

This training covers the major control arrangements for a VFD, starting with the simplest arrangement then moving to the more complex.

Many of the control arrangements shown in the previous lesson (Lesson 1: Functions of an VFD) were Closed Loop Control. There can be other arrangements which are covered in detail in this lesson.

- 1) Local or Hand Control
- 2) Remote or Auto Control
- 3) Multi-motor
- 4) Master/Slave
- 5) Closed Loop
- 6) Cascade Control Fixed Stages
- 7) Cascade Control Variable Stages
- 8) Build Automation System (BAS) Enable
- 9) BAS Enable and Reference
- 10) BAS Serial Communications



# 1. Local (Hand) Control

In the picture above, a VFD, motor and fan are operated from the keypad on the front of the drive. Local (Hand) control of the VFD means that operation of the VFD is completed strictly through the keypad on the front of the drive, or Local Control Panel (LCP). An operator monitors the readings and controls the VFD by using this keypad. Even if the keypad, LCP is remotely mounted away from the drive, maximum of 3m (10'), the control arrangement inside the program of the VFD is still considered as LOCAL. If any line is labeled as LOCAL in the program, think KEYPAD.



In the picture above there are 2 VFDs, each being controlled by its own LCP or keypad. The one on the right uses a remote keypad kit to place the keypad in a convenient location. The operational site on both VFDs is considered as LOCAL or HAND.

The "Hand Start" key starts the VFD, assuming safeties have been enabled. The display on the keypad changes as seen on the last page. This allows the operator to increase (+ key) or decrease (- key) the speed of the motor. Other start commands are ignored.

The "OFF Stop" key stops the drive. The display starts to flash to indicate that this key has been pressed. Other start commands are ignored. To remove this stop command, the Hand Start or Auto Start must be pressed.

The "Auto Start" key ends Local or Hand control. This means that remote controls, which are described in the pages that follow are in control.

The "Reset" key clears an alarm from the VFD, assuming that the alarm has been corrected and is set for manual reset. Some alarms require that power be removed (Disc.Mains) before they can be reset.



## 2. Remote (Auto) Control

Other arrangements are possible including remote signals. If there is a problem with the fan and it must be stopped immediately, it might be time consuming to run back to the VFD to stop it. Stop switches can be placed at key positions to stop the VFD, AC motor and fan. It is important that the VFD accept these stop signals as well as other remote signals. These remote control signals come in four types:

<u>1) Digital Inputs (DI)</u> are 2-position (ON/OFF) signals sent into the VFD. These commands check safeties, then tell the VFD to Start, to Stop, etc. A DI requires 24Vdc which is supplied by a terminal on the drive.

<u>2) Analog Inputs (AI)</u> are proportional or modulating signals sent into the VFD. These commands tell the VFD what the reference speed should be or tell the VFD what a feedback signal is doing such as static pressure. These signals are usually from 0-10Vdc or 4-20mA.

<u>3) Analog Outputs (AO)</u> are modulating signals sent by the VFD to a device such as a meter which could display feedback, speed or current.

<u>4) Digital/Relay Outputs (DO/RO)</u> are 2-position (ON/OFF) signals sent by the VFD to a device such as a light to indicate an Alarm, or when the feedback signal has reached a certain limit. Digital Outputs have power 24Vdc attached and Relay Outputs do not have power, which are known as "dry" contacts.



Besides stop switches, other signals can be sent into the VFD. These could be a reference pot to change the speed, increase and decrease buttons which would also change the speed, remote Start and Stop switches, or other signals. All the different options for remote signals are considered as control wiring. In the program of the drive, if the Hand keys are used, remote signal except for safeties are ignored. On the VFD shown above, all the control wiring terminals are shown on the black plastic cover just under the LCP keypad.

The amount of connections for the control wiring is a means of comparison between manufacturers of VFDs. As an example, the Danfoss drive shown above has the ability to accept the following signals:

- 8 Digital Inputs
- 3 Analog Inputs (2 are setup for 0-10Vdc; 1 for 0-20mA)
- 2 Analog/Digital Outputs (0-20mA or 4-20mA signals or these can be programmed as Digital Outputs with 24Vdc attached)
- 2 Relay Outputs (dry contacts)



#### 3. Multi-Motor Operation

The multi-motor arrangement is usually done because of strict cost considerations. Not only must the VFD have the current capacity for all the motors, but each individual motor must have overload protection. In the picture above, one VFD operates 4 AC motors, which in turn operates the 4 cooling tower fans together. They operate at the same speed or close to the same speed.

When this arrangement is used some VFD features are restricted. First the motors and fans must all run at the same speed. Another restriction is that the VFD can not be tuned to a individual motor. Motor Tuning is where the VFD is tuned or matched to an individual motor for better performance and energy savings. The last restriction given here is that the slip compensation (calculating the difference between the field speed and rotor speed) should be set to OFF.



If the cooling tower fans were operating with a very light load but motor 3 got jammed. The amp draw on motors 1,2 and 4, might be low, say 5 amps each, but the amp draw on motor 3 would need to surpass 45 amps before the drive saw any problem. This would cause damage to motor 3. As shown in this example, individual overload protection, such as thermal overloads are needed to protect each motor. Motors in this arrangement operate close to the same speed.



#### 4. Master/Slave (Leader/Follower)

This arrangement allows motors to operate closer together than in the multi-motor application. Each VFD also provides safeties for its own motor.

One VFD is selected as a Master or Leader drive. It is setup to send a reference signal and ON/OFF commands to the Slave or Follower drive. In the example above, 2 fans are used for Supply Air on a Variable Air Volume (VAV) system. The VFD operating the top fan is considered the Master or Leader. It varies its speed to match the static pressure needs in the supply duct. The bottom fan and VFD, follows the top supply fan and is known as the slave or follower. The slave can match the speed to within 0.3Hz of the master, over the operating range from about 6Hz to 60Hz.

Rather than always matching the speed of the master VFD, the slave VFD can operate at a percentage of the reference. If a positive pressure needs to be maintained in a zone, the slave VFD on a return fan can be slightly behind (-10% of reference) of the master VFD on the supply fan. The supply fan always runs faster than the return fan causing a positive pressure in the zone. In this last application using a volumetric sensor comparing the CFM (L/s) from supply and return to control the return fan would give a much greater accuracy than the Master/Slave arrangement.



In the picture above, the VFD on the first supply fan is the Master/Leader and it generates a reference signal for one of its analog outputs (AO). The VFD on the second supply fan is the Slave/Follower, and it monitors this 4-20mA reference signal from the master using the slave's analog input (AI).

It is possible with Danfoss drives to use a Digital Output (DO) as a pulsed reference. The follower uses a Digital Input (DI) to follow this pulsed reference signal. These 2 fans must run closely together, the greatest variance between drives using the pulsed signal is around 0.2Hz along the entire range of frequencies (6 to 60Hz). There is a time delay in this arrangement. The master drive starts going to its reference before it sends the signal to the slave drive. Usually this delay is very small, in milliseconds, and of no consequence in this application.



### 5. Closed Loop/PID Control

Up to this point most of the previous control arrangements have been closed loop, which means that there is feedback signal monitoring the controlled variable, going directly to the VFD. Closed Loop is used for stand alone control. In the example above, the VFD monitors the signal coming from the 4-20mA static pressure sensor in the supply duct. In a variable air volume (VAV) system it is important to maintain Static Pressure in the duct for proper operation of the VAV boxes.

In all closed loop applications, additional parameters must be programmed. These include a setpoint, and PID settings. In this application, the VFD is constantly comparing the static pressure setpoint, 2.5"wc, (625 pascals) with the actual feedback value coming from the pressure transmitter. The VFD modulates the speed of the supply fan to maintain that pressure.

Controller action is one of the parameters that must be checked in the VFD. There are 2 selections which are as follows:

<u>Normal Control</u> (Reverse Acting) which increases the speed of the fan when the signal decreases from the pressure sensor, as in the example above.

<u>Inverse Control</u> (Direct Acting) increases the speed of the fan when the signal increases from the sensor.



There is always a difference between the setpoint and the actual feedback pressure. This is referred to as Offset, "off the setpoint" or error. PID settings attempt to reduce this error. "P" stands for Proportional Gain which can be considered as a multiplier of the error. The higher the gain the more accurate, but if it is set too high, the control can become unstable and jittery. With too high of a gain setting, the VFD oscillates between maximum speed and minimum speed, "hunting" for the correct speed. The gain must be high enough to be sensitive but not too high to cause hunting. Each application is different, but a proper starting setting for pumps is 4.0 and 2.0 for fans.

"I" stands for Integral which looks at the error over a certain amount of time. The lower the number the more frequently it checks the error. If the I setting is too low, the motor again appears to be hunting. Based on most applications, a pump has its I setting for 20 seconds and 30 seconds for fans.

"D" stands for derivative which, if used, compensates for momentary changes in the load. In most HVAC applications, this parameter is not used, keeping it OFF.



#### 6. Cascade Control Card – Fixed Stages

There are some applications where multiple pumps or fans must operate together. It is desired to only operate the number of pumps necessary to achieve the load requirements, keeping other pumps off to save energy. A separate Cascade Controller card which can be mounted inside the VFD, can be used to coordinate the operation of up to a maximum of 5 pumps. One way to operate these pumps is to have the first pump be varied by the VFD and the fixed stages using soft starts. When it reaches 100% output, a fixed stage is started. Each time the 1<sup>st</sup> pump reaches 100%, another stage is enabled.

In the example above, the variable pump is the first pump to start. When this variable pump goes to 100% or 60Hz, a relay on the Cascade Card is enabled which starts a soft-starter on Pump #1. Since soft-starters do not modulate, pump #1 goes to 60Hz. The variable pump then drops its output. When the load requires more output, and the variable pump again reaches 100% then the soft-starter on Pump #2 is enabled.



The diagram above shows the operation of the variable pump, VFD at the bottom of the chart and how it relates to the fixed stages, which are shown at the top. Notice that every time the VFD reaches 100% or 60Hz, a fixed stage on the Cascade Controller card is enabled. When the fixed pump is running, this causes the VFD to drop its signal. With an increase in demand the VFD goes to 100% again causing the second fixed stage to come ON.

When the demand drops and the VFD goes to 0% or minimum speed, 20Hz, the fixed stages go OFF. With a loss of a fixed pump, the VFD then increases its signal. Every time the VFD drops to minimum speed, a fixed stage is turned OFF. It is possible to use 4 stages, but only 3 stages are shown here.



### 6. Cascade Control Card – Fixed Stages

There are some applications where multiple pumps or fans must operate together, but the operator wants each pump or fan to have a VFD. The same Cascade Controller card discussed in the last arrangement can be used to coordinate the proportional operation of up to a maximum of 5 pumps. When the lead pump reaches a certain output, say 75%, the second VFD is enabled and now they both modulate using the same reference. As the first VFD has its output go progressively higher say to 80%, an additional VFD is enabled. A further explanation of this operation is shown on the chart on the next page.



The diagram above shows the operation of the variable pump, VFD at the bottom of the chart and how it relates to pumps 2-4. When the 1<sup>st</sup> pump reaches 75%, pump 2 is enabled and quickly follows the same signal that goes to pump 1. If the demand for both pumps continues to increase to 80%, pump 3 is enabled. Pump 4 is enabled when the demand goes to 85%.

When the demand drops all the pumps start to slow down. Although this is NOT shown above, when the demand drops to 30%, pump 4 is disabled. When the demand drops to 20%, pump 3 is disabled; and pump 2 is disabled at 10%. Pump 1 then continues to monitor the demand. Remember that 0% is still a minimum speed of 20Hz.



#### 8) Building Automation - Enable

On numerous occasions a VFD works with a Building Automation System or BAS. The BAS coordinates the VFD with more information and commands such as occupancy schedules, holidays, energy optimization, electric demand limiting to name a few. There are a few ways to wire the VFD with the BAS; three arrangements are covered in this lesson. In the example above, a local area controller, also known as a Direct Digital Controller (DDC) which monitors and issues commands to an AHU, enables and disables the VFD based on BAS schedules. This is done with a DO coming from the DDC controller wired to the DI of the VFD which issues the Start and Stop commands. Any wire attachment to the DDC controller, other than communications, is known as a "point". On some DDC controllers, "points" or certain types of points, can be restricted. Here only one point is used on the DDC which saves on wiring costs.

In this arrangement, the pressure sensor is wired directly to the VFD. The closed loop inside the VFD modulates based on a setpoint to keep the proper pressure in the AHU. The BAS system only enables or disables the VFD. The DDC controller can not monitor or control the setpoint for the pressure, which makes this arrangement the least desirable for the BAS system.



Notice in the example above, a DO on the DDC controller, a relay output, which has no power of its own, completes the circuit between terminal 12, +24Vdc and terminal 18 of the VFD which is the start/stop input. The pressure transmitter is wired directly to the VFD, which saves a point on the DDC controller, but limits the operational use and adjustments by the BAS for this air handling unit. The operator must go to the VFD through its keypad, to monitor the pressure in the duct and to change the setpoint. Other information from the VFD, such as speed, temperature, alarms, etc. displayed through the keypad would also be done locally at the VFD. In this control arrangement, the BAS system can only indicate if the VFD had been enabled or disabled.



#### 9) BAS Enable and Reference

On the example above additional connections or points are used to gather more information and send more commands from the DDC controller. Notice that the DDC Controller sends a Start/Stop command and also sends a reference. The pressure sensor monitoring the static pressure in the AHU is sent to the DDC controller. A closed loop inside the DDC controller monitors the pressure and adjusts the reference to maintain the pressure setpoint.

The VFD, programmed for open loop, receives the reference and Start/Stop commands from the DDC controller. In this arrangement, the static pressure and setpoint can be monitored and modified by the BAS system. Additional connections can be made from the VFD back to the DDC controller to confirm commands and monitor alarms. Each connection requires an additional hard-wire point from the DDC controller.



In the example above, the DO of the DDC controller is wired to the VFD as in the previous example. Now, however, an AO from the DDC controller which sends a 4-20mA signal, is wired directly to the current input, AI of the VFD. The 4-20mA pressure transmitter is wired directly to the DDC controller, which is not shown above. More information and adjustments can be accomplished through the BAS system using this control arrangement. For each piece of new information such as alarm status, current going to the motor, and energy usage, wires are needed between the VFD and DDC controller.



#### 10. Serial Communications

Here is the last interface with a BAS system. A serial communications protocol is used inside the VFD to talk directly on the Local Area Network or Bus. With this arrangement numerous bits of information can be see at the DDC controller and the BAS. This information includes the start/stop command, static pressure, and reference, as in the previous example; but it also includes information about energy usage, alarming, running hours, input status, internal temperatures, and motor information. This information is sent over a 2-wire, RS-485 connection.

In the example above, it can be seen that the VFD is wired directly to the same bus that connects the Local Area controllers. This bus connection could be a LonWorks protocol. Local Area controllers operate specific devices in a building, such as a cooling tower, chiller, boiler and air handling unit.

The Local Controllers are in turn connected to a Global Area Controller. These Global Controllers operate individual buildings or large parts of a building. Global Controllers are wired together to form a Global Network. This connection could use an Ethernet protocol. Both LonWorks and Ethernet are popular within the HVAC market. Notice that a PC is wired to the Global Network. This PC has a Graphic User Interface program which is also known as a GUI.



In the example above, the 2-wire, RS-485 connection goes between a local controller and the VFD. Normally this 2-wire bus connection must be in a "Daisy Chain" arrangement. This arrangement only allows 2 ends. All the positive or + connections are wired together and all the negative or – connections are wired together. Addressing of each device must be unique, and can be accomplished with hardware switches or programmed in software, which is the case with this VFD.

This concludes Lesson 2. There is a Post Test to review this information.