

# AC MOTORS



## Practical Guide to AC Motors and Control Options

# AC Motors Handbook

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# What are AC Motors and How Do They Work?

AC motors are electric motors driven by alternating current (AC). AC motors are widely used in industry, primarily due to their high efficiency, and their ability to produce constant torque up to the rated speed.

## AC Motor Types

The two most widely used types of AC motors are induction motors and synchronous motors.



Figure 1A: IronHorse® Three-Phase, Premium Efficiency AC Induction Motor

## How AC Motors Work

The two basic parts of an AC motor are the stator (the stationary outer drum) and the rotor; the rotating inner portion of the motor which is attached to (and drives) the motor shaft. Both the stator and the rotor produce rotating magnetic fields. In the windings of the stator, this rotating field is provided inherently by the sinusoidal nature of alternating current. In the rotor, the magnetic field is created by permanent magnets, reluctance saliency, or by additional electrical windings.

Synchronous motors operate in lock step with the frequency of the supply current because their rotors have either permanent magnets or electromagnets generating the rotating electromagnetic field.

In an induction motor, the magnetic field in the windings of the rotor is “induced” by the magnetic field of the stator. In order for this induction to produce torque, the speed of the rotor’s field must lag the field of the stator’s magnetic field. This speed differential is known as “slip”, and is the reason that induction motors will have a “Nameplate RPM” rating that is about 5% less than their synchronous speed. For example, an Ironhorse model MTRP-001-3DB18 (1hp, three phase, four pole, AC induction motor) has a synchronous speed rating of 1800 RPM (assuming 60hz power), but the “Nameplate RPM” rating is 1760. This motor shaft will turn at 1760 RPM when powered directly with the US standard of 60 Hz three-phase power.

## Differences Compared to DC Motors

Industrial DC motors have historically been of the brush type. DC motors with brushes and commutators have a number of drawbacks when compared to AC motors: added maintenance (brush replacement), limited speed ranges and overall life expectancy is shorter. AC induction motors have no brushes and have a much longer life expectancy.

DC motor speed is controlled by varying the armature current, while AC motor speed control is achieved by varying the frequency of the alternating current, often with a variable frequency drive (VFD).

Brushless DC motors have become available over the last several decades, primarily as a result of the advent of the semiconductor control circuitry required to operate them, and the availability of high-quality permanent magnets. Brushless DC motors require no brushes or physical commutator and thus have increased service life. They also overcome the speed limitations of the brushed versions.

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# What are AC Motors and How Do They Work?

## AC Motor Control

When simple on/off control is required, contactors or manual motor starters are often employed. Contactors (large, three-phase relays) allow a PLC or other controller to toggle power to an AC motor. Reversing motor starters are specialized versions with two contactors wired such that they also allow reversing of the direction of spin of the motor shaft. Manual motor starters include a manually operated switch or knob that allows the operator to switch the power. All of these types are known as “across-the-line” control – as the motor is wired directly to the incoming power “line” (through the contactor or motor starter).

## Soft Starters

Soft starters are more complex motor controls that enable acceleration and deceleration ramps for stopping and starting the motors more smoothly than is possible with across-the-line control. Soft-starters typically use silicon control rectifiers (SCR control) to gradually increase or decrease the firing angle to slowly increase or decrease the amount of energy used, and give the application a softer start or ramp down than an across-the-line motor starter. Soft starters reduce wear and tear on the motor and any connected mechanical devices, and they also drastically decrease the inrush current required to start the motor. For large motors, this can have major implications for reducing utility costs.

## Speed Control (VFDs)

Three-phase AC induction motors are sometimes powered by Variable Frequency Drives (VFDs) which, as their name suggests, vary the frequency of the power to the motor in order to vary the speed of the motor. These devices accept standard 60hz input power (single- or three-phase), rectify it to DC, and then use pulse width modulation (PWM) to create simulated AC power at whatever frequency is required to spin the motor at the target speed. More about VFDs in [Chapter 7](#).

## Single-Phase Operation

Single-phase AC induction motors are also available. These motors require special circuitry to start (starting capacitors, and centrifugal switches) but operate identically to their three-phase counterparts once they are spinning. Single-phase AC induction motors are not compatible with VFDs, and can result in higher utility costs due to their inherently unbalanced load on the power grid.

## Specifying AC Motors

If you are specifying a motor for a new application, start by determining the voltage, speed and horsepower required along with the application type as detailed in [Chapter 2](#). If you are replacing a properly-sized motor in an existing application, you can find all the required information on the motor nameplate of the existing motor. If you are considering rewinding the motor in lieu of replacing, [Chapter 3](#) discusses both options and can help with that decision.

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# Selecting Motors for Industrial Applications

Efficient use of motors is always important, but there are many other things to consider when specifying an electric motor. Mechanical and environmental considerations are on the list, as is the application and operation. All of these factors are important, but the application is where the selection process should start.

## Selecting Motors

The application defines the motor load, speed, acceleration, deceleration and duty cycle of the motor. This all feeds into the horsepower and torque requirements. Control of motor speed and position also determines the type motor used and defines whether the motor load is constant or variable horsepower and torque.

After determining the application requirements, we'll walk you through the differences between inverter duty and non-inverter duty motors, and when you can use each (those answers may surprise you). Finally we'll go over some environment factors that also bear consideration.



## Applications Drive Motor Loads

Applications drive the type of motor load, and there are four main types in industrial automation:

- variable horsepower and constant torque
- variable torque and constant horsepower
- variable horsepower and variable torque
- positional control or torque control

Gear pumps, cranes and conveyors are examples of variable horsepower and constant torque applications. Constant speed AC and DC motors work well in these applications where the horsepower requirements may vary, but the load remains constant.

A web unwind or rewind machine is an example of a variable torque and constant horsepower application because the load increases with the diameter of the roll and vice versa. [DC motors](#) and [servo motors](#) work well here, and [AC motors](#) with closed loop drives are another option. Consider regenerative power in this case to increase efficiency.

Centrifugal pumps, fans and mixers/agitators require variable horsepower and variable torque. When speed increases, so does the motor load. [Variable frequency drives \(VFDs\)](#) are often used in these situations.

Motion control applications with linear motion slides and actuators often require accurate positional control, and some presses and tension control systems use torque control. Feedback is usually required, and [servo and stepper motors](#) are often a good choice.

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# Selecting Motors for Industrial Applications

## Pick a Motor

You only need to choose between two classifications of motors, AC and DC, but there are over three dozen motor types used in industrial applications. Fortunately, looking through AutomationDirect's Motion Control and Motors online catalogs, you'll find solutions for most motor applications using servo systems, stepper systems, general purpose and inverter duty AC motors, or general purpose DC motors and gearmotors.



The selection of motors and drives listed and pictured above should cover most industrial automation motor applications.

Some applications need a gearbox to increase torque. To help with motor, drive and gearbox sizing, AutomationDirect has online product selectors and configuration utilities for [SureServo Complete Systems](#), [AC Motors](#), [SureGear Gearboxes](#) and more. With application and environmental information in hand, it's possible to calculate load inertia, torque and speed, along with mass and size of the load.



## Tech Tip: Selecting a Motor

Learn More - Watch the Video  
[www.go2adc.com/pick-a-motor](http://www.go2adc.com/pick-a-motor)



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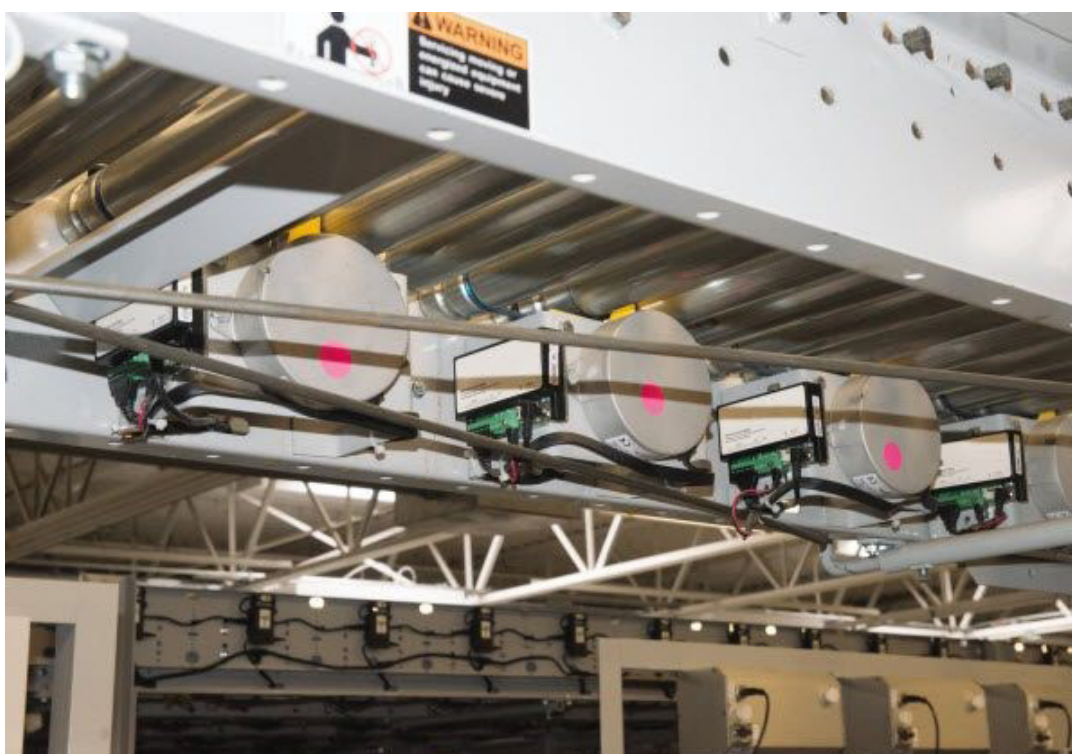
## Application Types

Three common motor speed/torque control applications include constant speed, variable speed and torque (or position) control.

## Constant Speed Applications

Many applications only require the motor to run at constant speed with no need for acceleration and deceleration ramps. Simple on/off control using branch circuit protection fusing, contactor and overloads are all that is needed to turn the motor on and off. Motor starters, manual motor controls or soft starters are also often used.

Typical Industrial AC and DC motors are suitable in these applications. Both are simple and efficient designs and require minimal maintenance.



## Variable Speed Applications

Precisely controlling the speed of fans, centrifugal pumps, mixers/agitators, conveyors and other loads can greatly increase energy efficiency. The ability to control acceleration and deceleration may also help handle product better, such as on a conveyor, and reduce mechanical issues by being gentler on the motor and drivetrain of the system. Coarse positioning of product can also be accomplished with variable speed control using slowdown and stop photoeyes.

DC and AC motors both work well in most variable speed applications. DC drives have been around for over 100 years, and variable speed drives for AC motors have been in use for about 30 years.

DC motors are commonly used on conveyors and other fractional horsepower applications because they provide full torque at low speeds, with torque remaining constant throughout much of the speed range. As mentioned in [Chapter 1](#), many DC motors use brushes which require maintenance, so keep that in mind or spend a little more money for brushless DC motors, or switch to AC motors and drives.

An AC induction motor with a VFD is the popular choice today. If it is a fan or pump application, this is often the best option, especially if motor loads are over 1 HP.



## Position Control Applications

Beyond simple constant speed and variable speed applications is the area of “motion control”. These applications are also beyond the scope of this ebook, but they warrant a brief mention here:

Executing precise position control, and implementing motion profiles with closed loop control, often requires a servo or stepper system. Dispensing applications and moving a linear slide or actuator are examples.

At the low speed end of the precision scale, a stepper system, open or closed loop, is a good choice, especially since the stepper has full torque at zero speed. As speeds and accuracy requirements increase, a servo system is a good choice because it handles dynamic loads and complex motion profiles better than a stepper.

There is a wide choice of AC, DC, stepper and servo motors available for your applications. Identify whether it is a constant speed, variable speed or position control application, and then size and select appropriately using online guidance from AutomationDirect.



We have a wealth of videos  
about Motion Control available

[www.go2adc.com/motion-control-videos](http://www.go2adc.com/motion-control-videos)



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## AC Motors - Design Type and Environmental Considerations

In addition to the standard specifications for motor speed, horsepower, and operating voltage, designers should also consider NEMA design (speed-torque-slip relationship), enclosure type and cooling provisions (if any), frame size, and mounting options. Here are some guidelines:

### NEMA Design Classifications

There are four different NEMA design classifications for speed, torque, and slip that help determine suitability for various applications:

- NEMA design A; suitable for a broad variety of applications, such as fans and pumps. Motors have maximum 5% slip, high to medium starting current, normal locked rotor torque, and normal breakdown torque.
- NEMA design B; intended for a broad variety of applications with normal starting torque (fans, blowers and pumps). Motors have maximum 5% slip, low starting current, high locked rotor torque, and normal breakdown torque.
- NEMA design C; intended for equipment with high inertia starts, such as positive displacement pumps. Motors have maximum 5% slip, low starting current, high locked rotor torque, and normal breakdown torque.
- NEMA design D; intended for equipment with very high-inertia starts (cranes, hoists etc.). Motors have maximum 5-13% slip, low starting current, and very high locked rotor torque.

### Enclosure Type and Cooling

Common enclosure types include Drip Proof (DP), Totally Enclosed Fan Cooled (TEFC), and Totally Enclosed Non-Ventilated (TENV).

- Drip Proof motors are open frame motors intended for indoor applications in clean environments. Ventilation openings are designed to prevent ingress from falling solids and liquids.
- TEFC motors have a fan attached to the rear of the motor shaft to help cool the motor. While there are no ventilation openings in the motor housing, the enclosure is not air or liquid tight. While a TEFC motor may be able to operate at a higher ambient temperature, be careful at low speeds (under VFD control) as the cooling fan is attached to the motor shaft, and may need certain minimum speed to effectively cool the motor.
- TENV motors are also non-ventilated, but the enclosure is not air or liquid tight.

Additional classifications include washdown rated motors (TEWD), explosion-proof motors (XPRF), and motors designed for hazardous locations (HAZ).

### Frame Size and Mounting

Most AC motors today are built to specific NEMA sizes. In small horsepower ranges many motors are available in a “NEMA 56C” frame size. The “56” refers to the motor frame dimensions. The “C” indicates a “C” face (flange) mountable motor. This is the most popular type of face mounted motor and has a specific bolt pattern on the shaft end to allow mounting. The critical dimensions on “C” face motors are the bolt circle, register diameter, and the shaft size. C flange motors always have threaded mounting holes in the face of the motor. Many motors are offered with both C-Face mounting options and a rigid or removable mounting base. As horsepower increases, a number of different “T” frame designations are used to denote the standard NEMA sizes.

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## How to Choose a General Purpose Motor vs. Inverter-Duty Motor

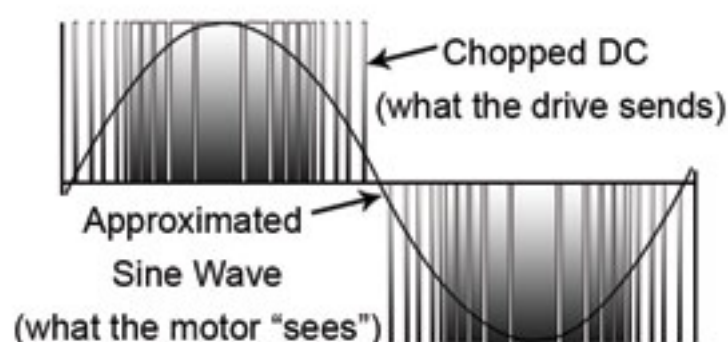
General purpose AC motors have been around for many years. They are the workhorse of almost every industry. An inverter-duty motor is a much newer concept that became necessary as motors began to be driven by VFDs (inverters or AC drives). An inverter duty motor can withstand the higher voltage spikes produced by all VFDs (amplified at longer cable lengths) and can run at very slow speeds without overheating. This performance comes at a cost: inverter-duty motors can be much more expensive than general purpose motors. Guidelines for choosing between Ironhorse general purpose motors vs inverter-duty motors are given below. If your application falls within the guidelines below, there is no need to apply an inverter-duty motor.

**Background:** AC motors can be driven by across-the-line contactors and starters. The electricity sent to the motor is a very clean (true) sine wave at 60Hz. Noise and voltage peaks are relatively small. However, there are drawbacks: the motors can only run electrically at one speed (speed reduction is usually handled by gearboxes or some other, usually inefficient, mechanical means) and the inrush of electrical current (when the motor is first turned on) is usually 5 to 6 times the normal current that the motor consumes. The speed reduction apparatus is expensive and bulky, and the inrush can wreak havoc with power systems and loading (imagine an air conditioning system in an old house – when the compressor kicks on, the lights dim; now imagine the same circumstances with a motor the size of a small car).

*Note: The following discussion applies only to 3-phase motors.*

### Enter the VFDs (Variable Frequency Drives):

Drives were introduced to allow the speed of these motors to be changed while running and to lessen the inrush current when the motor first starts up. To do this, the drive takes the incoming 60Hz AC power and rectifies it to a DC voltage. Every drive has a DC bus that is around 1.414 (sqrt of 2) \* incoming AC Line Voltage.



This DC voltage is then “chopped” by power transistors at very high frequencies to simulate a sine wave that is sent to the motor. By converting the incoming power to DC and then reconvert it to AC, the drive can vary its output voltage and output frequency, thus varying the speed of a motor. Everything sounds great, right? We get to control the frequency and voltage going out to the motor, thus controlling its speed.

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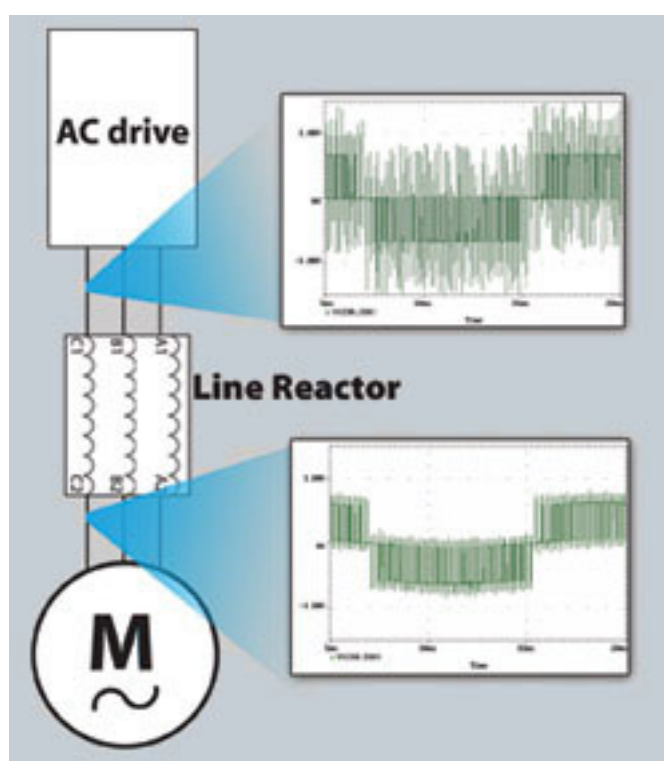
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## Some Things to Watch Out For:

A VFD-driven general-purpose motor can overheat if it is run too slowly. (Motors can get hot if they're run slower than their rated speed.) Since most general purpose motors cool themselves with shaft-mounted fans, slow speeds mean less cooling. If the motor overheats, bearing and insulation life will be reduced. Therefore, there are minimum speed requirements for all motors.

The voltage "chopping" that occurs in the drive sends high-voltage spikes (at the DC bus level) down the wire to the motor. If the system contains long cabling, there are instances where the peak of a reflected wave occurs at the motor. The reflected wave can effectively double the voltage on the wire. This can lead to premature failure of the motor insulation. Long cable lengths between the motor and drive increase the harmful effects of the reflected wave, as do high chopping frequencies (listed in drive manuals as carrier frequencies). Line reactors (1:1 transformers), placed at the output of the drive, can help reduce the voltage spikes going from the drive to the motor. Line reactors are used in many instances when the motor is located far from the drive.



In summary, general purpose motors can be run with drives in many applications; however, inverter-duty motors are designed to handle much lower speeds without overheating and they are capable of withstanding higher voltage spikes without their insulation failing. With the increased performance comes an increase in cost. This additional cost can be worth it if you need greater performance. Two important considerations for applying IronHorse motors with VFDs are given below.

| Heat considerations                                          |                                                  |                                                                             |
|--------------------------------------------------------------|--------------------------------------------------|-----------------------------------------------------------------------------|
|                                                              | IronHorse speed ratio                            | For an 1800 RPM motor, minimum IronHorse speed is:                          |
| Variable Torque applications (fans, centrifugal pumps, etc.) | 5:1 (MTR series)<br>10:1 (MTCP series)           | 1800/5 = 360RPM<br>1800/5 = 180RPM                                          |
| Constant Torque applications (conveyors, extruders, etc)     | 2:1 (MTR series)<br>4:1 (MTCP series)            | 1800/2 = 900RPM<br>1800/4 = 450RPM                                          |
| Voltage Spike considerations                                 |                                                  |                                                                             |
|                                                              | Max cable distance from drive to IronHorse motor | Max cable distance with a 3% line reactor between drive and IronHorse motor |
| For use with 230V and 460V VFDs*                             | 125'                                             | 250'                                                                        |

\*Up to 6 kHz carrier frequency

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# Replace or Rewind an AC Motor?

Every business is trying to conserve energy in the face of high utility costs, so getting the best return on investment (ROI) is critical for maintaining a healthy balance sheet. The decision to replace existing motors with newer premium efficiency motors needs to take into account both the increased energy efficiency as well as ROI gained by installing a new motor.

## Background on Classes of Motor Efficiency

There are three basic standards of motor efficiency: pre-EPA, EPA, and Premium Efficiency (also known as NEMA Premium). In 1992, the Department of Energy issued the Environmental Policy Act of 1992 (EPA '92). This legislation set minimum standards for efficiency of the majority of general purpose motors sold in the U.S. The actual requirements for motors went into effect in 1997. Motors sold after EPA '92 went into effect are commonly referred to as EPA motors.

In 2007, the Energy Independence and Security Act of 2007 (EISA) was signed into law. This legislation raised the minimum efficiency for most induction motors sold in the U.S. even higher. The requirements for this law went into effect in 2010. Motors that meet the latest efficiency guidelines are referred to as Premium Efficiency (PE) or NEMA Premium motors.

## Rewind or Replace?

One of the first decisions made when a motor fails is whether to rewind or replace the motor. The biggest determining factors in that decision are the age of the motor, the type of motor involved, availability, how often the motor runs, and its efficiency. When a pre-EPA motor isn't working properly, replacement is most always preferred (age of the motor and gains in efficiency play a significant role in the ROI).

When an EPA motor fails, the increased savings of replacing this motor with a Premium Efficiency motor requires consideration. If a Premium Efficiency motor fails, the repair/replace decision becomes even less clear-cut. The Department of Energy has information that can help you determine the payback when deciding on purchasing a new Premium Efficiency motor vs. repairing pre-EPA, EPA, or existing Premium Efficient motors.

In the past, rewinding a motor usually meant losing efficiency, but that's no longer true, as original motor efficiency can be maintained in most cases. In fact, it's sometimes possible to increase efficiency with a motor rewind. To determine the effect on efficiency for a specific motor, experts at a motor repair shop should be consulted.

When the motor in question is a special or custom motor, additional factors help determine whether to repair or replace, such as the longer lead times required for custom motors, and the higher costs of replacing them.

In these cases, rewinding may be a more attractive proposition. For non-custom standard efficiency motors, replacement is often the better way to go because the efficiency gains usually outweigh the cost of a new motor.

The amount of time a motor runs can also help determine whether rewinding or replacing is the better option. For motors that operate continually, the ROI for a new, Premium Efficiency motor can be achieved fairly quickly. For motors that only run periodically, careful analysis is needed in the cost calculations for replacing versus rewinding. To help with these calculations there are several websites, such as the Department of Energy website. The Department of Energy also provides a free software package, MotorMaster+, which assists with motor rewind/replace decisions, as well as creating a motor survey if replacing is determined to be the better option.

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## Considerations for Replacing a Motor

A common mistake that happens when the decision is made to replace a motor is thinking that buying any new Premium Efficiency motor will deliver optimal efficiency. When trying to boost savings by increasing energy efficiency, selecting the right-sized motor is at least as important as the energy efficiency of the new motor.

If the new motor is oversized, the energy savings will be less than if the right sized motor was installed. The best method for determining the right size motor is to conduct a thorough motor survey. Correctly sizing an AC motor is important because overloaded motors can overheat, and underloaded motors waste energy. A motor's energy usage accounts for more than 95 percent of its lifetime cost, so achieving maximum energy efficiency is crucial, and rightsizing the motor is a key step.

## Sizing and Output Speed

The two most important factors when sizing any type of load are required torque and speed. Finding the required output speed is usually easily accomplished by determining the design specifications. However, it's usually more difficult to determine the correct torque.

A too-frequent problem in today's industrial applications is the use of oversized motors, an issue that can be addressed with more precise up-front engineering. For example, if an application really requires slightly more than 5 horsepower (hp) at infrequent intervals, a 7.5 hp motor is often installed to make sure there's enough headroom. In this situation, the 7.5 hp motor will definitely work, but it will be running well below full load torque and further down the efficiency curve (wasting energy).

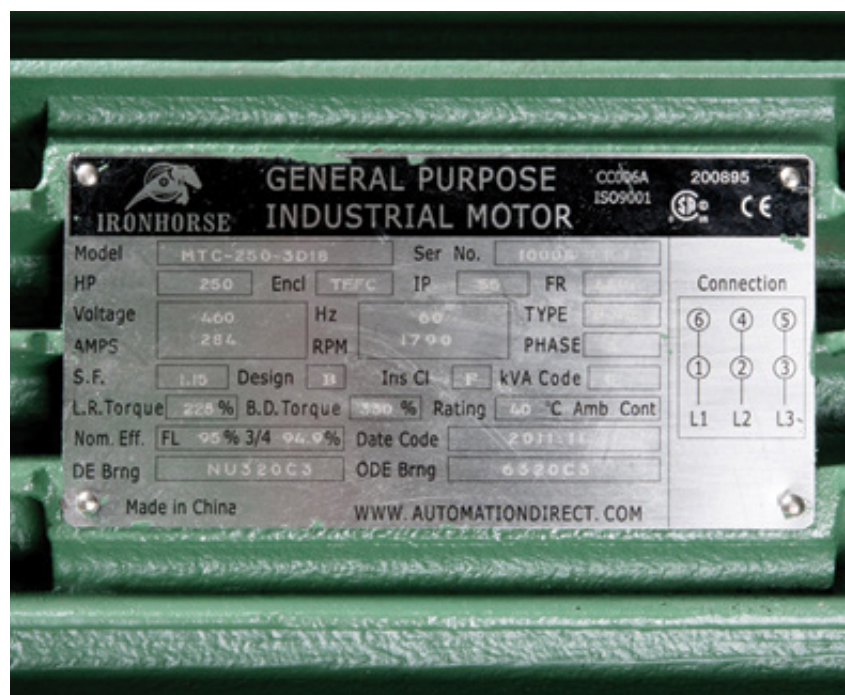
For applications that only require the motor to operate above full load for short periods of time, selecting the right size motor with a higher service factor could be a better option. For example, if a motor has a 1.15 service factor, it can occasionally handle an additional 15 percent load without damaging the motor.

## The Importance of a Motor Survey

Conducting a motor survey is the best way to correctly size a replacement motor. A motor survey should begin by reviewing and cataloging the nameplate information on the current motor to obtain the rated speed, efficiency, full-load current, etc.

The motor nameplate is the first step of a motor survey. It supplies available information, such as speed and full-load current, to help select the right size motor.

The next step is to use a clamp-on meter to monitor the current the motor is drawing during normal operation. Most systems have many unknown factors, such as friction and mechanical transmission efficiencies, which affect motor loading. Thus, getting an actual measurement of the current going into the motor helps determine the true required motor size.



Motors operate most efficiently near full load, so determining load requirements accurately is important. The greatest efficiency is achieved above 70 percent of full load torque. Below 50 to 60 percent, efficiencies start to drop off dramatically.

Conducting a thorough motor study may seem like a complicated task, but there are tools available to help with the calculations.

Moreover, investing the time to conduct a thorough motor survey will help ensure the correct size motor, one that will deliver maximum savings throughout the motor's life.

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# Overview of AC Motor Control Options

Most automatic controls involve [motor control](#) in some way, especially in factory automation. Applications such as pumps, fans, robotics, and conveyors use motors. Whether general-purpose 3-phase AC motors, which are great for simple on/off systems, or the inverter-duty motors specifically designed for operation with variable frequency drives (VFDs), one could say that motors are ubiquitous in nearly all manufacturing industries. Check out the different types of AC motor control options available.

## AC Motor Control Options

While there are different motor types for different situations, motor sizes vary to accommodate varying loads. And with varying motor sizes comes varying motor-starting scenarios. Small general-purpose motors typically are connected to the main power circuit with a master circuit breaker or fuses. Contactors enable and disable the power to the motor while overloads protect the motor-driven equipment from unexpected overcurrent/overheating that can be caused by jams or breakdowns.



## Starting AC Motors Across-the-Line

As the name implies, an across-the-line motor starter applies full voltage, current, and torque immediately to the motor when the circuit is energized. In industry, a motor starter is the most common method of across-the-line motor starting. Typically, a motor starter consists of a contactor to open or close the flow of energy to the motor, and an overload relay to protect the motor from thermal overload.

A contactor is a 3-pole electromechanical switch whose contacts are closed by applying voltage to a coil, much like a relay. When the coil is energized, the contacts are closed, and remain closed until the coil is de-energized. Because motors are inductive devices, breaking the current (magnetizing, or motor and torque-producing, or load) is more difficult than applying it. Therefore, the contactor must be rated for both horsepower and current.

The overload relay has three current-sensing elements that protect the motor from an overcurrent, one for each phase. If the overload current exceeds the setting of the relay for a sufficient length of time, a set of contacts opens to protect the motor from damage.

Reversing starters reverse the shaft rotation of a 3-phase motor by interchanging two of the phases that supply the motor. Reversing magnetic motor starters feature a forward and a reverse contactor as part of the assembly. Electrical and mechanical interlocks are provided to ensure only the forward or the reverse contactor can be engaged at any given time, but not at the same time.

Typically, AC motor starter circuits can be controlled from simple pushbuttons or from remote signals such as from a programmable logic controller (PLC).

Across-the-line motor starting is used when the application can run at the motor's maximum speed and when speed and voltage sags/spikes don't pose a problem. Motor starters are commonly used with smaller motors where users don't need the electrical and mechanical softening effects of a soft starter.

[Chapter 5](#) goes in-depth into the selection of across-the-line control components and how to wire them.

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## Soft Starters Minimize Electrical, Mechanical Impact

There are electrical and mechanical advantages to using a soft starter. When a motor is started across-the-line, the sudden impact of going from 0 rpm to full speed of 1,800 or 3,600 rpm is felt mechanically down the line through the connected mechanical load, and typically draws six to 10 times full load amps (FLA) in current. Soft starters can reduce the load on the motor, the electrical current it uses, and the shock to the downstream machinery. Electrically, it makes little impact to the utility company when starting a 1 hp motor across-the-line, but there is still mechanical shock to downstream equipment. However, starting a 300 hp motor across-the-line will get the power company's attention. Demand charges may result from spikes occurring at certain times of the day. The larger motor imposes an even greater mechanical impact on downstream equipment. The use of a soft starter minimizes mechanical shock to downstream machinery and the power company doesn't impose charges for the huge peak inrush currents.

A **soft starter** uses voltage to control the current and torque. Motor torque is proportional to the square of the applied voltage. The current during starting is directly related to the voltage applied to the motor. In most soft starters, three pairs of back-to-back silicon-controlled rectifiers (SCRs) are used to start and stop the motor, which correspond to the three motor phases. The back-to-back orientation of the SCRs allows the AC voltage to be controlled by changing the firing angle every half cycle. Voltage is either ramped up to full voltage, or is limited to provide current limited starts.



When the motor reaches operating speed, the bypass contactor is pulled in. Whether it's an internal bypass or an external bypass, the SCRs stop firing, which makes the soft starter more efficient. After a motor stop command is provided, the SCRs again take control from the bypass contactor for the stop. The contactor never makes or breaks a load, which allows smaller contactors and SCRs to be used. Soft starters can be between 99.5% to 99.9% efficient. Typically, less than 1 V is dropped across an SCR pair. Efficiency depends on the size of the soft starter and the 3-phase voltage applied. In some cases, after the starting process is complete, a soft start with integrated bypass pulls in an internal bypass contactor. The SCRs are no longer firing and all running current is across the contacts. When operating at full speed and properly loaded, soft starters are more efficient than VFDs, yet unlike VFDs, cannot control the speed of the motor.

To recap, soft starters are used where both electrical and mechanical impact of motor starting must be minimized. With smaller motors, it's more about protecting downstream machines from mechanical shock. With larger motors, in addition to protecting equipment, it's minimizing demand charges.

Soft starters are commonly used with conveyors, pumps, fans, and blowers. Unlike with VFDs, users don't have to worry about generating harmonics. However, soft starters don't have speed control. See [Chapter 6](#) for more information on sizing and selecting a soft starter.

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## Controlling speed, and saving energy with VFDs

Variable Frequency Drives (VFDs) are best where speed control is desired, and energy efficiency is important. VFDs control an AC motor's speed and torque by adjusting the input frequency and voltage to 3-phase AC induction, permanent magnet (interior or surface), or synchronous motors. VFDs also provide overload protection, start/stop control, and adjustable acceleration/deceleration. Programmable acceleration and processor-controlled current limiting can reduce motor inrush current at startup.

When specifying a VFD, it's important to understand the application and select the drive accordingly. The operating profile of the load must first be considered. With both constant torque applications such as conveyors, mixers, and compressors, and variable torque applications such as pumps, fans, and blowers, careful attention must be paid to overload ratings. For example, attempting to drive a fan motor faster than its base speed can significantly impact the amount of power required because the fan horsepower varies with the cube of the speed. Running a fan too fast can consume excess power and may overload the VFD, while running it at half speed can reduce horsepower requirements by 75% or more, per the affinity laws, which apply to pumps and fans. See [Chapter 7](#) for more info on specifying and sizing a VFD.



A [VFD](#) converts AC line voltage to DC voltage, filters it, and then inverts it back into a usable waveform. The RMS value of the inverted signal simulates an AC voltage. The output frequency of the VFD usually varies from 0 Hz to the AC input line frequency. However, higher frequencies also are possible when required for certain applications. Many AC drives historically used a full-wave diode bridge or SCR rectifier bridge in the converter section to convert the AC source to a DC voltage. However, VFDs with insulated-gate bipolar transistors (IGBTs) are now used. The filter section, primarily a capacitor bank, smooths out the rapidly-switched DC voltage produced from the converter.

A choke or inductor can be added to improve power factor and reduce harmonics. The smoothed DC voltage is then used by the IGBT inverter. The fast-acting switching from the inverter section generates the proper RMS simulated AC voltage levels, also known as a pulse width modulated (PWM) waveform. Older IGBT drives were 6-pulse. However, 12-pulse and 18-pulse VFDs are now available.

Modern VFDs provide many advanced functions. The feature-rich line of [DURApulse GS4 AC drives](#) from AutomationDirect includes a built-in, fully-functional PLC, which enables users to program drive-related logic requirements, such as control for multiple pumps. Other features include multiple high-speed communication interfaces, numerous digital and analog I/O points/channels and a 100-kA short circuit current rating (SCCR).

VFDs offer the same benefits as soft starters with the added benefit of speed control. A motor is most efficient when loaded between 80% and 100%. An oversized motor is less efficient than a properly sized motor, but a VFD helps to minimize this inefficiency, reducing the oversizing penalty to little more than the initial cost for oversizing the drive and motor. Drives are typically 95% to 98% efficient. The higher number of pulses in the drive, the higher the efficiency. For example, a 6-pulse drive is 96.5% to 97.5% efficient. An 18-pulse drive is 97.5% to 98% efficient.

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# How to Wire a Motor Starter

A motor starter is a combination of devices used to start, run, and stop an AC induction motor based on commands from an operator or a controller. In North America, an induction motor will typically operate at 230V or 460V, 3-phase, 60 Hz and has a control voltage of 115 VAC or 24 VDC. Several other combinations are possible in North America and other countries and are easily derived from the methods shown in this document.

## Motor Starter

As previously mentioned, the motor starter must have at least two components to operate: a contactor to open or close the flow of energy to the motor, and an overload relay to protect the motor against thermal overload.

A contactor is a 3-pole electromechanical switch whose contacts are closed by applying a voltage to its coil. When the coil is energized, the contacts are closed, and remain closed, until the coil is de-energized. The contactor is specifically designed for motor control but can be used for other purposes such as resistive and lighting loads. Since a motor has inductance, the breaking of the current is more difficult, so designers must adhere to both a horsepower and current rating when specifying the size of the contactor.

The overload relay is a device that has three current sensing elements and protects the motor from an overcurrent. Each phase going from the contactor to the motor passes through these current sensing elements. The overload relay has a selectable current setting based on the full load amp rating of the motor. If the overload current exceeds the setting of the relay for a sufficient length of time, a set of contacts opens to protect the motor from damage.

This article shows how to wire various motors using the [Fuji series](#) of contactors sold by AutomationDirect. Other brands of contactors may be wired the same or similarly. Consult the manufacturer's wiring diagrams for other brands of contactors. Other devices for disconnecting and short-circuit protection may be needed, typically a circuit breaker or fuses. Short-circuit protection will not be shown in the examples that follow.

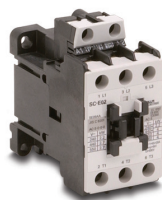
## There are Four Basic Wiring Combinations:

- Full-voltage non-reversing 3-phase motors
- Full-voltage reversing 3-phase motors
- Single-phase motors
- Wye-delta open transition 3-phase motors

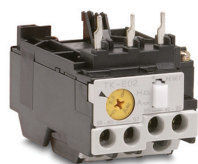
You must supply a disconnect switch, properly sized wire, enclosures, terminal blocks and any other devices needed to complete your circuit, and to meet applicable safety codes.

**WARNING!** Follow the instructions supplied for each specific device. Failure to do so may result in electrical shock or damage.

The following components are typical and are shown in the following wiring diagrams:



Contactors



Overload Relays



Aux Contacts



Mechanical Interlock



Normally Open Pushbutton



Normally Closed Pushbutton



24 VDC Power Supply

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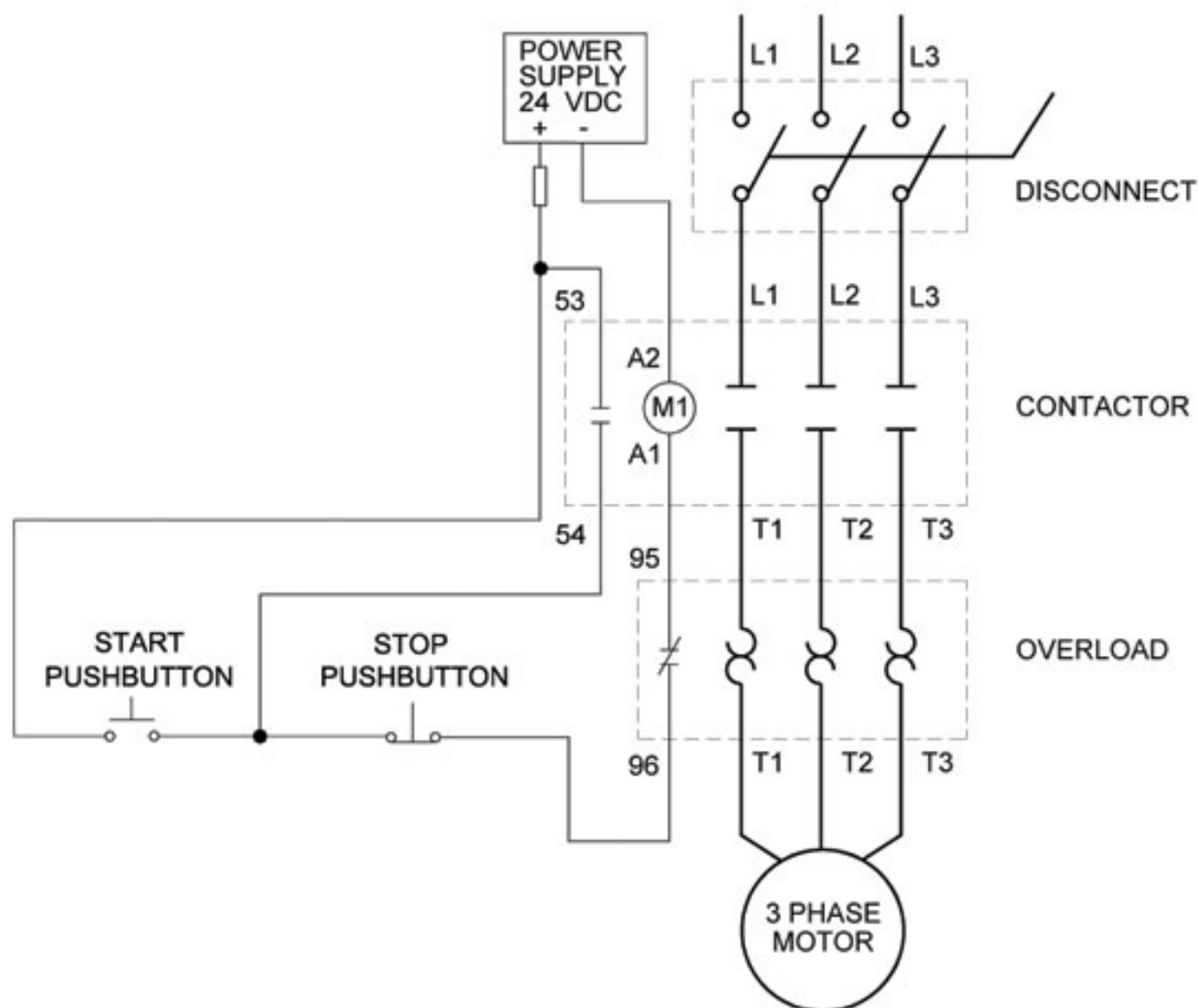
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### Full-voltage non-reversing 3-phase motors

The following diagram depicts 3-phase non-reversing motor control with 24 VDC control voltage and manual operation. We will use a contactor, an auxiliary contact block, an overload relay, a normally open start pushbutton, a normally closed stop pushbutton, and a power supply with a fuse. The start and stop circuits can also be controlled using PLC inputs and outputs.



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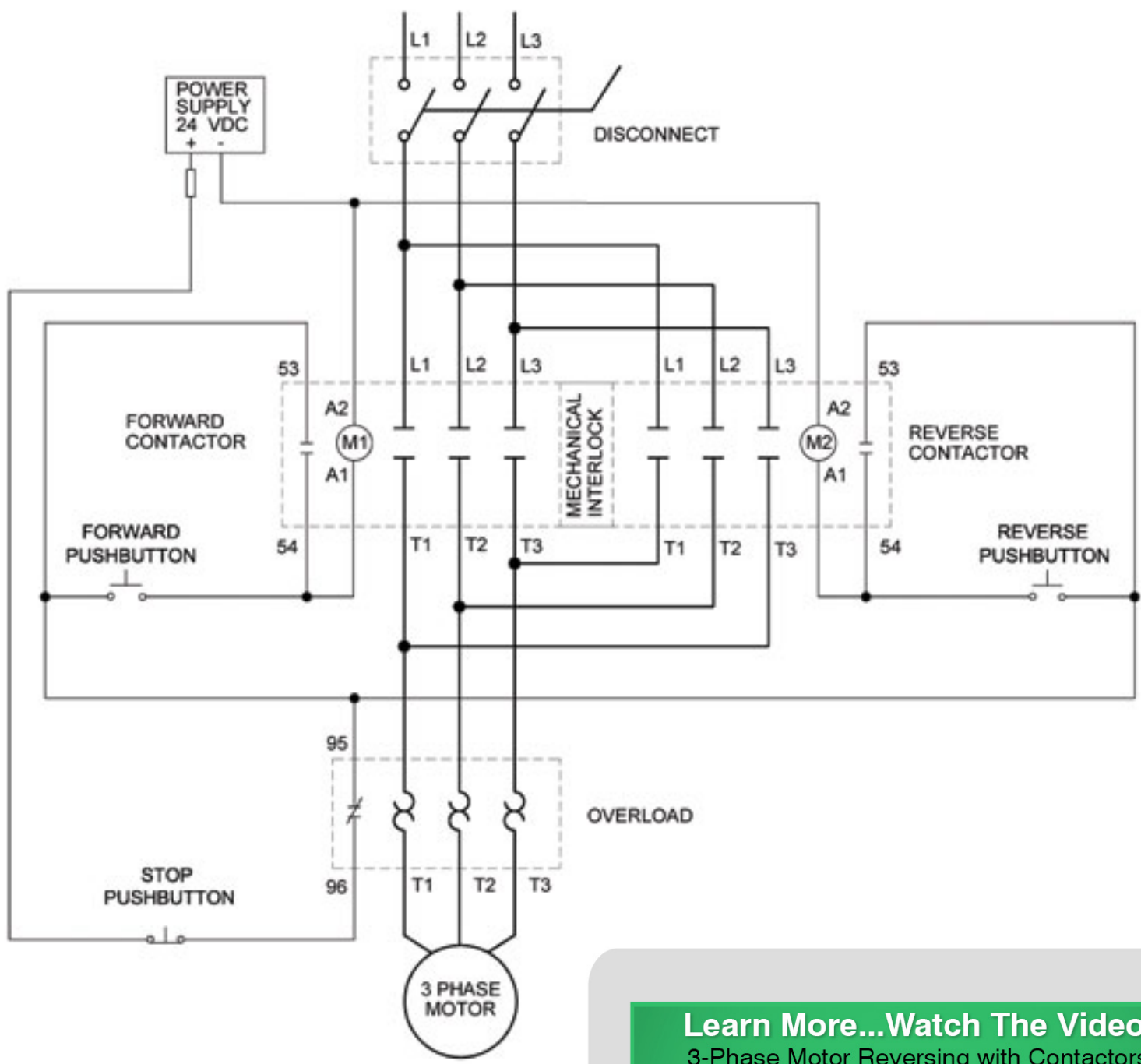
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### Full-voltage reversing 3-phase motors

This diagram is for 3-phase reversing motor control with 24 VDC control voltage. It uses two contactors, two auxiliary contact blocks, an overload relay, a mechanical interlock, two normally open start pushbuttons, a normally closed stop pushbutton, and a power supply with a fuse. The forward, reverse, and stop circuits could alternatively be controlled using a PLC. *Note that Reversing Kits for both the load and line side of the contactors may be available and may simplify the process of wiring a reversing contactor.*



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3-Phase Motor Reversing with Contactors

99 Tech Tip: Learn How To Properly Reverse the Direction of ...

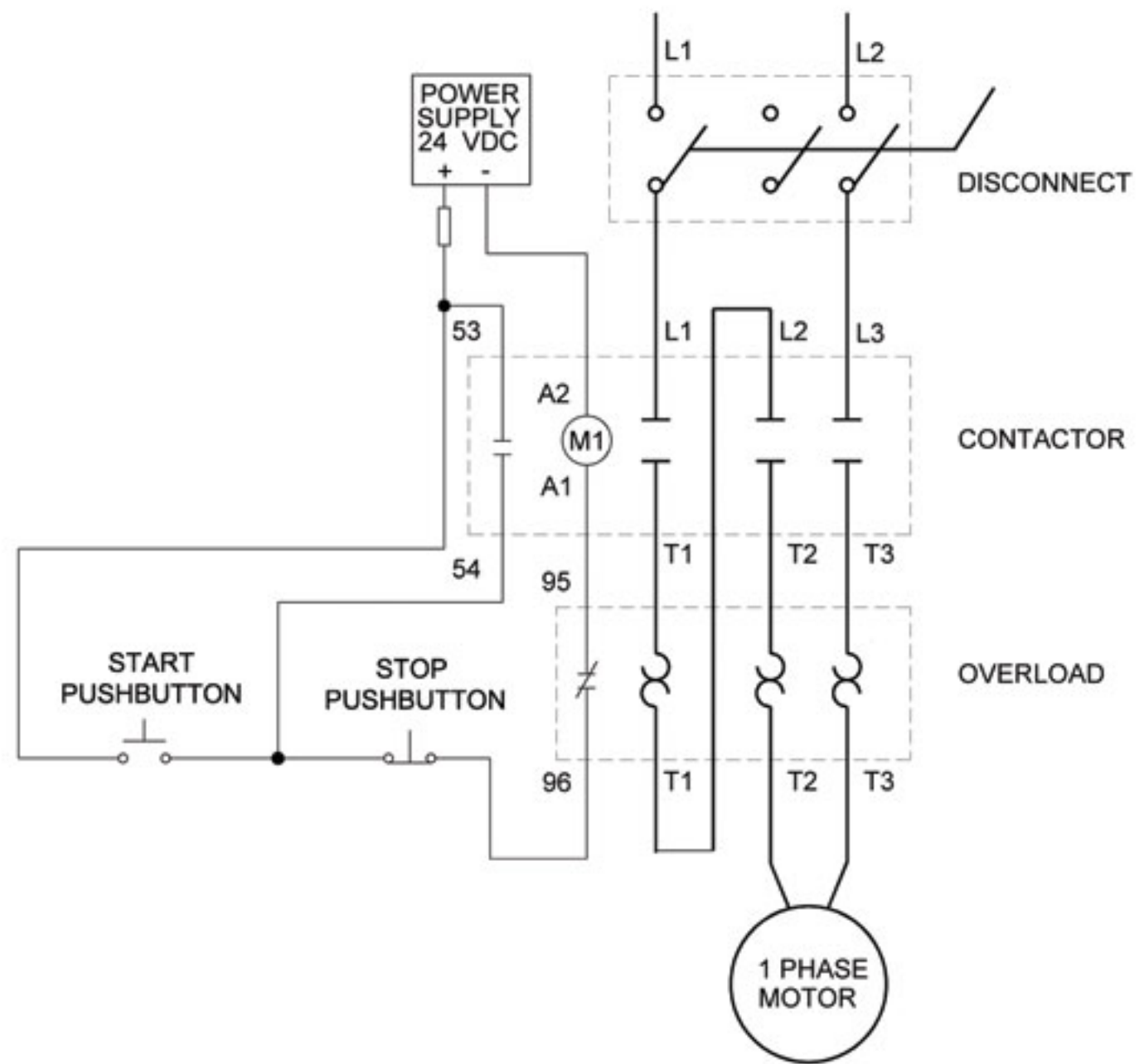
**3-Phase Motor Reversing with Contactors**

www.go2adc.com/3-phase-motor



### Full-voltage single-phase motors

This diagram is for single-phase motor control. It uses a contactor, an overload relay, one auxiliary contact block, a normally open start pushbutton, a normally closed stop pushbutton, and a power supply with a fuse. The start and stop circuits could alternatively be controlled using a PLC.

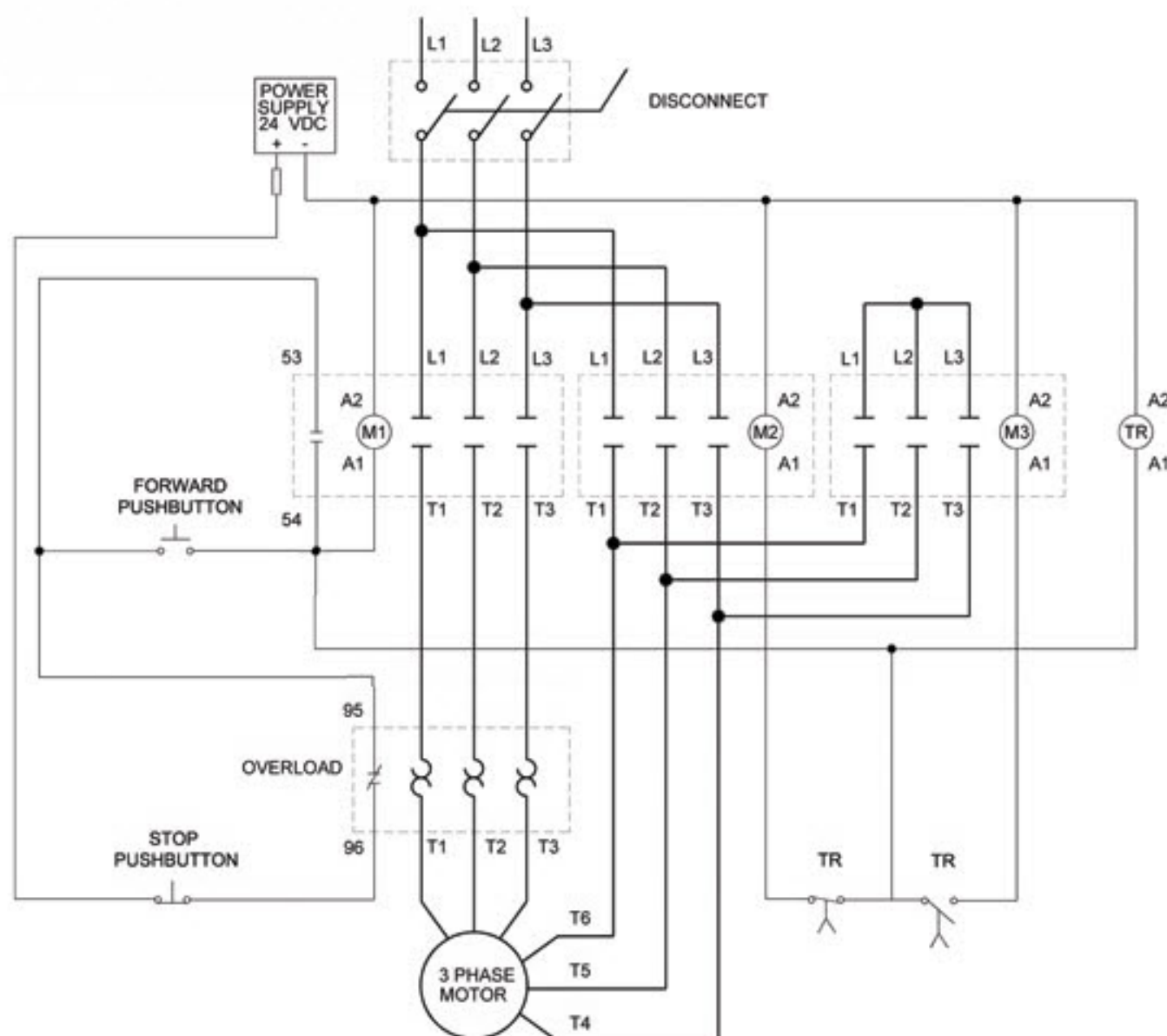


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### Wye-delta open transition 3-phase motors

The following diagram is shown for 3-phase motor control of a delta-star connection. It uses three contactors, an overload relay, one auxiliary contact block, a normally open start pushbutton, a normally closed stop pushbutton, an on-delay timer of 0-20 seconds and a power supply with a fuse. The start, stop, and timing circuits could alternatively be controlled using a PLC.



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# How to Select a Soft Starter for Your Motor

What may seem to be a simple task of selecting a [soft starter](#) for your motor may be a more demanding task than first meets the eye. “I just need to know the horsepower and Voltage to pick the correct one, isn’t that right?”

Well, in fact, it’s not quite that simple. To properly select a soft starter, there are a number of physical and application attributes that need to be considered for longevity and correct handling of the soft starter, the motor and the attached equipment. So, when you need to select a Soft Starter for your application, where do you begin?



As mentioned before you do need to know the Motor Horsepower and Voltage, and those are readily available from the name plate of the motor, but just as important as those attributes are the application, environment, and operating conditions for the entire system; of which the soft starter is a key component.

The selection process begins with the application type which falls into one of three categories or Classes; Class 10, Class 20, or Class 30. These classes are differentiated by the amount of current required during the starting and stopping processes, which are normally the most demanding portions of use time for the motor; and the current temperature of the motor. Lightly loaded motors that do not need to accelerate very quickly, and do not require too many starts and or stops with in an hours’ time normally fall into the Class 10 category. Class 10 applications include some fans, blowers, unloaded/lightly loaded conveyors, unloaded/lightly loaded mixers, etc. Median loading of a motor while coupled to the load may require classification as a Class 20 application. Applications such as most compressors, hammer mills, grinders or loaded mixers normally fall into this class. The most demanding applications are classified as Class 30. These are heavy applications such as shredders, crushers, or high inertia fans requiring greater than 85 running amps. Added to these are the use and environmental conditions that affect the motor’s temperature, such as altitude, as thinner air means less cooling, and starts and stops per hour which add to the motor’s stress and temperature.

With these and a few more factors such as type of motor electrical connection (Wye or Delta) and the ambient temperature, you can properly select a soft starter. Without considering all these factors, an undersized or otherwise inadequate soft starter might be selected and operational difficulties or damage to the starter or other system components can result.

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# How to Select a Soft Starter for Your Motor

## But wait, its easy

But before your eyes glaze over, you may not have to worry about all of those technical details. In consideration of all those issues, we've created a [selector](#) to make the selection process simple and much more comprehensive, enabling confidence in the selection of a soft starter for your application.



With a simple dropdown style menu, you can choose from a comprehensive list of over 40 soft starter applications that most closely match your requirements (or simply choose an application class), select your motor voltage and size, then answer a few simple questions such as “Anticipated starts per hour” (you can try a conservative number and a liberal number to see how it affects the product offering); “Ambient temperature”; “Altitude” etc., and the selector will provide suggestions for an appropriate soft starter. You’ll also find technical data and definitions to help you gain more soft starter application knowledge, increasing your confidence as you make your selection. Once you’ve decided on the criteria that best matches your application needs, you can simply choose from the list of models offered and add one to your shopping cart. The end result is the purchase of a correctly sized (and economically priced) soft starter that will meet your needs and requirements: quickly, easily and confidently.

Check out the AutomationDirect Soft Starter Selector Tool by visiting: <http://go2adc.com/ss-selector>

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# All About Variable Frequency Drives (VFDs)

In this chapter we discuss the benefits and proper sizing and selection of variable frequency drives (VFDs), also called AC drives or inverters. There are many reasons to use a VFD, including the desire to save energy (money!), the VFD's ability to provide smooth starts and stops, and complete control of speed and torque output of the motor. There are even some specialty features such as multi-motor control, logic control, and various safety related advantages that we'll discuss later in the chapter.

## Focus on Energy Conservation

Today, energy conservation and cost-cutting solutions have become a major focus in the manufacturing sector. Energy costs continue to increase and the extreme growth in China is contributing to rising costs in other areas of goods, including steel and coal. Managers of manufacturing facilities are faced with many questions regarding energy conservation and efficiency. They are evaluating what is viable for their facility. Periodic reviews of soaring costs are necessary to stay competitive as the implementation of new processes can be expensive. That's where today's more energy efficient **AC drives** can help. Historically, manufacturers of drives have been able to differentiate their product offerings from those of their fellow competitors on a combination of price, performance, quality, and service. As the market has matured, drive prices have continued to decrease, the performance gap has narrowed, and the level of quality has increased. AC drives have almost become commodities; however, there are still areas where drive manufacturers can add value for their customers and differentiate their products from their competitors. In addition to energy efficiency and cost, other notable areas are power quality, ease of use, size, and integrated functionality.



AC drives are primarily installed for either improvement in energy efficiency or for better control of industrial processes. In each type of installation, users must decide which manufacturer's model offers the desired mix of characteristics for cost, performance, precision, environmental impact, ease of use, communications, interface, installation, and size.

Typical industrial applications for AC drives include extruders, centrifuges, presses, pumps, conveyors, material handling, and cranes. The AC drive's ability to reliably control speed and/or torque is critical. Not only must the drive provide precise control of its load, it must also operate for extended periods of time, with many applications requiring 24-hour operation. The primary evaluation criteria for AC drives in industrial applications have typically centered on reliability and performance. Initial cost is usually a secondary consideration, limited to the AC drives that have met the initial performance requirements.

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## Energy Savings

As energy costs continue to rise, the savings from the use of drives become even more significant. Electric motors consume approximately half of all the electricity used in the United States. Motors controlled by AC drives are among the most efficient of all types of motors in use. Therefore, widespread use of AC drives in industrial, HVAC and similar applications can help reduce current levels of energy consumption.

In applications designed with energy efficiency in mind, AC drives are used to control the speed of devices such as blowers, fans, pumps, and chillers. The primary objective in many of these applications is the reduction of energy usage, measured over a pre-defined period of payback. Typical payback periods as short as 18 months or even one year are used to justify the purchase of an AC drive system. In some cases, the energy cost savings can pay for the AC drive and installation in even less time. Of course, payback periods and the amount of savings will vary with the application. Typically, all motors must be sized for the worst case scenario, often the starting of the device. Once running, the motor no longer requires the same amount of current to keep running, but without an AC drive in the system, most motors will continue to draw unnecessarily high current levels. With an AC drive operating the motor, the drive adjusts the current levels automatically to meet the demands of the application. Additional savings are also possible during lower demand cycles, as the motor speed can be reduced, which in turn reduces the energy used during those periods.

One promising mainstream application in this category is the use of sub-micro drives on residential HVAC units. As the cost of drives continues to fall and the potential energy savings continue to increase, this application should become more common. The compressor pump motor and the condenser fan motor on a residential air conditioner each require high start-up current. Once up to speed, the efficiency of both motors can be improved if they are controlled by drives. Under drive control, these motors can also operate very efficiently at slower speeds on certain days, based on the temperature differential between the indoor and outdoor environments.

Though the immediate and primary impact of applying an AC drive is the reduction in energy costs, the introduction of the AC drive into the installation must not affect reliability. For this reason, redundant systems, as well as bypass options and mechanical flow control, are often installed.

## Power Quality

There are many compelling reasons to implement AC drives. However, due to their consumption of non-sinusoidal currents, power quality problems can arise. Without proper protection and power input considerations, the installation of AC drives can cause power quality and interference problems that may affect nearby electrical equipment.

Most of today's AC drives use diode-rectifier circuits on the power input side (front end) of the drives. When these drives are installed without [line reactors](#), [EMF filters](#), and [RF filters](#) on their power inputs, they can negatively impact the power quality of an entire factory or facility. The Insulated Gate Bipolar Transistors (IGBTs) that are already used extensively on the motor control side (back end) of most AC drives are now being used to replace the diode-rectifiers on the front end of the drive. IGBT-based rectifiers offer several advantages. Lower order current harmonics can be eliminated while maintaining a near-unity displacement power factor across the entire load/speed range. These drives will not require the extensive filtering of the more common diode-rectified drives, and "power factor" is crucial to cost savings for large electrical users. A side benefit of IGBTs on the input side of the drive is a highly reliable "soft-start" function, with no contactors or resistors to fail. Another benefit of IGBT-based rectifiers is their ability to regenerate electrical energy back into the AC lines during braking operations, saving energy and eliminating the need for dynamic braking transistors and resistors. While the higher costs associated with IGBT front-end drives have limited their widespread use, middle to high horsepower applications that demand regeneration will be the obvious early adopters. As the cost of AC drive technology continues to fall, more manufacturers will begin to offer IGBT front-end drives for smaller horsepower applications.

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## Ease of Use

Due to increased reliability and lower cost, it is not uncommon today for AC drives to be considered commodities. This concept is strengthened by the fact that only minor differences exist between the various hardware platforms used for AC drives. Thus it becomes increasingly difficult for manufacturers to differentiate their products from their competitors. Offering products that reduce training time is an extremely effective competitive advantage. This can be accomplished through:

- Keypad designs with increased functionality: – larger display size, a greater number of keys, graphical displays, and user-defined keys.
- Hierarchical parameter structures with advanced/complex functions hidden from the average user.
- More intuitive parameter descriptions and error messages that allow customers to interact with the drive in plain English.

## Shrinking Cost and Size

AC drives will continue to become smaller and cheaper. Three major factors will be responsible for the continuation of this trend:

- The reliability, performance, and cost of electronic power components continue to improve.
- Successive generations of microprocessors continue to offer higher levels of performance and reduced cost.
- Competition between manufacturers across the globe who are all striving to produce high-quality products at substantially lower costs.

## Integrated Functionality

In addition to connecting to the AC power system and the motor, an AC drive must also interface with external devices, such as PLCs, limit switches, push buttons, potentiometers, etc. In order to connect to these auxiliary devices, an AC drive typically provides a number of both digital and analog I/O connections. Because of the flexibility inherent in the microprocessor-based design, these inputs and outputs can usually be configured to perform many different functions. This flexibility allows an off-the-shelf product to be custom tailored to each individual application. In many instances, the need for specialized function cards is eliminated due to the additional functionality present in the AC drive. The following are areas in which manufacturers will continue to add integrated functionality to their products:

- Manufacturers will continue to add programmable functionality, some drives even offering the functional equivalent of an embedded PLC.
- With more emphasis placed on ease of use, the user interface will be a primary focus. Manufacturers have already begun replacing simple alphanumeric keypads with “real- language” LCD-based models. Remote mounting of the keypad is also now possible with some models. This trend is expected to continue with additional features, such as graphics, being offered.
- With the adoption of flux vector technology, the line between AC and servo drives continues to blur. Manufacturers will continue to add enhanced motion control algorithms to their AC drives, making the distinction between AC and servo drives even more difficult to define.

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## Future Trends

It seems ironic that the global pressures that have increased the “commoditization” of AC drives now provide an opportunity for manufacturers to create product differentiation. As the global AC drive market matures, downward cost pressures have forced many manufacturers to develop global designs for their AC drive product lines. Manufacturers can leverage these universal hardware platforms and develop differentiated products through firmware/software customization for the different markets of the world. Manufacturers can focus on the unique needs of each market and develop products that incorporate the “ease of use” and integrated functionality that each market requires. What more could a customer want: an AC drive that possesses the characteristics of high quality and low cost derived from a global platform coupled with a feature set specific to his needs.

## How to Select a Variable Frequency Drive

It may be tempting to size a variable frequency drive (VFD) based on horsepower alone. Did you know there are six other factors you should take into consideration to ensure that you specify the correct AC drive for your application?

### Full Load Amperage

The first step in this process is making sure the drive can handle the motor’s current demands. Check the motor nameplate for the Full Load Current requirement, then find a drive that’s rated for at least that much current. If you are feeding the drive with single-phase power, be sure to use the drive ratings for single-phase. Variable frequency drives are significantly derated for single-phase operation. *NOTE: All AC motors used with VFDs must be three-phase motors. VFDs always create three-phase output for the motor, even when the drive is powered with single-phase power.*

### Overload

Be sure the drive can handle any overload conditions you may expect during startup or intermittent extra loading. You may need to upsize the drive until you find one that can handle it. Many applications experience temporary overload conditions due to starting requirements or impact loading. Most AC drives are designed to operate at 150% overload for 60 seconds. If the application requires an overload greater than 150% or longer than 60 seconds, the AC drive must be oversized. *NOTE: Applications that require replacement of existing motor starters with AC drives may require up to 600% overload.*

### Application Type

There are two application types: variable torque (VT) and constant torque (CT) and separate ratings for each. Use VT ratings for fans and pumps or consult the CT ratings for conveyors and general machine control. It is important to know the application type because the drive specifications are organized accordingly. If you aren’t sure which one to use it’s recommended to go with CT.

### Altitude

The altitude at which you’re using your VFD also has an effect on cooling. As the altitude increases, the air becomes less dense. This decrease in air density decreases the cooling properties of the air. Most VFDs are designed to operate at 100% capacity at altitudes of up to 1000m. If you’re at a higher altitude, the drive must be oversized to compensate for the decrease in cooling.

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Temperature

AC drives generate a significant amount of heat and can cause the internal temperature of an enclosure to exceed the temperature rating of the drive. Enclosure ventilation and/or cooling may be required. Make measurements/calculations for the maximum expected ambient temperature. *NOTE: GS4 drives are ‘flange mountable.’ This through-the-wall mounting technique puts the drive’s heatsink fins on the outside of the enclosure. This drastically reduces the thermal load inside the enclosure.*

Use the following worksheet to determine the derating factors and the required drive FLA for your application:

|                                                                                                                                 |                                                                                                               | Example 1 | Example 2     | Example 3 |
|---------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------|-----------|---------------|-----------|
|                                                                                                                                 |                                                                                                               | GS1/GS2   | DURAPULSE GS3 | GS4       |
|                                                                                                                                 |                                                                                                               | 4         | 8             | 12        |
| Overload Derate (overload %)                                                                                                    | <b>Example 1:</b> Motor FLA=4, Overload=200%@45 secs, Altitude=800m, MEIT=45° C, <b>GS1 or GS2</b>            |           |               |           |
|                                                                                                                                 | <b>Example 2:</b> Motor FLA=8, Overload=135%@75 secs, Altitude=1100m, MEIT=35° C, <b>GS3</b>                  |           |               |           |
|                                                                                                                                 | <b>Example 3:</b> Motor FLA=12, Overload=145%@45 secs, Altitude=800m, MEIT=45° C, <b>GS4 Open Type*</b>       |           |               |           |
| ENTER Motor FLA                                                                                                                 |                                                                                                               |           |               |           |
| If                                                                                                                              | Overload is less than 150% and less than 60 seconds, <b>Then ENTER 1</b>                                      |           |               | 1         |
|                                                                                                                                 | Overload is greater than 150% and less than 60 seconds, <b>Then ENTER (overload/150%)</b>                     | 1.33      |               |           |
|                                                                                                                                 | Overload is greater than 60 seconds, <b>Then ENTER (overload/100%)</b>                                        |           | 1.35          |           |
| Multiply FLA x overload entry (This entry is the overload result)                                                               |                                                                                                               | 5.32      | 10.8          | 12        |
| Altitude Derate (meters)                                                                                                        | Altitude is less than 1000m <b>Then ENTER 1</b>                                                               | 1         |               | 1         |
|                                                                                                                                 | Altitude is more than 1000m and less than 3000m <b>Then ENTER 1+ ((altitude -1000) x 0.0001)</b>              |           | 1.01          |           |
|                                                                                                                                 | Multiply overload result x altitude entry (This entry is the altitude result)                                 | 5.32      | 10.91         | 12        |
| Ambient Temperature (°Celsius)                                                                                                  | Max enclosure internal temperature (MEIT) is less than 40° C (or 50° C if GS4 Open Type*) <b>Then ENTER 1</b> |           | 1             |           |
|                                                                                                                                 | 40° C < MEIT < 50° C and GS1 or GS2 Series AC drive up to 5 hp <b>Then ENTER 1</b>                            | 1         |               |           |
|                                                                                                                                 | 40° C < MEIT < 50° C and GS1 or GS2 Series >5 hp or GS3 series AC drive <b>Then ENTER 1.2</b>                 |           |               |           |
|                                                                                                                                 | 40° C < MEIT < 50° C and DURAPULSE GS4 Type 1 <b>Then ENTER 1 + ((MEIT - 40) x 0.2)</b>                       |           |               |           |
|                                                                                                                                 | 50° C < MEIT < 60° C and DURAPULSE GS4 Open Type* <b>Then ENTER 1 + ((MEIT - 50) x 0.2)</b>                   |           |               | 1.08      |
| Multiply altitude result x MEIT entry (This result is the required drive FLA)                                                   |                                                                                                               | 5.32      | 10.91         | 12.96     |
| *Open Type temperature ratings apply to GS4 frame sizes A–C with top covers removed, and frame sizes D–G without conduit boxes. |                                                                                                               |           |               |           |

Figure 7A: Selecting the proper VFD rating for your application

Carrier Frequency

Generally, you want to look for the lowest carrier frequency your motor can handle. Most of the time the default carrier frequency will work fine, but if you need to reduce the audible noise, the heat dissipation or the power consumption, then make sure you are able to modify the carrier frequency for the drive.

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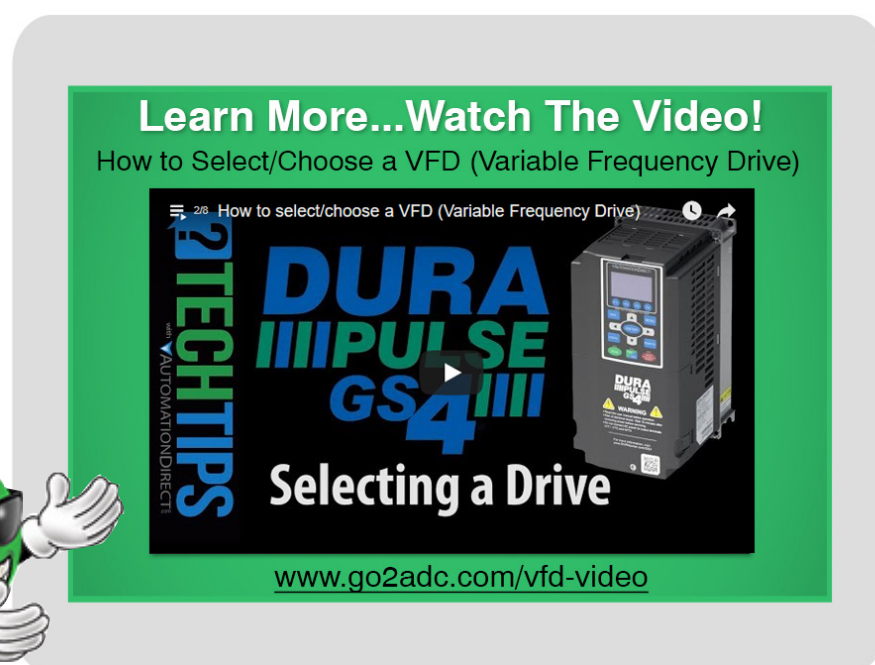
### Tips for Specifying VFDs

For well over 30 years, variable frequency drives (VFD) have been controlling the speed of three-phase alternating-current (AC) induction motors. In addition to saving energy, there are many things to consider for maximum efficiency, control, operation and motor life when using VFDs. The table below contains a list of the top ten considerations that will allow the user to realize the full benefit of using VFDs in variable speed motor applications.



Table: **Top Ten Tips for Specifying and Using VFDs**

1. Understand and use benefits and features
2. Size based on loads
3. Select braking options
4. Interface to the VFD
5. Understand digital communication options
6. Apply the right control mode
7. Define the motion profile
8. Outline installation requirements
9. Specify operation parameters
10. Handle noise and harmonics



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## All About Variable Frequency Drives (VFDs)

Reducing motor speed saves energy in a variety of fan, blower and pump applications. Reduced inrush current when starting a motor along with controlled acceleration and deceleration are also big benefits. Features on the VFD, such as a keypad or potentiometer, allow manual adjustment of parameters, including speed and torque. Automatic adjustment of these parameters is also possible using a PLC or other controller.

When it comes to sizing the VFD, don't just match the horsepower of the motor. Review of the operating profile is important as changing loads, and continuous running or frequent starts and stops, changes torque and peak current demands.

Peak current demands may create temporary overload conditions, yet the VFD must provide adequate current for proper motor performance. In an application such as a conveyor with a heavy load, high breakaway torque may demand power and torque, requiring an oversized VFD. The additional headroom provided by a larger drive is worth the slight increase in price and extra required panel space.



When decelerating a motor, a VFD can provide approximately 20% of the available torque for braking. For heavy loads and frequent start-stop applications, adding a braking resistor can significantly increase braking torque.

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## Interface, Communication and Control

Typical run, jog and speed control functions in a VFD are selected using discrete or analog outputs signals from a controller.

Often a combination of discrete, analog and preset control is used. For example, a controller sends an analog speed signal to a drive, and discrete signals to control run and jog functions, with acceleration and deceleration parameters hardcoded.

To reduce or eliminate hardwiring, digital communication such as Modbus RS-232/RS-485, EtherNet/IP or other protocols can be used to control the drive and set parameters. This type of communication also enables monitoring of the drive status, such as speed and current, and may also enable remote configuration capability.

Some drive control modes require specific types of AC drives. Volts-per-Hertz (V/Hz) drives are most common, and work well for pump and fan applications. As speed accuracy requirements increase, open-loop sensorless-vector drives and closed-loop VFDs with encoder feedback provide accurate speed regulation for web handling, paper mills, printing presses and converting applications.



## Understand Motion, Installation and Operation

Before setting a drive's parameters, be sure to understand the motion profile required. What speed is needed; and can the motor accelerate slowly or must it start quickly, are just some of the questions to be answered. VFD parameters must also be understood for optimum drive setup and control.

VFDs create heat during operation that may need to be vented out of the control cabinet, particularly if there are frequent starts and stops. Running a motor at low speeds for extended periods also adds heat and usually requires an inverter-duty rated motor, which includes a built-in fan.

The AC drive manual covers many installation requirements. An important installation note is to not use a contactor or disconnect switch at the AC drive input for run-stop control, but only to remove power from the drive input under an emergency stop condition. Use discrete signals or digital communication for non-emergency start and stop functions during normal operation.

Noise and harmonics generated by a VFD can damage connected motors and nearby equipment. Passive harmonic filters such as AC line reactors and chokes are often installed to reduce these problems. Check the drive installation manual and use these filters to reduce harmonics and protect the VFDs from transient overvoltage. Active harmonic filters can also be used to reduce noise generated by the VFD.

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## To VFD or Not to VFD

It takes about \$40k of electricity to run a 100 HP motor for a year at full speed, so it's worth a look to see if these costs can be cut. Good candidates for VFD operation are motors that need to operate with their output throttled down to meet varying demand. Installing a VFD on these motors can result in substantial savings, with payback periods often measured in months, particularly when utility company rebates are considered.



## Extra VFD Benefits for Pump Motors

Many AC motors can benefit from adding a VFD, and the cost/benefit calculation procedures provided below apply to all AC motor installations. But centrifugal pump motors are particularly good candidates for VFDs because required pump motor power changes at a much faster rate than flow.

Per the table below, if pump speed decreases from 100% to 50%, then flow also decreases from 100% to 50%. But, pressure decreases from 100% to 25%, and power consumption drops from 100% to 12.5%. A VFD will therefore cut required pump power by a factor of 8 for a 50% reduction in pump flow, quite a bang for the buck.

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## Effects of the Affinity Law on Pump Applications

| Pump Speed (% of Rated Speed) | Pump Flow (% of Rated Volume) | Pump Head (% of Rated Pressure) | Pump HP (% of Rated Horsepower) |
|-------------------------------|-------------------------------|---------------------------------|---------------------------------|
| 150%                          | 150%                          | 225%                            | 338%                            |
| 140%                          | 140%                          | 196%                            | 274%                            |
| 130%                          | 130%                          | 169%                            | 220%                            |
| 120%                          | 120%                          | 144%                            | 173%                            |
| 110%                          | 110%                          | 121%                            | 133%                            |
| 100%                          | 100%                          | 100%                            | 100%                            |
| 90%                           | 90%                           | 81%                             | 73%                             |
| 80%                           | 80%                           | 64%                             | 51%                             |
| 70%                           | 70%                           | 49%                             | 34%                             |
| 60%                           | 60%                           | 36%                             | 22%                             |
| 50%                           | 50%                           | 25%                             | 13%                             |
| 40%                           | 40%                           | 16%                             | 6%                              |
| 30%                           | 30%                           | 9%                              | 3%                              |

## Determine the Need for Variable Frequency Drives

Unfortunately, it's not a simple matter to figure out if a VFD is a good idea for a particular AC motor application. But it's not incredibly complex either, just follow these steps:

**Operating Conditions**

- Specify the motor to meet both minimum and maximum requirements (only needed for new installations)
- Estimate the time the motor runs at different speeds

**Costs**

- Determine the installed cost of the VFD including required supplementary equipment for power factor correction, noise filtering, etc.

**Savings**

- Estimate cost of KWH at each of the selected motor speeds, include a 3% VFD loss, and translate these costs into yearly savings as compared to running the motor at full speed
- Add in savings from reduced maintenance, and from longer motor and other component life, all realized by running at lower speeds
- Add in any rebates from the utility for VFD installations

If savings exceed cost significantly, then a VFD is a good idea. If they don't, it's not, at least strictly from an energy savings point of view, although VFDs are often needed for other reasons related to process control.

Some suppliers suggest a VFD is a no-brainer for every AC motor over a few horsepower, but this is not always the case. Instead, each application must be examined individually.

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## Frequently Asked Questions About VFDs

AutomationDirect's technical support team has compiled a list of customer frequently asked questions for many of our products. The complete listing can be found on the [technical support page](#) of our Web site. Here are some of the frequently asked questions for variable frequency drives (VFD).

### Q: What is sensorless vector control?

A: Sensorless vector control is a technique used in variable frequency drives to rotate the force vector in the motor without the use of a shaft position sensor. The goal of AC sensorless vector technology is to give the user "DC" like control while making traditional speed or shaft position feedback from the motor unnecessary. Sensorless vector control removes a major source of complexity and potential for failure, such as tachometer feedback, while simplifying many AC drive installations. The sensorless vector algorithm must be tuned to match the characteristics of the particular motor being controlled by the drive. This improves torque performance at very low speeds as compared to typical volts per hertz control.

### Q: Does a motor need a chassis ground connection?

A: Yes, for several reasons. Chassis grounding is used for protection in the event of a short in the motor that puts a live voltage on its housing. Motors and other components exhibit leakage currents that increase with aging and a grounded chassis generally emits less electrical noise than an ungrounded one.

### Q: What type of motor is compatible with inverters?

A: Inverter motor type must be a three phase AC induction motor. Preferably, you should use an inverter-grade motor that has 800V insulation for 200V class inverters, or 1600V insulation for 400V class inverters. For motor size, in practice it is much better to find the right size motor for your application; then look for an inverter to match the motor.

### Q: How will I know if my application will require resistive (dynamic) braking?

A: For new applications it may be difficult to tell before you actually test a motor/drive solution. In general, some applications can rely on system losses such as friction to serve as the decelerating force, or otherwise can tolerate a long decel time. These applications will not need dynamic braking. However, applications with a combination of a high-inertia load and a required short decel time will need dynamic braking. This is a physics question that may be answered either empirically or through extensive calculations.

### Q: What is ringing and what happens to the motor when I place it more than 50 feet away from the drive without a line reactor?

A: High voltage ringing (reflective voltage) occurs on all VFDs. With IGBTs replacing SCRs on smaller, more inexpensive drives, ringing has become more pronounced. This capacitive-coupling effect is caused by high speed switching (commutation). Distance greatly enhances the effect. Cables on the output side of the drive act like capacitors. When the IGBTs switch or produce the PWM output, the higher frequency part of the current will find a path through that capacitance. Think of the cable as a capacitor that increases in size as the cable length increases. Ringing is very detrimental to motors; it weakens the first stage rotor windings and shortens the life expectancy of a motor. This is especially true for motors under 10 hp. Typically they are machine wound, have thinner coats of varnish, and have neither phase nor end paper (I.E. aggregate insulation properties). That's why we always recommend a drive rated motor. Vintage and non-drive rated motors that are used with VFDs have a lifespan of unknown length. You simply cannot know what to expect from them. Long cable runs with ringing can add 10 to 15% to the drive's current rating, causing the drive to trip out on excessive current. The capacitance will also cause a voltage drop that may cause speed performance problems on the lower end of the speed scale (increased current demand for demanded torque). A few general guidelines: 1) Try to reduce distances as much as possible, 2) Use an output line reactor on cabled distances greater than 50 feet, 3) Always use a drive-rated motor.

### Q: Is there a standard for inverter rated motors?

A: NEMA MG-1, Section IV, Parts 30 and 31. Part 30 pertains to fixed supply motors; part 31 pertains to inverter supply motors. Always talk to your motor manufacturer for additional details. Note: the international standard is IEC 60034-17.

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**Q: What drive power cable do you recommend and why?**

A: Belden 29500 – 29507 [cables](#) are specifically designed for use with VFDs. Using the wrong cable can increase the detrimental effects from ringing due to capacitive coupling. Thermoplastic insulation, found in standard THHN cable, will break down over time if used to connect inverters to motors. The standing waves caused by pulse width modulation (PWM) will cause high voltage potential on single conductors. This renders corona (reflective/ringing voltage) in the air gaps between the conductors, which could break down and cause a system failure.

**Q: Can a drive replace a softstart?**

A: Yes. Softstarts are used for reduced torque starting and stopping of standard 3-phase induction motors (such as centrifugal pumps, compressors, ball mills, jar mills, fans, blowers and saws). If the motor is not adequately protected from sudden changes in rotational torque associated with starting and stopping, the current will be excessive to the system and the motor will surge, causing damage to all the equipment linked to it. Over the long term, this leads to increased over-current tripping and increased mechanical wear of gearboxes, clutches, transmission and conveyor systems. ANSI/IEEE Std. 141-1993 (Red Book) provides a comparison of different reduced voltage starting methods. An electronic softstart of VFD, although not listed, would have similar characteristics to the autotransformer starter.

**Q: Can I run my drive at extremely low speeds?**

A: Three major problems exist with both conventional methods of motor control and VFD control: 1) When a motor is directly coupled and run at a low speed, it becomes very inefficient. You could go with a high torque motor that is significantly larger than the standard and would have the same results most of the time. 2) Typical motors do not cool themselves well at extremely low speeds. The added heat buildup in the windings can cause premature motor failure. Check with the motor manufacturer for more details. 3) The third issue is load inertia, which is larger than that of the motor. The effects of all of these things increase greatly with a sloppy transmission system. A speed reducer or gearbox should be employed to solve this problem. It will match the inertial changes and increase efficiency. Speak with a technical resource about sizing the gearbox to meet your application needs.

**Q: Are variable frequency drives phase sensitive?**

A: The input wiring is not sensitive to phase. If you were to change one set of input leads, the rotation would not change. The opposite is true for the output of the drive. It is sensitive to phase, so changing one set of leads to the motor changes the direction of rotation.

**Q: What is a line reactor and what will it do for my application?**

A: A line reactor is a special type of inductor used on the line side or the motor side of a drive application depending on the specific circumstances. They are used on the line side of the drive to smooth inrush current, reduce noise, and to act as a buffer and protect the drive system. The line reactors have a 3% voltage drop based on impedance. This drop can be beneficial for drives on systems exceeding the rated input voltage of the drive. In this regard, the [line reactor](#) has been used to replace the much larger drive isolation transformer. Line reactors are used on the motor side of the drive to protect the motor by smoothing the drive output waveforms and by reducing ringing and capacitive coupling, especially with long cable runs between the drive and the motor.

**Q: What is grounding and what reference material is available?**

A: Equipment or conductor-enclosure ground refers to connecting the non-current-carrying metal parts of the wiring system or equipment to ground. This is done so the metal parts which a person might contact are at or near ground potential. The grounding of motors is referenced in NEC Article 430, Part M and methods are described in article NEC 250.

**Q: What are some of the common reasons why motors fail?**

A: The EPRI Power Industry Study by General Electric in 1985 offered the following causes based on 6,000 utility motor failures: 41% were bearing related, 37% were stator related, 10% were rotor related and 12% were other causes. Other institutions like DOD and the IEEE came up with similar results.

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**Q: My pump is losing speed; does the drive have a problem?**

A: Pumps are divided into three basic categories – centrifugal, rotary, and reciprocating. Take any of the three types and break them down further into four parts: the rotating element, the casing, the motor, and the drive. The rotating element has a shaft, sleeves, bearings and an impeller. The casing has a pump shell, wear rings, and shaft seals.

Here is a basic remediation list:

- 1) The belts are slipping (if applicable)
- 2) The impeller is worn
- 3) The impeller is loose on the shaft or the shaft is sheared
- 4) The casing is worn
- 5) The original motor was replaced with a slower model or one with a greater amount of motor slip
- 6) The requirements have changed beyond the design specifications of the system

First, using a manual tachometer, verify the speed problem. If all the above listed items have been investigated and a problem still exists, then you may need to increase the maximum frequency of the drive. Note that anything beyond 60 Hz will result in a shift from a constant torque to a variable torque operation. There is a low probability that the drive is detrimentally affecting the intrinsic speed of the system.

**Q: Is there a reference for application help?**

A: NEMA standards publication “Application Guide For Adjustable Speed Drive Systems”.

**Q: What is the difference between torque control and torque limiting?**

A: Torque control can be done with any of AutomationDirect’s PID capable drives. This would be a closed loop system using torque as the process variable. There should be both a torque reference and torque feedback signal. The user would establish a torque setpoint and configure the drive to maintain that setpoint. Many customers have used torque sensors, load cells, and current transducers to establish an analog input to the drive. Ideally, a vector drive would work better than a volts/hertz drive. A vector drive allows tighter speed regulation and better control in the lower speed range. Torque limiting is also a possibility with a supporting drive. Instead of using an external torque sensor, torque limiting uses the drive’s internal current sensor. The operator would set the torque limit, and when that level is exceeded, the drive would act like a governor on a generator. The speed would be restricted until the appropriate level is again maintained. Mechanical devices, in addition to drives, are also employed for torque limiting, such as clutches, shear pins, gearboxes, etc.



We have a huge video library covering a variety of topics including over 50 “How To” and “Tech Tips” videos on VFDs.

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# Collection of AC Motor/Motor Control Application Stories

Want some examples of what people are doing with AC motors and control options? We have a full collection of application stories on our website at [Library.AutomationDirect.com/application-stories](http://Library.AutomationDirect.com/application-stories). For your convenience we took the time to list some of them on the next few pages. You can see a preview in the table of contents below and then pick the ones that look the most interesting to you. And you can check out all of our [application stories on our website](http://Library.AutomationDirect.com/application-stories).



## Teaching an Old Dog Some New Tricks



## Converting a Mill/Drill and Installing a VFD



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By: Peter James

A woodworking enthusiast improves the performance and capabilities of several large shop tools by installing variable frequency drives.

## Converting a Mill/Drill and Installing a VFD

Several years ago I purchased a Wadkin lathe made in England in late 1964. It is equipped with a very special motor that is 220V, three-phase and 50Hz. Because of the special design of the motor, it has a long extended shaft that carries the four sheave pulley, and because I do not have three-phase power in my shop, some means of creating it locally was needed.

I do have 220V power and the 50Hz design of the motor is not a problem. I knew about rotary phase converters and so called static phase converters, but neither really seemed to fit my needs. While doing my research of possible solutions, I learned about Variable Frequency Drives (VFDs). This seemed like the answer that I needed and further investigation showed that several manufacturers of new machinery were using three-phase motors/VFDs to provide better control over machine speed, soft start (programmable acceleration) and forward/reverse functions.

I looked at several different VFD brands and found the ones from AutomationDirect best fit my application. I liked the keypad setup and the ease of programming the VFD for my lathe; also helpful is the ability to mount the keypad remotely with the optional extension cable. I even programmed the display to show actual spindle lathe RPMs.

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After I had my lathe up and running and found how well the AutomationDirect VFD worked out, I decided to convert my Rockwell ramtype radial drill back to three-phase and install another VFD on it. Because this only has a ½ HP motor, I was able to use a VFD with 120V single-phase input and 220V three-phase output. Again I went with AutomationDirect and used a remote control for the forward/off/reverse and speed controls.

I had been experimenting with the programming, changing things like the acceleration times, method of stopping, what the display showed, and some of the other programmable functions. Once I became comfortable with the programming procedure, I found that I could customize the the VFD to my exact needs.

The remote controls that I used in both of these installations are simple to build and in fact, so simple that I called the support team at AutomationDirect to be assured that it was as simple as it looked. The support people were able to explain things in a manner that clearly answered my questions.

### Issues with a Milling Machine

I recently purchased a mill/drill milling machine patterned after the popular Rong Fu model. I soon found that there were some issues with the machine that I felt could be corrected with the three-phase motor/VFD conversion.

Because it is a three-pulley, two-belt drive setup, with the center pulley acting as an idler with both belts on it, changing the spindle speed requires removing and changing the position of both belts. This is very time-consuming and inconvenient.

Also it had a capacitor start/capacitor run motor that, while powerful, was not smooth running. Another issue was a flimsy motor mount that kept bending. Replacing the motor and adding a VFD would provide electronic speed and reverse control, add soft start and a smoother running motor; it also gave me the opportunity to fabricate a stronger motor mount.



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## Materials Required to do the Conversion

In order to keep the same size motor (2HP), I used a chart to determine the proper NEMA frame size needed for the replacement motor. If you have a motor with a NEMA frame, then all you need to do is get a replacement with the same frame number and it will bolt right in without any modifications. The same NEMA frame size can have different horsepower, different base RPMs, and be either single or three-phase. The NEMA 145T model MTCP-002-3BD18 motor from AutomationDirect most closely matched the metric motor on my mill. Because I was replacing the motor mount anyway, the difference in mounting holes for the motor base was not a problem.



I chose to use the GS2-22P0 VFD from AutomationDirect rated with my 2HP motor. I also used the optional extension cable, GS-CBL2-1L, to allow mounting of the keypad on the outside of the door of the Hubbell-Weigmann N1C121208 steel enclosure.

For the remote control unit to be mounted on the mill/drill itself, I used an SA-106-40SL enclosure, a GCX1370-22 forward/off/reverse switch, and an ECX2300-5K potentiometer.

The cable that powers the VFD is a 12/3 SOOW SO cord and a 14/4 SOOW SO connects the VFD to the motor. To connect the VFD to the remote control, I used an 8-conductor 24-gauge Ethernet computer cable, run inside a piece of 3/8" flexible conduit for protection. (You only need six of the conductors for the remote.) These cables are readily available at [www.automationdirect.com](http://www.automationdirect.com) and most electronics stores.

## The Installation

The first thing that needed to be done was to fabricate a new motor mount. I found the best way to mount the motor was to build a temporary platform for the motor and then lower the mill into position on the motor. I temporarily moved the old motor out of the way and with the new motor in position, determined the size of the new motor mount and the location of the mounting holes.

I used a piece of 1/4" steel plate and welded on two ears for the hinge bolts. I then used the mill to machine in the four slots for the motor to ride and adjust in and drilled the hinge bolt holes. After applying a coat of paint, I was ready to install the motor.

The remote control box was mounted to the mill housing using a piece of 3" angle aluminum. This provided a very sturdy mount and placed the controls right up front where they are easy to reach.

The VFD unit is mounted inside a wall-mounted steel cabinet behind the machine. It is close enough so that the display can be read easily and the unit programmed using the keypad.

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The VFD generates a small amount of heat, so I installed four soffit vents with a fine screen inside. There are two on the bottom and one on each side near the top which allows for air flow within the closed cabinet.

When connecting the power cables, it is best to use crimp-on connectors because the connecting screws on the VFD are relatively small. The control cable can be connected directly if you tin the ends of the wires. Tinning the ends makes it easy to insert the wires into the terminals on the switches and the VFD and prevent them from becoming crushed by terminal screws.

You need a means of disconnecting the unit from the power source and it should be protected with a circuit breaker. The electric panel is about 5 feet from the VFD and it is on a dedicated circuit, so my means of disconnecting is a plug on the end of the power cable and a twist lock outlet. When it is unplugged, I know it is disconnected.

The keypad is removed from the VFD unit by squeezing the two tabs on the sides and pulling out. The cabinet door needs to have three holes drilled to accept the keypad.

### Materials Required to do the Conversion

After all the components are installed and the power and control cables are hooked up, the next step is programming the VFD to set up the parameters for the particular installation; detailed programming provides the maximum benefit and performance from the VFD.

The VFD comes with a "Quick Reference Card" and a user manual. Both list the parameters used in programming the VFD. The information shown on the motor data plate is the first item to input. Once the scheme for programming is understood, it becomes easy to customize the VFD to your particular needs. The programming mode is entered by pressing the "Program" key on the keypad. Selections are started by pressing the "enter" key and changes are entered using the "up/down" arrows on the keypad, followed by pressing the "enter" key to save the selection.



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The four most commonly used programming sections include: motor data, motor control, remote control activation and display customization.

Programming section “P 8.00” is the display function. There are many options here. I like to use one that shows the spindle or cutter speed in RPMs. This is accomplished by entering “02” which shows the output frequency multiplied by a factor. That factor is the spindle speed divided by the output frequency. This can be determined several ways. One way is to use the specifications for the machine which will show spindle speed with the standard motor speed.

Another way is to use a tachometer to measure the spindle speed at a given frequency. I used an inexpensive digital tachometer to determine the spindle speed at 60Hz and found it was 485 RPMs. 485 divided by 60 gave me 8.08 which I entered at “P 8.01”. The display now shows actual spindle speed for my particular belt and pulley configuration. If using multiple belt configurations and you have a chart showing the speed for those at a given motor RPM, changing the display to show percentage of RPM works nicely. This is achieved by changing the value to 1.66.

This installation was on a mill/drill, but the same procedure would be used on most any machine used in a woodworking or machine shop.

The power from the VFD would go to the three-phase motor and the remote control would be mounted in a convenient location and you are ready to go.

The most important rule for sizing the VFD to the motor is that the VFD needs to be rated at least as large as the motor. If you were using a VFD on a machine such as a table saw, planer, grinder, etc. then the Reverse function would be disabled by using an Off/On switch and only connection to the “D11” terminal on the terminal strip. If the motor runs in reverse when you want it to go forward, swapping any two of the power leads from the motor to the VFD will correct this.

For many years, woodworkers thought that the only way to use three-phase machinery was to have three-phase power from the electric company or use an expensive and inefficient rotary converter or a static converter that only allowed the motor to operate at 2/3 of its rated output. For motors up to 3HP, modern VFDs have the ability to take single-phase electricity, convert it to three-phase with full power, speed control, reversing ability, and more.

The VFD is really a “game changer” for anyone restoring old machinery or dealing with methods of speed control, such as Reeves drives and variable diameter pulleys. The VFD is truly “a better way.” I have three in my shop now and have plans to install two more very soon.

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By: Brian S. Elliott  
V.P. of Engineering and Manufacturing  
Air Options, Inc.

Modernizing The Speed Controls Of Hardinge  
Turret Lathes Using AutomationDirect GS2  
Variable Frequency Drives

## Teaching an Old Dog Some New Tricks

Just about every machinist in the U.S. has encountered a Hardinge turret lathe during the course of their career. These little machines, commonly referred to as “second operation lathes”, are astoundingly productive pieces of equipment which still have great value in almost any machine shop. This holds true even in the face of the CNC tidal wave that seems to be overwhelming the machine industry. Used Hardinge turret lathes are inexpensive, readily available and use commonly available tooling. Once set up, a minimally trained operator can man the machine and generate production that will rival most CNC machines. These attributes allow these little lathes to produce substantial quantities of high precision parts at a very low cost per unit.

If the Hardinge turret lathe has a significant flaw, it would be the spindle speed control system. The spindle motor is generally a two-speed, 3-phase motor with 1750 and 825 RPM ranges. The motor speed and direction are easily changed during operation via a pair of levers mounted on the front of the spindle, which actuate large drum switches mounted in the control cabinet.

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The drive system comes in two different varieties, a fixed belt drive and a vary-drive. The fixed belt system uses a step pulley arrangement to change spindle speeds, which provides the operator with only two easily changeable speeds during operation. The vary-drive utilizes a pair of variable sheaves, which are controlled with a set of buttons adjacent to a speed indicator mounted on the top of the spindle. The vary-drive retains the two-speed motor and is a significant improvement over the fixed system. However, the vary-drive is slow to change and has a tendency to disrupt the flow of production. In addition, the two-speed motor selection will only allow the operator to halve the spindle speed at any given setting. If, as an example, the part being turned requires high speed operations, such as turning and/or drilling, a medium speed operation, such as reaming, and a low speed operation, such as threading, then the factory drive system begins to hinder production. Most machinists who have used these machines would agree that the speed control system is adequate, but a more flexible system would be a great improvement.

After we purchased the Hardinge turret lathe shown in Figure 1, it became obvious that something had to be done to improve the speed controls. I had very good experiences with AutomationDirect GS2 variable frequency drives on several other pieces of equipment in our shop, so I decided to design a system for the turret lathe that would utilize one of these units. I configured a system that would retain the factory lever controls but expand on their basic function. Coupled with a variable frequency drive, this arrangement provides the operator quick access to a wide range of speed variations.

The original controls consisted of a fairly traditional motor controller with two heater blocks, a control transformer and a collection of lesser components, including a front-mounted panel switch rated at two horsepower. The forward and reverse functions are controlled with a pair of drum switches mounted on the back plane of the control cabinet. Even though they are overkill for logic switching, I retained the original drum switches because they are very high quality units and provided excellent tactile feedback to the operator.

Figure 2 shows the schematic I designed for this particular project. If you take a minute to study the schematic, it becomes clear just how simple a wiring system can be when using a GS2 variable frequency drive. M1 is the spindle motor, M2 is the coolant pump, S1 is the original panel toggle switch, S3 is the speed control drum switch and S2 is the forward/off/reverse drum switch. I specified fuses for the main line and the coolant pump. The MOV is a metal oxide varistor intended to suppress inductive kick back when the coolant motor is turned off. R1 is a 200 ohm, 100 watt braking resistor intended to provide electrical braking action. This feature of the GS2 drive allowed me to completely remove the old mechanical brake that was originally supplied from the factory. P1 through P3 are 5K ohm potentiometers that provide quick adjustment to each of the three speeds selected by the lever on the front of the spindle. Since the potentiometers are mounted on the top of the spindle, a shielded cable is specified per the drive manual's recommendation.



Figure 1:Hardinge Turret Lathe

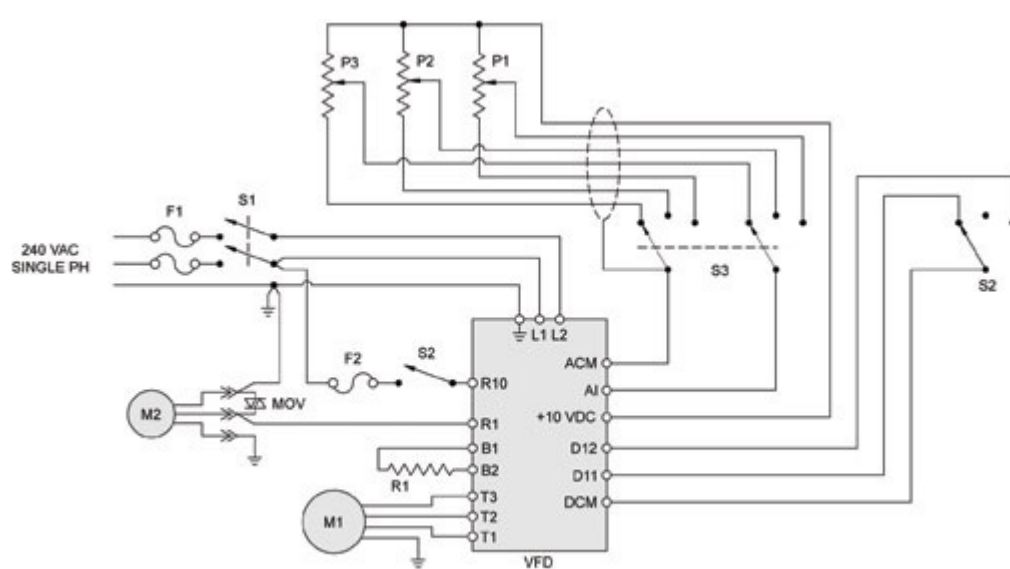


Figure 2:Electrical Schematic

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Figure 3: Three Potentiometers wired to a shielded cable

The second step I took was to configure the small cabinet shown in figure 3, which carries the three potentiometers wired to a shielded cable.

I also designed a simple pin bracket so it could be mounted into one of the existing equipment holes on the back of the spindle head. The label shown was made by printing the graphics on an ink jet printer and then laminating the page. The label was cut out and two-face carpet tape was used to bond it to the face of the cabinet. If you're careful, this little trick can produce a clean, professional panel at almost no cost.

Next, I designed the control system to fit with the existing machine configuration. I typically make a general layout, as shown in Figure 4, which guides the technician in the placement of the major components and routing of cables.

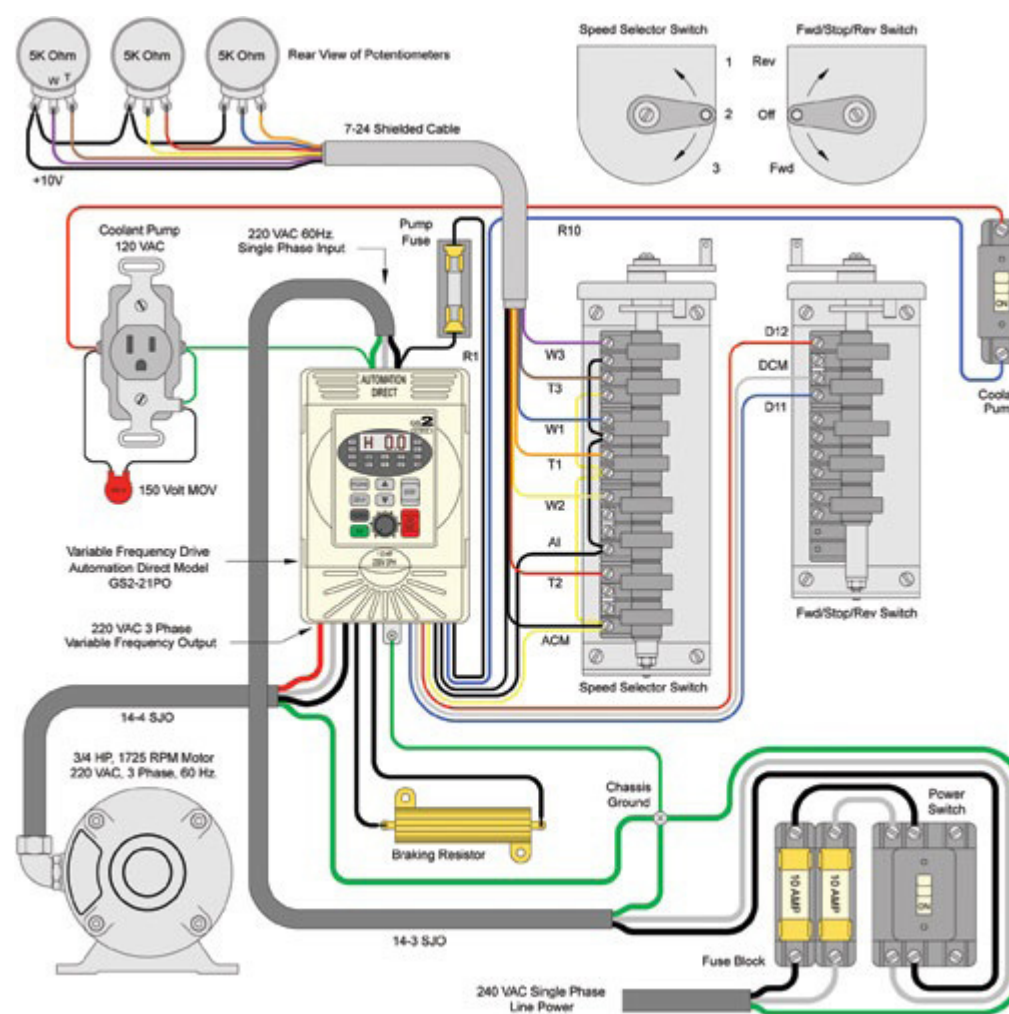


Figure 4: Basic Motor Control Layout

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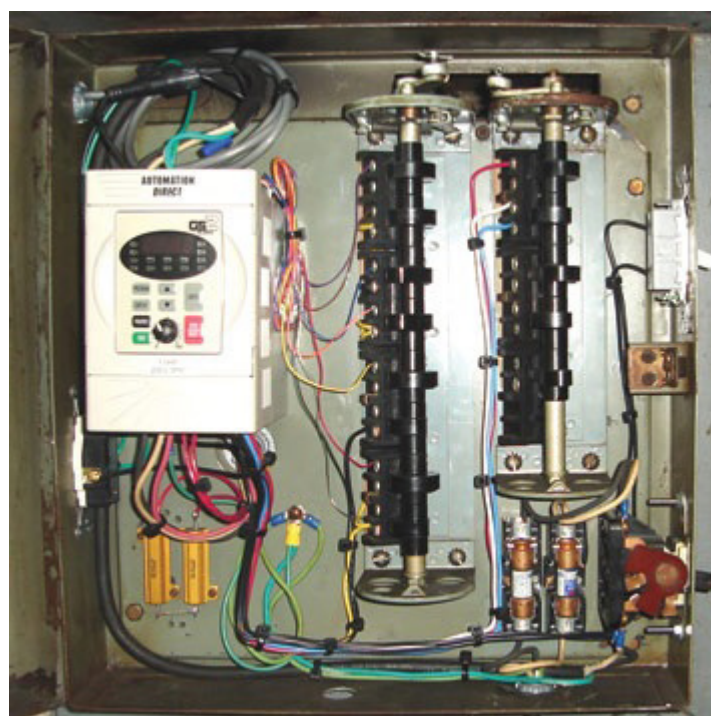
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Figure 5 shows the control cabinet after completion, with the GS2 mounted at the upper left of the panel and the braking resistors placed just below. The original toggle switch (lower right) is now used as the primary power and connects to the double fuse block shown. A single-pole toggle switch was installed in the hole left by the original push button actuator (upper right). This switch overrides the coolant pump which plugs into the 120 VAC receptacle (lower left).



*Figure 5: Completed Control Cabinet*

The GS2 drives are designed to suit nearly any motor application that one may encounter. As such, a little study was required to pick the parameters applicable to our specific project. However, once I familiarized myself with the unit, I found setting the parameters was a rather simple, step-by-step, process that you get accustomed to very quickly.

After double checking all of the completed wiring, I turned on the power to the GS2 drive and set up the basic parameters of the selected motor. Next, I programmed the source of frequency control to accept input from the potentiometers and set the acceleration and deceleration time to one second. There was a slight amount of over-spin (continued rotation) after the spindle was turned off, so I adjusted the DC injection current level, DC injection during stopping and the start-point for DC injection. This had the effect of stopping the spindle dead whenever the switch was turned off.

Overall material costs for the project were only \$461.97. In anybody's book, this is a small cost to bear, considering that this project reduced manufacturing time for two of our parts by 60% and three others by approximately 35%. This translated to the total material cost of the project being paid off in just one production run!

In conclusion, the modifications dramatically improved the functionality of our Hardinge turret lathe. With minimal costs, a productive machine was made even more productive. Overall, I would highly recommend this modification to any Hardinge turret lathe that is in regular service; it is well worth the effort.

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By: Jonathon Payton  
Mount Vernon Mills

Modernizing the control system for a denim finishing line in a large textile mill in North-west Georgia.

## Denim Manufacturer Upgrades Controls to Add Flexibility to Process Lines

Nestled along the Chatooga River, in Trion, Georgia, Mount Vernon Mills is one of the largest and oldest textile mills in the United States. Its long history dates back to 1845. The initial 5,000 square foot two-story mill had 40 employees and produced 5-lb. bunches of yarn to sell to local merchants from wagons.

Over the next 160 plus years, the mill survived General Sherman's march through Atlanta, a fire in 1875, bankruptcy in 1912, two World Wars, the fight to become unionized, and a major flood in 1990. Through all of this, the mill has continually expanded, renovated, and modified in order to tailor its end products to change with the times. The mill has produced many different products over the years, including fabric used for military uniforms, crop sacks, sheeting, shirting and even gloves.

In 1971, the decision was made for this Trion, Georgia, plant to produce denim. This turned out to be one of the best decisions in the mill's history. By installing new equipment, the plant rode the wave of growth in the denim industry. By 1976, Mount Vernon Mills had over 1,100 looms producing denim. The company continued to grow, but nearly experienced disaster when the "Hundred Year Flood" hit Trion in 1990. The company spent the next several years modernizing its plant with state-of-the-art machines to gear up denim production.

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After its latest round of renovations, the mill now operates with state-of-the-art machines in over one millionsquarefeetofmanufacturingspace. Denim from Mount Vernon Mills is woven and finished for sale to many major manufacturers across the country, such as Wrangler™ and Lee™. Mount Vernon is now the third largest producer of denim in the United States. (See Figures 1 & 2)

Over the years, the company has endeavored to continually upgrade machines and technologies, and the past few years have been no exception. On some of the finishing ranges and re-beamers, control systems still worked, but finding replacement parts had become more difficult, thus making it harder to give operators features and functions they wanted. Even modest changes and modifications were difficult based on the age of the control system. Late in 2006, the mill decided to embark on upgrades for re-beamers and one of its finishing lines.

The task of replacing the control system for the finishing line, a very large multi-motor machine, seemed daunting. All the motors have to work together and are self-adjusting, with dancer position sensors which send signals back to a PLC system. The PLC system automatically adjusts motor speeds to keep everything running together.

Because of the machines' size and complexity, the mill sought bids for the work. When job bids came back with costs far exceeding budget, the decision was made to use AutomationDirect components, and do the whole project in-house. To save time, new backplanes were purchased to bolt onto the old cabinet back so they could be assembled and tested before installing in the machine. This task would be performed in the system designers' spare time over a period of three months. They ended up having only three weeks to build and no time for testing. Electricians were finished mounting the motors and drives before programmers had the software completed.



Figure 1: Denim Finishing line at Mount Vernon Mills



Figure 2: Denim Finishing line at Mount Vernon Mills

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The old finishing line was powered by DC drives with field regulators. The new system has been upgraded to AutomationDirect's Durapulse AC Drives all networked via Ethernet to a DL-260 DirectLOGIC PLC System. A 15" C-more touchscreen operator panel was chosen to replace the main operator console. The mill purchased, installed and programmed the entire system within the three weeks allotted. All HMI and PLC programming was performed in-house, and AutomationDirect's telephone technical support staff answered questions when problems arose. (See Figures 3 & 4) The solution has been a great success. The mill saved nearly \$40,000 compared to the bids received, and now the control system is largely software based. Operators have much more control of the machine, including setup parameters of dry cans and dancers, line speeds, trimming capabilities, as well as some fault indication and maintenance screens. New functions or features can also be added, as they continually refine the process to improve productivity.

On a second project, Mount Vernon retrofitted the legacy control system for a re-beamer in order to improve performance and flexibility. The re-beamer is a speed-controlled center winder which winds yarn from several section beams onto a single-loom beam prior to weaving. The winding speed requires constant adjustment to maintain a constant yarn velocity.

The original control design for the re-beamer featured manual controls (pushbuttons, pilot lights, and meters) on the operator station and a DC drive to wind the spool. With dozens of these machines throughout the facility, not only was it more difficult to obtain replacement parts for outdated equipment, but it was also difficult to make changes to the machines, operator interfaces, and control system.



*Figure 3: Jonathan Payton stands in front of the new finishing line control cabinet which includes a DL260 DirectLogic PLC, 8 Durapulse variable frequency drives, and all the associated control equipment. The entire design including software was installed during their 3-week shutdown.*



*Figure 4: The 15" C-more touch screen operator interface brings all the controls of the finish line to a common point on the machine and includes set-up screens, maintenance screens, operations screens as well as diagnostics.*

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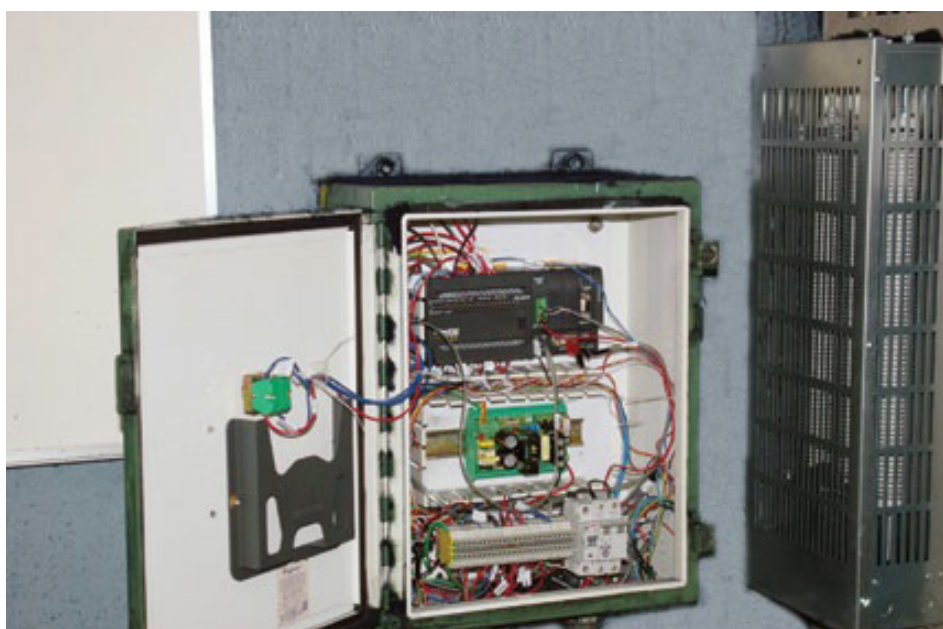
The re-beamer is now equipped with a DirectLOGIC DL06 PLC, a Durapulse AC variable frequency drive, a proximity sensor and a C-more operator interface panel. Because the outsourced PLC program never worked correctly, it was scrapped and rewritten in-house. This allowed placing more parameters and adjustments at the operators' fingertips. Additionally, operators continually suggest improvements to the process or machine, and now system programmers are able to act on their inputs, and use the software based control system to streamline the process. (See Figures 5 & 6)

Mount Vernon Mills continues to retrofit additional control systems as time and budgets permit. The control solutions put together with AutomationDirect equipment have provided quite a cost savings over alternative solutions on the initial purchase. Changing the controls to software-based HMI and controls also provides the flexibility to easily make changes and improvements to the line.

Control engineers at Mount Vernon Mills agree the free technical support from AutomationDirect is the best they have ever used. They also feel the quality and service of AutomationDirect products to be comparable to more costly products purchased from previous suppliers.



*Figure 5: An operator works the rebeamer during production.*



*Figure 6: The move to a software based C-more has given the operator more capability to change parameters during production.*

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