is the job of the **sensor** or transmitter to measure a variable, in the example above, this is water level. This sensor sends a signal (usually a 4-20mA) to the controller.

The sensor is wired to the current input of the AFD, the **controller**. This signal is programmed in the AFD as the feedback signal. This feedback signal must be given engineering units, say “feet” or “meters”. The feedback signal must also be given a range that matches the sensor. For example, when the sensor sees 4mA it is 0 feet (0 meters) and when the sensor sees 20mA, the reading is 10 feet (3 meters).

The AFD, controller, has a setpoint, action and PID settings (explained later) to calculate the response necessary to maintain the desired value seen at the sensor. The AFD sends a signal to the pump to speed up or slow down to maintain a certain level.

The pump, **controlled device**, responds to match the signal from the AFD, controller. It speeds up when the level of the water increases and slows down when the level of the water drops.

4. a) Control Action



Normal Control – as the incoming signal decreases the output speed increases.

Inverse Control – as the incoming signal increases the output speed increases

In process closed loop applications, the AFD must always be programmed for the correct action. There are 2 choices:

(Note: different controllers use different terms for the same function.)

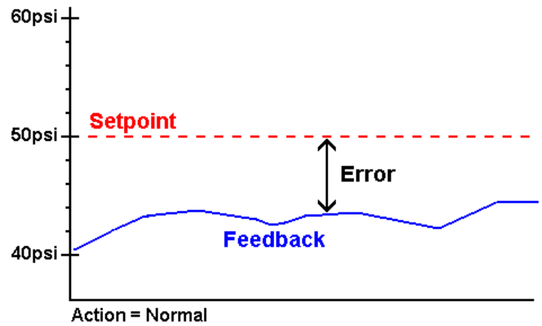
Normal Control (also know as Reverse Acting). As the signal from the sensor increases above the setpoint the output from the AFD decreases. Notice the tank on the left. The action is correct if the sensor is down stream from the controlled device, pump. As the level sensor sees an increase, the signal to the pump decreases, slowing the pump down. As the level sensor sees a drop, the speed of the pump increases.

Inverse Control (also know as Direct Acting). As the signal from the sensor increases above the setpoint the output from the AFD increases. This action is correct if the level sensor is upstream from the pump as pictured by the tank on the right.

If the wrong action (Normal) were programmed in the AFD the in the tank application on the right, the pump would slow down as the level in the tank rose higher. Eventually the water in the tank would over flow. If the incorrect action is programmed in an application the AFD is locked at minimum or at maximum speed.

4. b) Setpoint, Error & Gain

Danfoss



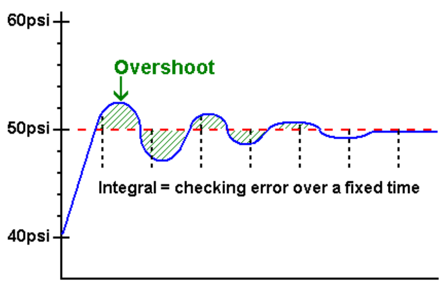
- Setpoint or reference is the desired value for a controlled variable; example: 50psi (345kPa).
- Error (offset) is the amount the feedback is from setpoint at any given time, example: 7psi (45kPa)
- Proportional Gain is a multiplier times the error (offset). Example above the Gain starts at 0.3

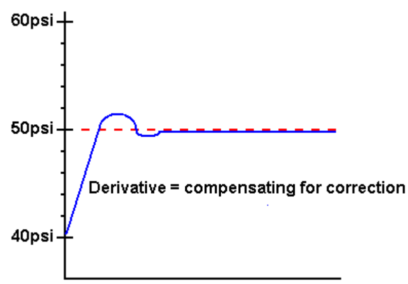
Setpoint is the desired value or reference of the controlled variable for a process closed loop application. In the example above 50psi (345 kPa) is the desired setpoint or reference.

Error is a difference between the setpoint, 50psi (345 kPa) and the actual feedback pressure, 43psi (300 kPa) for the system. This difference is also known as Offset (off setpoint).

Proportional Gain is multiplied by the error to create an output. The larger the proportional gain, the larger the output change for a given error. If the proportional gain is too small (0.01) this multiplier times the error has no effect on the speed of the AFD. If the proportional gain is too large (3.00 or higher) the system can become unstable, modulating between minimum speed and maximum speed which is called “hunting”. A good starting place for the Proportional Gain is about 1.00 but changes depending on the application. If Proportional Gain is only used, without I or D (explained on the next slide), the output is relatively close to setpoint but there is always an error.

4. c) Integral & Derivative



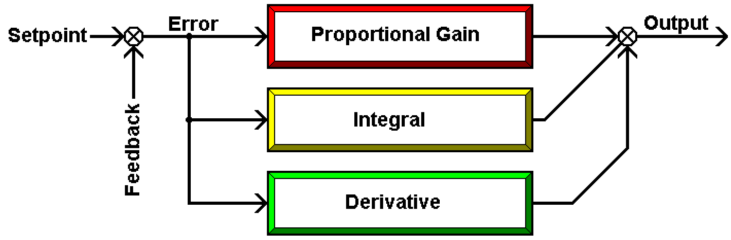


- Integral checks the offset over a period of time and makes corrections.
- Derivative checks the offset and corrects for the speed of the integral correction.

Integral Gain is based on the history of the error. The integral function maintains a running total of the error and creates an output based on this total. The lower the number used for the integral gain the more frequently the error is checked and the larger its influence. If the integral time is too low (less than 5 seconds), the system can become unstable and starts to hunt. A good place to start is 10 seconds, but again this can vary based on the application. Integral gain eliminates the steady error inherent to proportional control. As pictured above, integral gain adds overshoot, but eventually settles close to setpoint.

Derivative or differential is based on the rate of change of the error. It is used to limit overshoot and dampen system oscillation. The larger the derivative time, the larger the influence. If the derivative time is too large, the system becomes unstable. Derivative is very sensitive to noise on the feedback signal and historically seldom used in process control systems. In speed closed loop applications, derivative is used extensively.

4. b) PID



Summary: There are many different PID algorithms. All contain these 3 features, Proportional Gain, Integral, and Derivative. The ways these terms are combined may be different.

In some implementations the 3 values operate independently of each other and in others, changing one value effects the others.

Proportional Gain contributes to the output in a direct relationship to the error between the feedback and setpoint.

Integral contributes to the output based on the history of the error.

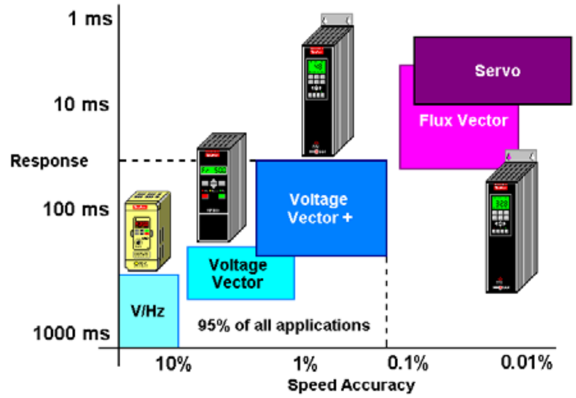
Derivative contributes to the output based on the rate of change to the error.

Setpoint is the desired value for the variable being controlled.

Feedback is the actual value of the variable being controlled.

Error (offset) is the difference between the setpoint and feedback

5) Different Types of AFDs



There are different types of AFDs, which are briefly covered here. They include Volts/Hz, Voltage Vector, Voltage Vector +, Flux Vector and Servo.

Volts/Hz drives also known as a Basic Scalar drives, are the least expensive drive with the least features. This drive is usually setup for CT and Open Loop only.

Voltage Vector drives also known as Space Vector drives have more features and may have the ability to do both CT/VT and Open/Closed Loop.

Voltage Vector Plus drives have more features than the others and therefore have more cost than previously mentioned drives. They can calculate motor characteristics without spinning the shaft of the motor.

These last 3 types of AFD account for 95% of all applications. There are a few that need greater accuracy which follow.

Flux Vector drives have more calculations which makes them more expensive and more accurate. Some Flux vector drives require special motors.

Servo drives are DC and do not operate with AC induction motors. They are expensive in comparison to AFDs. They are the most responsive to dynamic changes.

These drive types are explored in greater detail in a later lesson.

5) Different Types of AFDs

Summary:

Type	Response	Accuracy	Speed Range
V/Hz	500 – 1000ms	10% +	10:1 – 180rpm
Voltage Vector	200 – 700ms	2% - 8%	50:1 – 36rpm
Voltage Vector +	50 – 300ms	0.2%-2%	
		Open	100:1 – 18rpm
		Closed	900:1 – 2rpm
Flux Vector	5 – 60ms	0.02% - 0.1%	1400:1 – 1.3rpm
Servo	2 – 8ms	0.007% - 0.08%	1800:1 – 1rpm

As a comparison above, each type of motor control shows,

Response to dynamic changes

Accuracy and

Speed Range.

Speed Range indicates how slow the motor can turn but still have proper operation. Speed Range is always indicated as a ratio. The higher the ratio the better control at slow speeds. The minimum rpm for each type has been calculated, assuming 1800 base speed.

Voltage Vector Plus has 2 values, one for open loop and the other for closed loop.

This completes this lesson.

There are Review Questions in the Post-Test section.