Drives 101
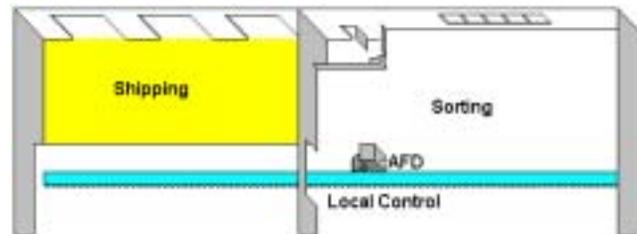## Lesson 2
Control Arrangements for an AFD

1) Local Control

Local control means displaying and controlling the system through the keypad on the AFD.

This training covers the major control arrangements for an AFD. The control arrangement shown in the previous lesson (Lesson 1: Functions of an AFD) were all Local Control. There can be other arrangements such as Remote control, Multi-motor, Master/Slave, Closed Loop, PLC signals and Serial communications, which are shown in this lesson. This lesson covers the simplest arrangement first then moves to the more complex.

1.   Local Control

In the picture above, an AFD, motor and conveyor are operated from the keypad on the front of the drive. Local control of the AFD means that operation of the AFD 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 AFD 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 AFD is still considered as LOCAL. Anytime LOCAL is seen in the program, please think KEYPAD.

1) Local Control
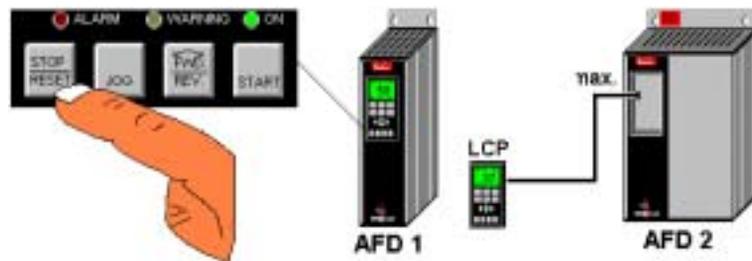
Start key starts the drive

Stop/Reset key stops the drive and also resets the
drives after an alarm.

FWD/REV changes direction

Jog is a pushbutton that runs at a low frequency,
say at 10Hz, usually used during setup.

In the picture above there are 2 AFDs, 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 AFDs is considered as LOCAL. Anytime the word Local is used in the programming, example: Parameter 002 (Quick Menu 12 of 13), it means the local keypad operates the drive.

The bottom keys on the keypad can be used to start, change direction FWD/REV (Forward/Reverse), jog, stop and reset the drive. The Jog key acts like a push button which sends a slow (10Hz) signal to the motor usually used during setup. When the drive is in Local the drive only responds to the keypad; all other commands coming to the drive are ignored.

2) Remote Control
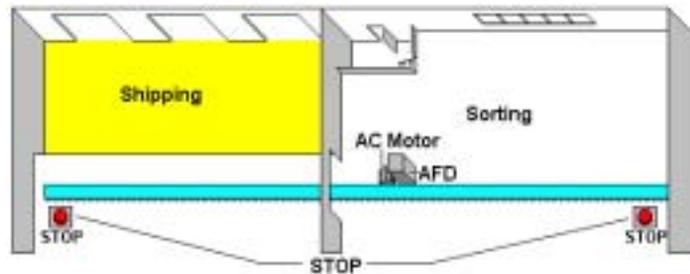
Remote signals are wired into the control section of the AFD. They come in 4 types:
Digital Inputs, Analog Inputs,
Analog Outputs, Digital/Relay Outputs.

2.   Remote Control

Other arrangements are possible including remote signals. If there is a problem and the conveyor must be stopped immediately, it would be difficult to run back to the AFD to stop it. Stop switches can be placed at key positions to stop the AFD, AC motor and conveyor. It is important that the AFD accept these stop signals as well as other remote signals. These remote control signals come in Four Types:

1) Digital Inputs (DI) are 2-position (ON/OFF) signals sent into the AFD. These commands tell the AFD to Start/Stop, go Forward/Reverse, Jog or No Jog, etc. A DI requires 24Vdc which is supplied by a terminal on the drive.

2) Analog Inputs (AI) are proportional or modulating signals sent into the AFD. These commands tell the AFD what the reference speed should be or tell the AFD what a feedback signal is doing such as pressure.

3) Analog Outputs (AO) are modulating signals sent by the AFD to a device such as a meter which could display speed or current.

4) Digital/Relay Outputs (DO/RO) are 2-position (ON/OFF) signals sent by the AFD to a device such as a light to indicate an Alarm, or when the AFD has reached a certain speed or to a relay to remove the mechanical brake. Digital Outputs have power 24Vdc already attached and Relay Outputs do not have power also known as "dry" contacts.

2) Remote Control
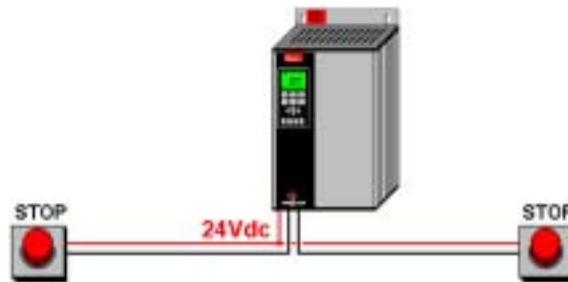
In the picture above, 2 normally-closed push-button stop switches have been wired to 2 Digital Input (DI) connections of the control section of the AFD. Notice that 24Vdc coming from the AFD is also connected to the switches.

Besides stop switches, other signals can be sent into the AFD. 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, a Jog switch or other signals. All the different options for remote signals are considered as control wiring. In the program of the drive, if anything other than the keypad is used to control the drive the operational site, Parameter 002 (Quick Menu 12 of 13), is considered as REMOTE. On the AFD shown above, all the control wiring terminals are shown on the black plastic cover just under the keypad (LCP).

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

8 – Digital Inputs (2 inputs can accept pulsed signals from an encoder)

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
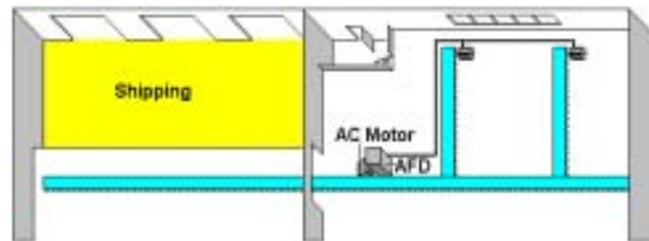
One AFD is used to operate 3 separate AC motors.
The AFD must be able to handle the maximum
current for the 3 motors. Some features of the AFD
in this arrangement are restricted.

3.   Multi-Motor Operation

The multi-motor arrangement is usually done because of strict cost considerations. Not only must the AFD have the current capacity for all the motors, but each individual motor must have overload protection. In the picture above, one AFD operates 3 AC motors, which in turn operates the 3 conveyors together. They operate at the same speed or close to the same speed.

When this arrangement is used some AFD features are restricted. First the motors and conveyors must all run at the same speed. Another restriction is that the AFD can not be tuned to a individual motor. Motor Tuning is where the AFD is tuned or matched to an individual motor for better performance and energy saving. The last restriction given here is that the slip compensation should be set in the OFF position.

3) Multi-Motor Operation
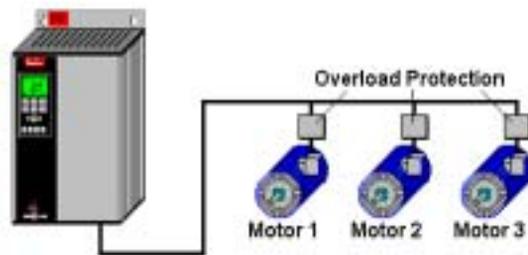
In the example above each of the 3 AC motors is the same size and has a maximum current rating, Full Load Amps (FLA) of 5 amps. The AFD must be sized for 15 amps. Note individual overload protection on each motor.

If the conveyors were operating with a very light load but motor 3 got jammed, the amp draw on motors 1 and 2, might be low say 2 amps each, but the draw on motor 3 would need to surpass 11 amps before the drive saw any problem. 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)
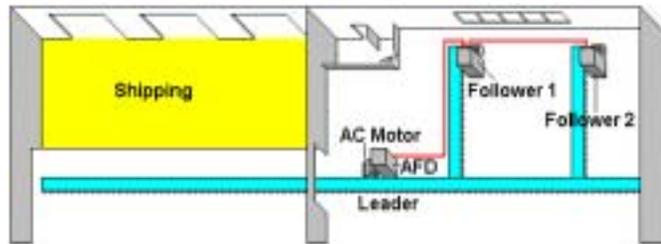
In the Master/Slave arrangement a Master or Lead AFD is used to operate a single motor and send its corresponding signal to the other 2 following motors. Features of the AFD which were restricted in the multi-motor can be used in this arrangement.

4. Master/Slave (Leader/Follower)

This arrangement allows motors to operate closer together than the multi- motor application. One AFD can be selected as a Master or Leader drive. It is setup to send a reference signal and ON/OFF commands to the Slave or Follower drives. In this arrangement the special features of the drive can be used such as automatic motor tuning and slip compensation. This arrangement is used when the motors are generally operating at the same speed with a variance between the drives of 0.3Hz or more.

Different gear ratios (say 2 to 1) can also be programmed electronically so that when one drive is at 30Hz the other drive is at 15Hz. The Master/Slave arrangement is not used where precision of the conveyors and their speeds must be exact.

4) Master/Slave (Leader/Follower)
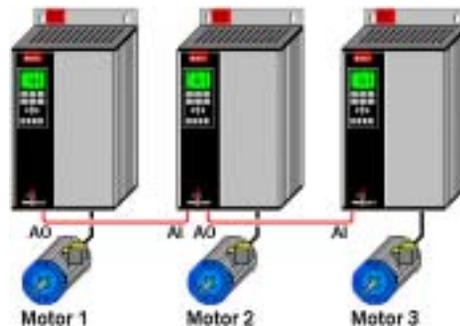
Motor 1, the Master/Leader, sends a reference using a 4-20mA signal from its AO to the AI of motor 2. It is also possible to send a pulsed signal as a reference.

In the picture above, motor 1 is the master and it sends a reference signal using one of its analog outputs (AO). Slave/Follower 1, motor 2, then monitors this 4-20mA signal from the master using its analog input (AI). This same arrangement is copied between motors 2 and 3. The greatest variance between drives is around 0.3Hz along the entire range of frequencies, say from 2 to 60Hz when using the analog 4-20mA signal.

It is possible with Danfoss drives to use a Digital Output (DO) as the reference simulating a pulsed output similar to the signal coming from an encoder. The follower uses a Digital Input (DI) to follow this pulsed reference signal. The greatest variance between drives using the pulsed signal is around 0.2Hz along the entire range of frequencies (2 to 60Hz). There is an additional time delay in this arrangement. The master drive starts going to its reference before it sends the signal to the slave drives. Usually this delay is very small, in milliseconds, but it can have a very harmful effect on certain exact processes. This delay is referred to as a "propagation delay".

5) Closed Loop/PID Control
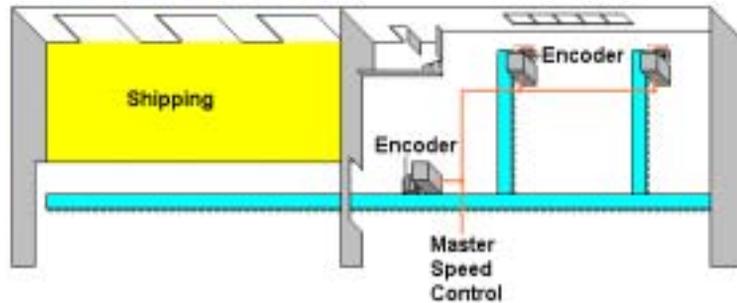
In this arrangement, a master speed command is sent as a reference to each AFD. An encoder at each motor verifies the speed. This is referred to as Closed Loop, because the AFD has a direct feedback from the motor.

5. Closed Loop/PID Control for Speed Regulation

Up to this point all the previous control arrangements have been open loop, which means that there is no feedback going directly to the AFD. Closed Loop is used for more accurate control. In the example above, each drive is monitoring and controlling at a certain rpm (revolutions per minute), which may vary from say 100 to 1800rpm (1500rpm for 50Hz motors) Danfoss drives have the ability to accept a signal from an encoder (one for speed, A; the other for direction, B) into the AFD without any additional cards or modules.

In all closed loop applications, additional parameters must be programmed. These include a speed reference (setpoint), and PID settings. In this application, the AFD is constantly comparing the reference or setpoint with the actual feedback value coming from the encoder. If 900 rpm must be maintained, the encoder should send enough pulses to match it. There is always a difference between the reference, 900rpm and the actual speed say 893rpm, 7rpm to be exact. 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 the control can be unstable, jittery. "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 jittery. "D" stands for derivative which, if used, compensates for momentary changes in the load.

5) Closed Loop/PID Control
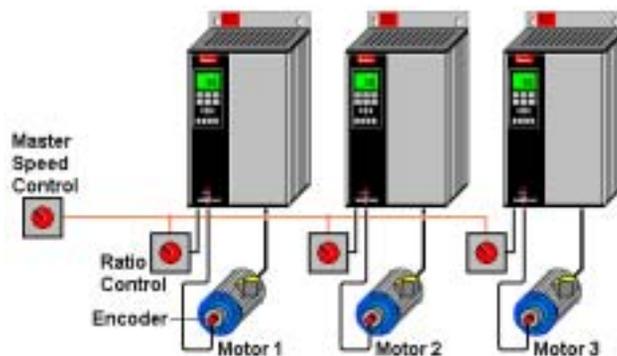
In the picture above, the master speed control is sent through ratio control pots. Each AFD has its own ratio pot to trim the master reference signal, either being at full speed or a fixed ration of the master speed.

The application above is an example of how conveyors are used to mix product together in a certain ratio. In a frozen food plant when packages of mixed vegetables are put together, there is a certain ratio of carrots, of green beans, of corn, etc. Each ratio control pot can be placed so that carrots run at 1000rpm, green beans at 600rpm and corn at 1200rpm. Even though this arrangement is still used, most factories use PLCs which are covered later in this section.

The arrangement without the feedback, known as Open loop is accurate to 0.5% of actual speed. At 30Hz, 900rpm, open loop is within + or – 4.5rpm. With feedback from the encoder, using Closed loop the accuracy is 0.1% of actual speed. At 30Hz, 900rpm, closed loop is within + or – 0.9rpm. For the best precision, a separate card called the Sync-Pos card is installed inside the drive. Not only does it have as good if not better accuracy than the closed loop, it also gathers additional information from the encoder to correct the speed if it lags behind. The Sync-Pos is covered next.

Before going on to the Sync-Pos arrangement, another example of closed loop must be mentioned. Besides Speed Closed Loop, there can also be Process Closed Loop. Instead of an encoder sending a feedback signal to the drive, another feedback device such as a 4-20mA pressure transmitter sends a signal back to the drive. As with any closed loop application, this application requires proper feedback setup, a setpoint, controller action and PID settings.

6) Multi-motor with Sync-Pos card
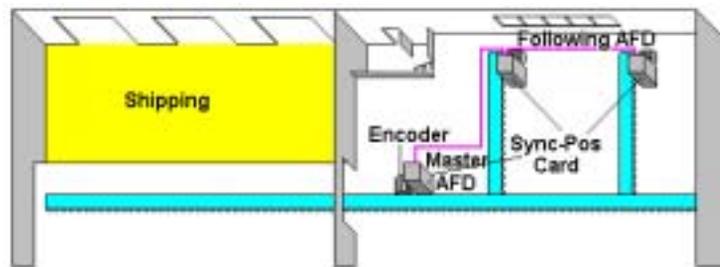
For precise applications where the drives must be
timed perfectly together, less than 0.1Hz. This
arrangement requires the use of encoders.

6.   Multi-motor operation using Sync-Pos Card

On other applications it is important that AFDs and motors work
preciously together. In the example above there is a master or leader AFD
and slave or follower AFDs. The special Sync-Pos
(Synchronizing/Positioning) card is placed in all 3 drives. This card fits on the
back of the control card so that no additional space is required. The master
Sync-Pos card sends a virtual master signal to all 3 drives. All drives follow
this signal even the master at precisely the same time. Each drive uses an
encoder on the motor to insure that position is maintained exactly. Although
in the example above, matching motors is not essential; there are
applications where timing between processes, such as a bottling line, are
critical.

6) Multi-motor with Sync-Pos card
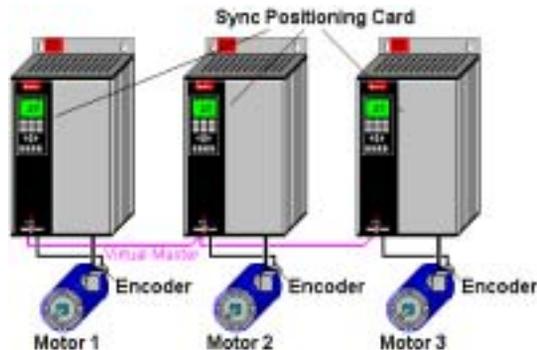
Here the master drive sends a virtual signal to all drives. Encoders [example:4096 ppr (pulses per one revolution)] on each motor check for accuracy, which can be within 1/2 of a pulse between drives.

The synchronization example has been used here, but the Sync-Pos Card has other functions. It can be used to enter a special program for positioning. Perhaps the motor needs to run 10 turns forward then waits 5 seconds and returns 10 turns, waits 30 seconds then starts the process all over again. The Sync-Pos card has programmable capabilities to operate an AFD in such a manner. A computer or laptop with the proper software is used to enter this type of program into the Sync-Pos card.

Danfoss has preprogrammed different applications into the Sync-Pos card, one for Synchronization and the other for Positioning. These "canned" applications add a new parameter group into the drive, which allows the programmer to enter information through the keypad of the drive without a computer or laptop. Anytime an application is "canned" there are restrictions on inputs, outputs as well as some programming features.

7) PLC Signals
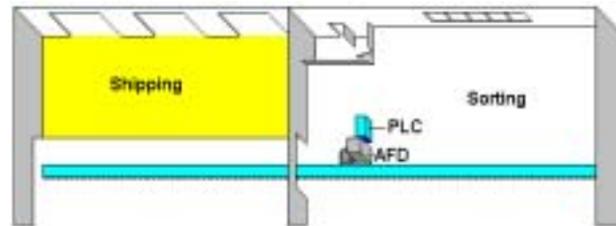
Programmed Logic Controllers (PLC) coordinate the use of the AFD with numerous other schedules and commands. This can be used in very sophisticated control arrangements.

7.   PLC signals

On numerous applications an electronic controller known as Programmable Logic Controller or PLC is used to add other sensing devices, scheduling and other coordinated signals. Danfoss does not make PLCs but it is important that the AFD has the capability to interact with these devices. The PLC sends a start/stop command (digital output) and the reference (analog output) to directly control an AFD. These different types of connections can be referred to as "points".

It is also important that the AFD send information back to the PLC, such as an alarm using a digital/relay output. Using an analog output from the AFD a true indication of the speed might also be sent back to the PLC.

7) PLC Signals
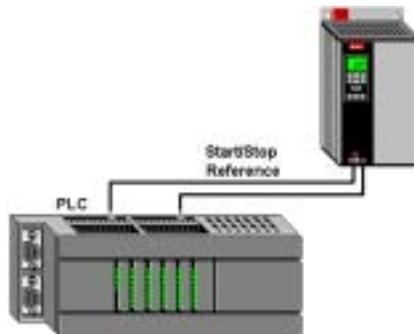
Start/Stop command from a DO of the PLC goes to a DI
of the AFD. A Reference command from an AO of
the PLC goes to an AI of the AFD.

An example of a PLC is shown above. Connection wires are run from the PLC to terminals in the AFD to start/stop and give a reference point. Other wires can be run from the outputs of the AFD back to PLC to indicate the status of the drive. With each request for a command or status information, additional wire connections must be used. Obviously there is an added expense with each set of wires.
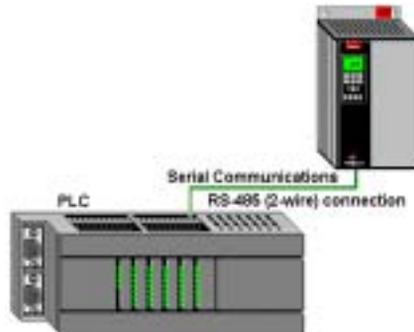
8) Serial Communications
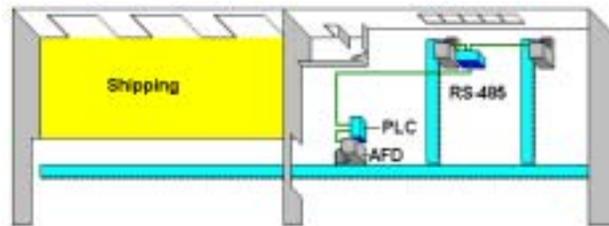
Serial Communications is accomplished by the wiring
of 2 wires between each device, which is also
known as an RS-485 connection. All the +
terminals are attached together and all the – are
attached together.

8.   Serial Communications

With complex PLC applications there can be numerous wires,
perhaps 5 to 10 pairs of wire, between a PLC and the AFD. To reduce this
group of wires the industry is embracing the idea of serial communications
between PLCs and other devices including the AFDs. This allows the
sharing of all sorts of signals including frequency, power, voltage,
temperature, warnings and alarms with the use of an RS-485 (2-wire, + -)
connection.

8) Serial Communications

In the example shown, the PLC controls (start/stop direction change, reference speed, etc) the AFD using the RS-485 connection. The AFD also sends back status information to the PLC.

But with serial communications there are some challenges. Different manufacturers of PLCs communicate in different computer languages. Siemens which is very popular in Europe communicates using a language called Profibus. North America uses a great deal of Allen Bradley which communicates with DeviceNet. These 2 languages do NOT communicate with each other directly. There are more than just 2 languages, as there are more than a few PLC manufacturers. A separate communication card must be installed into the AFD to communicate with each different language.

Presently, Danfoss has a number of different types of serial communications cards that slide into the AFD. There is a DeviceNet card used with Allen Bradley PLCs, Profibus used with Siemens PLCs, Modbus Plus used with Modicon PLCs/ Square D, an Echelon Lonworks card, which is used mainly in building automation, HVAC (Heating Ventilating and Air-Conditioning) and an Interbus card, which is used in the automotive industry.

9) Control Combinations
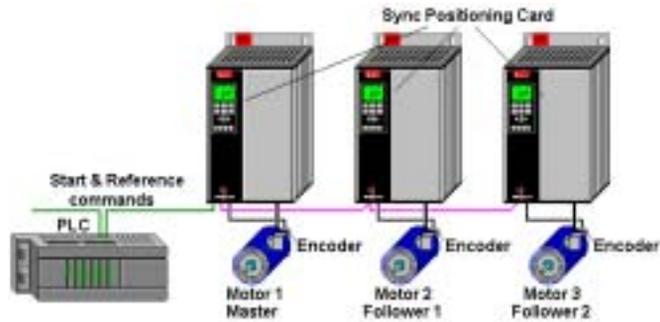
It is very possible to have combinations of different control arrangements, such as pictured here where a PLC, using serial communications, sends signals to 3 AFDs that have Sync-Pos cards.

9.   Combinations

There can be any number of combinations. Perhaps an operator wants to flip a switch and shift between Local and Remote control, or shift between serial communications and remote. In the Danfoss drive there are 4 different setups which allow for this shifting between control arrangements if needed.

Summary

Local	Parameter 002 (Quick Menu 12 0f 13) = Local
	Start/Stop commands are made at the keypad
	Local Reference changes are made at keypad-Parameter 003 (Quick Menu 13 of 13)
Remote	Parameter 002 (Quick Menu 12 0f 13) = Remote
	Digital Inputs give Start/Stop commands
	Analog Input - Pot changes speed – reference
	A Drive always needs a Start command and a reference other than 0 to operate.
Multi-motor	FLA of all motors = Amps of Drive
	Individual protection for each motor
	Do not use AMA (Motor Tuning)
	Do not use Slip comp

Summary

4) Master/Slave

5) Closed Loop/PID

6) Sync-Pos

Summary

Master/Slave   Leader/Follower

AO of Master goes to AI of Slave (4-20mA)

DO of Master goes to DI of Slave (Pulse)

Synchronization – close but not precise

Closed Loop   Feedback using an encoder for speed

PID (Proportional Gain, Integral, Derivative)

Sync-Pos   Precise synchronization is critical

Sync-Pos Card generates Virtual master

Encoder required monitoring each motor

A special Sync-Pos card is available just for Synchronizing and another special card just for Positioning. The original Sync-Pos card can be programmed for either of these or many more applications.

Summary

7) PLC Signals

8) PLC Serial Communications

9) Combinations

Summary

PLC Signals	Digital Outputs from PLC to Digital Input on AFD
	Analog Outputs from PLC to Analog Inputs on AFD
	"Points" are connections to PLC
	AFD Status uses AO and DO back to PLC
PLC Serial	RS-485 (2 wire, + and -) connection
	DeviceNet – Allen Bradley
	Profibus – Siemens
	Modbus Plus – Modicon Square D
	Lonworks – Echelon -HVAC
	Interbus - Automotive
Combinations	Numerous combinations of control arrangements are possible