Several items need to be considered in order to properly install and wire an electric motor drive and motor circuit. The motor controlled by the electric motor drive, system power quality, safety, installation factors, and both power and control wiring all need to be checked for compatibility with the motor and drive. A properly installed electric motor drive can function correctly and safely for a long time without introducing any problems into an existing electrical distribution system.

INSTALLATION CONSIDERATIONS

Special considerations are necessary when installing an electric motor drive and motor circuit. These considerations involve motors, power quality, safety, and engineered applications. The items that need to be addressed to ensure that the motor and electric motor drive function properly are the electrical distribution system, the electric motor drive, the motor connected to the drive, and the load connected to the motor.

ELECTRIC MOTOR CONSIDERATIONS

Electric motors connected to AC drives receive a simulated AC sine wave known as pulse width modulation (PWM). The PWM waveform is created by the AC drive rapidly pulsing the DC bus ON and OFF using insulated gate bipolar transistors (IGBTs). The height of each pulse is equal to the DC bus voltage. The width of the pulses is controlled to provide an effective rms voltage, similar to that of a pure sine wave. See Figure 9-1. The number of pulses in the PWM waveform is controlled to vary the output frequency of the voltage to the motor. The carrier frequency or pulse frequency (PWM frequency) of an electric motor drive determines how quickly the IGBTs must turn ON and OFF. The carrier frequency is constant and independent of the voltage frequency applied to the motor. The carrier frequency is selectable and can vary from 2 kHz to 20 kHz. The higher the carrier frequency, the quieter a motor runs.

**Figure 9-1.** The width of the pulses determines the voltage to the motor; the wider the pulse, the higher the voltage.
Inverter Duty Motors

An inverter duty motor is an electric motor specifically designed to work with electric motor drives. A PWM waveform creates insulation problems for standard electric motors because the leading edge of each PWM pulse begins with a voltage spike. A voltage spike is due to the rapid rise time of the IGBTs. A voltage spike is typically twice the DC bus voltage of the AC drive. See Figure 9-2. Voltage spikes create damage insulation and shorten the life expectancy of standard electric motors. Inverter duty motors are designed to withstand voltage spikes.

The National Electrical Manufacturers Association (NEMA) has developed a set of specifications for electric motors used with electric motor drives. The NEMA standard MG-1, Section IV, Part 31 provides an enhanced insulation requirement for electric motors, allowing compatibility with electric motor drives. Most motor manufacturers produce motors to comply with NEMA MG-1, Motors and Generators, Section IV, Part 31; these motors are referred to as “inverter rated” or “inverter duty” motors.

Standard motors that are not compliant with the NEMA MG-1, Section IV, Part 31 standard, and are used with electric motor drives may fail prematurely. The speed at which a standard motor fails depends upon the specific motor application. Before connecting power from an electric motor drive to a standard motor, contact the manufacturer to verify compatibility of the motor in a drive circuit.

Service Factor. Service factor (SF), is a multiplier that represents the percentage of extra load that can be placed on a motor for short periods of time without damaging the motor. A motor with a service factor of 1.25 can be overloaded by 25% for a short time. Motors that are NEMA MG-1, Section IV, Part 31 compliant have a service factor of 1.0 per NEMA requirements. A motor that is used with an electric motor drive that is not NEMA MG-1, Section IV, Part 31 compliant must not be operated beyond a service factor of 1.0 regardless of the nameplate rating.

Lead Length. Lead length is the length of the conductors (motor leads) between the electric motor drive and the motor. The motor leads T1, T2, and T3 have a line-to-line capacitance and a line-to-ground capacitance. Capacitance increases the magnitude of the voltage spikes at the motor terminals. The longer the motor leads, the greater the capacitance and the greater the magnitude of the voltage spikes.

Long lead lengths also cause reflected waves, known as standing waves or voltage ring-up. Reflected waves are dependent on lead length and carrier frequency. The longer the lead length and the higher the carrier frequency, the more pronounced the problem. Reflected waves are the result of a portion of the voltage waveform being reflected back from the motor terminal due to an impedance mismatch. The reflected portion combines with the voltage from the AC drive, increasing the voltage at the motor terminals. The voltage can be as high as 1500 V at the motor terminals when fed from a 480 V electric motor drive.

The easiest way to avoid problems caused by lead length is to keep the lead lengths as short as possible. Typically, lengths less than 100 ft should not pose a problem. It is not always possible to avoid long lead lengths. Electric motors may be located in harsh environments with the electric motor drive located a long distance away in a clean, air-conditioned control room. In this case an output reactor, also referred to as a load reactor, can be installed at the electric motor drive. A load reactor helps eliminate voltage spikes by slowing down the rate of change in the output voltage.

Load reactors are installed as close as possible to the output of the electric motor drive. Load reactors are sized based on the electric motor drive input voltage and frequency, the drive horsepower, and the impedance of the reactor. See Figure 9-3.
Electric motor drive manufacturers may recommend output filters instead of load reactors. Output filters are also referred to as motor terminators. Output filters consist of inductance, capacitance, and resistance. An output filter may be installed at the output of the electric motor drive or at the motor. See Figure 9-4.

Another method to diminish the effects of lead length is to lower the carrier frequency. The result is fewer voltage pulses per unit of time and less stress on the motor insulation. At lower carrier frequencies, motors make more audible noise. Noise can be a problem for people working near the motor or if an HVAC fan motor transmits the noise through the ductwork.

AC drives are often used in industrial and commercial HVAC systems, and are increasingly used in residential HVAC systems.

Electric motor drive manufacturers provide specifications for maximum lead lengths for various carrier frequencies and for shielded or unshielded cable with output reactors or output filters.

**Bearing Currents.** A bearing current is the result of induced voltage in the motor rotor created by the electric motor drive. Bearing current causes premature failure of motor bearings. The spikes on the leading edge of the PWM waveform are induced into the rotor, and a voltage potential is developed between the rotor and the stator. The bearing race and balls or rollers serve as the current path for the voltage potential, and a continuous flow of current through the bearing occurs. The current flow causes atoms of metal to be removed. Over time, roughness, known as fluting, develops in the race, which eventually destroys the bearing.

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**TECH FACT**

Follow manufacturer installation guidelines on motor lead length to avoid premature failure of motors.
Electric motor manufacturers have developed shaft grounding systems to eliminate the problem. A *shaft grounding system* is a system that connects (shorts) the rotor voltage to ground via a brush or other device in contact with the shaft to discharge unwanted voltage. See Figure 9-5. Another method to reduce or eliminate bearing currents is to lower the carrier frequency of the electric motor drive. Bearing currents are common in HVAC fan applications. Bearings are the only path for the potential to discharge to ground in fan applications.

**Low-Speed Operation.** The cooling effect of a fan attached to the motor shaft, and/or fins that are part of the rotor end ring, is reduced when a motor is operated at low speeds. Electric motors that are continuously operated at low speeds must be derated or provided with auxiliary cooling. Auxiliary cooling is accomplished by using a separate blower and motor mounted to the motor to provide cooling. Auxiliary blower motors operate on fixed voltages, and are either ON or OFF. The blower motor must be connected to a power source independent of the variable voltage output of an electric motor drive. Temperature sensors are installed in the stator windings of a motor and are connected to an electric motor drive through a relay. The leads of a temperature sensor are labeled J1 (P1) and J2 (P2). When internal temperatures of a motor exceed safe limits, the temperature sensor opens, de-energizing the relay, shutting down the electric motor drive and motor. See Figure 9-6.

**Operating Temperature.** NEMA has standardized the maximum ambient temperature for motors as 104°F (40°C). Ambient temperature is the temperature of the air surrounding an object. Electric motors operated at a higher than ambient temperature must be derated. NEMA has also standardized altitude ratings for motor operation. Electric motors are designed to operate up to 3300′ (1000 m). Electric motors operated above 3300′ must be derated. The derating is required because at higher altitudes, air is thinner and does not dissipate heat as quickly. Consult the charts provided by motor manufacturers for specific derating tables.

**TECH FACT**

*Failure to derate or provide auxiliary cooling to motors operating at low speeds results in premature failure of motors.*
SHAFT GROUNDING SYSTEMS

Figure 9-5. A shaft grounding system eliminates bearing currents that lead to bearing failures.

TEMPERATURE SENSOR

Figure 9-6. When excessive motor heat is detected, the temperature sensor opens, de-energizing the relay and sending a signal to the electric motor drive to stop the motor.
Power Quality

Electric motor drives are adversely affected by poor power quality. Electric motor drives can also introduce power quality problems into a power distribution system. Power quality is affected by voltage and frequency variations, and by whether a system is grounded or ungrounded.

Voltage and Frequency. Electric motor drives are designed to operate over a wide range of input voltages. Most electric motor drives are designed to operate with input frequencies of either 50 Hz or 60 Hz. Operating outside the specified frequency range can result in damage to an electric motor drive or cause various drive faults.

Grounded and Ungrounded Systems. Electric motor drives are intended to be powered from grounded systems with 3φ power lines that are electrically symmetrical with respect to ground. The NEC® permits ungrounded distribution systems in a limited number of instances. Electric motor drives contain metal oxide varistors (MOVs) to provide phase-to-phase and phase-to-ground protection from voltage surges. In an ungrounded system, there is no path back to the power source to activate an overcurrent device. The phase-to-ground MOV can become a continuous path for current, resulting in damage to the electric motor drive. See Figure 9-7.

Current. An electric motor drive is a nonlinear load. A nonlinear load is any load where the instantaneous load current is not proportional to the instantaneous voltage. Voltage and current are not proportional because nonlinear loads draw current in short pulses, even when the source voltage is a sine wave. It is important that the power source for an electric motor drive has sufficient current capacity. If the power supply cannot deliver enough current, voltage flat-topping occurs. Flat-topping is the lowering of the peaks of the voltage sine wave. Flat-topping results in lower supply voltage to an electric motor drive. The lower supply voltage causes undervoltage faults and undependable motor operation. See Figure 9-8.

Input Reactors. Input reactors or isolation transformers are recommended for AC drives in a variety of situations. Input reactors are sized based on the electric motor drive input voltage and frequency, the drive horsepower, and the impedance of the input reactor. Input reactors are used in the following situations:

- When line impedance is too low. A reactor raises the line impedance and protects an electric motor drive from voltage spikes in the electrical distribution system caused by large loads or lighting being switched ON and OFF.
- When power factor correction capacitors are installed.
- When the electric motor drive causes harmonics in the electrical distribution system. Harmonics produce power quality problems on the electrical distribution system. The effects of harmonics are cumulative; the greater the number of electric motor drives installed in a facility, the greater the harmful effects. Harmonics can be either voltage harmonics or current harmonics.

Input reactors may also be used as output reactors. Input reactors should be part of every drive installation because they provide multiple benefits and add little to the overall motor system installation costs.

Power Factor Correction Capacitors. A power factor correction capacitor is a capacitor used to improve a facility’s power factor by improving voltage levels, increasing system capacity, and reducing line losses. Power factor is the ratio of true power to apparent power. True power is the power that actually performs work. Apparent power is the total power delivered. Utility companies penalize customers with low power factors. Facilities with many inductive loads have a poor power factor because voltage is leading the current. The common practice is to install power factor correction capacitors to improve the power factor of a facility because capacitors cause the current to lead voltage.

Power factor correction capacitors can be placed ahead of an electric motor drive in the AC supply lines but not between the drive and motor. Power factor correction capacitor units with automatic switching must not be used unless specifically recommended by the manufacturer. See Figure 9-9.
METAL OXIDE VARISTOR (MOV) VOLTAGE SURGE PROTECTION

Figure 9-7. Electric motor drives are intended to be powered from 3φ lines with a common ground.
Figure 9-8. In nonlinear loads, instantaneous load current is not proportional to the instantaneous voltage, allowing flat-topping to occur and causing electric motor drive faults.
The effects of inductive and nonlinear loads can be compensated using properly sized power factor capacitors.

**SAFETY**

Electric motor drives are part of a system that includes a motor, a driven load, and possibly external controls. Care must be taken to ensure that all items are compatible, and that any item or combination of items does not introduce a safety hazard. Electric motor drive control circuits are not to be used as emergency stops. An emergency stop is used where accidental contact with moving equipment, or the unintended flow of product, can result in physical injury or property damage. If an emergency stop is required, an additional hard-wired stop circuit that removes AC line power to the electric motor drive is necessary. When AC line power is removed, the braking effect of the electric motor drive is lost and the motor coasts to a stop. The motor may require an auxiliary electromechanical brake to stop quickly or to stop and hold a load. See Figure 9-10.

The brake is mounted on the end of the motor opposite the shaft. When power is applied (solenoid energized), the brake disengages and allows the motor and load to rotate. When power is removed (solenoid de-energized), springs cause the brake to engage and hold the motor and load. The brake operates on an ON or OFF fixed voltage. The brake must be connected to a power source independent of the variable voltage output of the electric motor drive.

**WARNING**

*DC injection braking and dynamic braking are auxiliary braking functions and are not intended to take the place of electromechanical brakes.*
ENGINEERED APPLICATIONS

An engineered application is an electric motor drive application that requires a licensed engineer to be safely implemented. A licensed engineer provides drawings, answers questions, and oversees the installation to ensure that it conforms to all applicable codes. Engineered applications include those where a motor is operated above its rated base speed, where an emergency stop button is required, or where a drive is controlling people-moving equipment. Base speed is the nameplate speed (rpm) at which a motor develops rated horsepower at rated load and voltage. When using an AC motor, base speed is typically the point where nameplate voltage and nameplate frequency are applied. When using a DC motor, it is typically the point where full armature voltage is applied with full rated field excitation. Operation of a motor above base speed is governed by the mechanical limits of the rotor, armature, and bearings.

ELECTRIC MOTOR DRIVE INSTALLATION

An electric motor drive installation process requires receiving shipment of a drive from a manufacturer, selecting a suitable location and enclosure, mounting the drive (taking into account derating factors), and minimizing electromagnetic interference. Paying close attention to all installation factors results in a smooth start-up and years of trouble-free service.

Receiving Drive and Hardware

Upon receipt of an electric motor drive and any associated hardware, there are several steps to follow:

- Thoroughly inspect the items for any damaged or missing parts. Immediately report any problems to the freight company.
- Verify the size, rating, configuration, etc., of the items ordered.
- Remove the instructions and other documentation, and store in a safe location for future reference.

Figure 9-10. An electromechanical brake is used to hold a motor shaft stationary after voltage is removed from the motor.

**WARNING**

Always consult the electric motor drive manufacturer or licensed engineer regarding drive application questions. Incorrect application of an electric motor drive can result in serious personal injury or damage to the drive and/or driven load.
• Store the electric motor drive and related hardware in a clean, dry, and secure location that conforms to the operating manufacturer specifications.
• Do not store an electric motor drive for longer than a year. Electric motor drives contain electrolytic capacitors, which deteriorate if not powered for long periods of time.

Location
Electric motor drives should be mounted in a clean and dry location. High temperatures, high humidity, dust, particles or fibers in the air, corrosive or explosive vapors, constant vibration, and direct sunlight should be avoided. The location should have sufficient lighting and sufficient working space to facilitate the installation, start-up, and maintenance of the electric motor drive.

Enclosures
NEMA rates enclosures based on use and service. Most electric motor drives are delivered from a manufacturer in NEMA Type 1 enclosures. An electric motor drive in a NEMA Type 1 enclosure may be placed in a suitable environment or in another enclosure. Other NEMA rated enclosures are available for installing electric motor drives in hostile environments. See Figure 9-11.

An electric motor drive in a NEMA Type 1 enclosure may require a NEMA Type 3R enclosure if the enclosure is subjected to falling rain, ice, or other damaging environments. The enclosure that is to house the electric motor drive should be mounted, and any metal debris must be discarded before the drive is installed in the enclosure. All precautions must be taken to prevent debris from falling into an electric motor drive and causing a problem. The person responsible for installing the electric motor drive must decide whether the drive can be installed as is or whether it requires installation in another enclosure.

When an electric motor drive is installed in an enclosure, heat buildup can be a problem. The electric motor drive radiates heat and the enclosure may not be able to dissipate the heat. The heat may cause electric motor drive faults, or premature component failure. Extra cooling may be required to supplement the fan(s) that are integral to the electric motor drive. The additional cooling can be in the form of a fan or a cooling unit.

Mounting
An electric motor drive should be mounted on a smooth, nonflammable vertical surface, with the name of the manufacturer facing out and right side up. Small electric motor drives are mounted in rack slots or on a DIN rail. Medium-size electric motor drives may be mounted directly to a motor or in a cabinet using mounting holes. Larger electric motor drives have separate mounting holes for individual fasteners. See Figure 9-12. The fastening method should be adequate to support the weight of the electric motor drive.

Heat is generated during the normal operation of an electric motor drive. An electric motor drive is mounted to allow the free flow of air across the heat sink(s), possibly aided by integral cooling fans. Adequate clearances must be maintained around the electric motor drive for the free flow of air. Follow manufacturer specifications for mounting an electric motor drive.

Derating
Electric motor drives are designed for specific operating ranges of temperature, voltage, altitude, and humidity. Derating is required if an electric motor drive is operated outside the normal operating ranges specified by the manufacturer. Electric motor drives operated above the normal temperature range, from a 1Φ power source or from a power source with reduced voltage, or at a high altitude, or higher carrier frequencies, must be derated. Manufacturers supply charts and derating multipliers for each particular condition.

Omron IDM Controls
Cabinets with multiple electric motor drives require extra attention to mounting positions, airflow, and derating to avoid heat buildup and drive failures.
### ENCLOSEMENT SELECTION

<table>
<thead>
<tr>
<th>Type</th>
<th>Use</th>
<th>Service Conditions</th>
<th>Tests</th>
<th>Comments</th>
<th>Type</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Indoor</td>
<td>No unusual</td>
<td>Rod entry, rust resistance</td>
<td>Do not provide protection against internal condensation or internal icing</td>
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<td>3</td>
<td>Outdoor</td>
<td>Windblown dust, rain, sleet, and ice on enclosure</td>
<td>Rain, external icing, dust, and rust resistance</td>
<td>Do not provide protection against dust, internal condensation, or internal icing</td>
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</tr>
<tr>
<td>3R</td>
<td>Outdoor</td>
<td>Falling rain and ice on enclosure</td>
<td>Rod entry, rain, external icing, and rust resistance</td>
<td>Do not provide protection against dust, internal condensation, or internal icing</td>
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</tr>
<tr>
<td>4</td>
<td>Indoor/outdoor</td>
<td>Windblown dust and rain, splashing water, hose-directed water, and ice on enclosure</td>
<td>Hosedown, external icing, and rust resistance</td>
<td>Do not provide protection against internal condensation or internal icing</td>
<td>4</td>
</tr>
<tr>
<td>4X</td>
<td>Indoor/outdoor</td>
<td>Corrosion, windblown dust and rain, splashing water, hose-directed water, and ice on enclosure</td>
<td>Hosedown, external icing, and corrosion resistance</td>
<td>Do not provide protection against internal condensation or internal icing</td>
<td>4X</td>
</tr>
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<td>6</td>
<td>Indoor/outdoor</td>
<td>Occasional temporary submersion at a limited depth</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>6P</td>
<td>Indoor/outdoor</td>
<td>Prolonged submersion at a limited depth</td>
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<td>7</td>
<td>Indoor locations classified as Class I, Groups A, B, C, or D, as defined in the NEC®</td>
<td>Withstand and contain an internal explosion of specified gases, contain an explosion sufficiently so an explosive gas-air mixture in the atmosphere is not ignited</td>
<td>Explosion, hydrostatic, and temperature</td>
<td>Enclosed heat-generating devices shall not cause external surfaces to reach temperatures capable of igniting explosive gas-air mixtures in the atmosphere</td>
<td>7</td>
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<td>9</td>
<td>Indoor locations classified as Class II, Groups E or G, as defined in the NEC®</td>
<td>Dust</td>
<td>Dust penetration, temperature, and gasket aging</td>
<td>Enclosed heat-generating devices shall not cause external surfaces to reach temperatures capable of igniting explosive gas-air mixtures in the atmosphere</td>
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<td>Indoor</td>
<td>Dust, falling dirt, and dripping noncorrosive liquids</td>
<td>Drip, dust, and rust resistance</td>
<td>Do not provide protection against internal condensation</td>
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<td>13</td>
<td>Indoor</td>
<td>Dust, spraying water, oil, and noncorrosive coolant</td>
<td>Oil explosion and rust resistance</td>
<td>Do not provide protection against internal condensation</td>
<td>13</td>
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</tbody>
</table>

**Figure 9-11.** Depending on the application, an enclosure with a cooling unit may be required.
Electric Motor Drive Mounts

Figure 9-12. Mounting methods vary with the size of electric motor drive.

An electric motor drive model may have multiple output ratings, depending on the type of load and the carrier frequency used. Constant torque loads require the same current from zero to base speed. Variable torque loads require less current at lower speeds. Consequently, an electric motor drive model typically has higher output ratings for a variable torque load than for a constant torque load.

Power losses occur when the IGBTs of an electric motor drive are between states (neither ON nor OFF). The higher the carrier frequency, the more pulses per unit of time, and the more loss of power the IGBTs create. An electric motor drive has lower output ratings at higher carrier frequencies because of IGBT power losses.

Electromagnetic Interference

Electromagnetic interference (EMI), also known as electrical noise, is the unwanted signals generated by electrical and electronic equipment. All electrical and electronic equipment generate EMI. Low frequency magnetic-field EMI can be emitted from the cables connected to equipment, or from inductive loads in proximity to equipment. High frequency electric-field EMI can emanate from equipment as electromagnetic radiation, also known as radio frequency interference (RFI). EMI can be received by other equipment and interfere with its proper operation. EMI problems range from corrupted data transmissions to electric motor drive damage.

All electrical and electronic equipment should have some level of immunity to EMI. Electromagnetic compatibility (EMC) is a comparison of how different pieces of equipment work together with varying levels of interference. As use of electronic equipment in industrial environments has increased, manufacturers have taken steps to both minimize emissions and maximize EMI immunity in the design of equipment.

Regulations regarding EMC/EMI are very complicated and vary from country to country. A properly installed electric motor drive minimizes potential problems from EMI. Installation techniques and supplemental devices that minimize emissions and maximize immunity include wiring techniques, grounding, shielding, and isolation of power and signal or control cable.
**Power Wiring.** The drive output power wiring (load conductors) contains high-voltage switching waveforms which can affect the line conductors. The line and load conductors of an electric motor drive need to be installed in separate metal conduits. Metal conduit serves as a shield, preventing conductors from radiating EMI and protecting conductors from any radiated EMI. Nonmetallic conduit does not provide the shielding effect. A separate grounding conductor must be installed in each conduit and connected at each end. In the event that multiple electric motor drives feed multiple motors, the line and load conductors of each drive need to be installed in separate metal conduits.

When cable trays are used, armored metal cable with a separate grounding conductor, or shielded power cable with a separate grounding conductor, must be used. The grounding conductors contained in the cable need to be connected at each end.

**Control Wiring.** Control wiring is all external wiring connected to an electric motor drive, excluding the line and load conductors. Electric motor drives have control wiring that communicate signals to start and stop the drive, communicate sensor conditions to the drive, and carry output signals from drive auxiliary contacts. See Figure 9-13. Control wiring can communicate four types of signals: AC digital signals, DC digital signals, DC analog signals, and serial communication signals. Digital signals are signals that have only two states, ON or OFF like a momentary pushbutton. Analog signals are signals that vary over a range of values such as 0 VDC to 10 VDC for speed reference. Serial communication signals are digital data signals from an external source such as a PLC or PC.

![Figure 9-13. Power wiring and control wiring are terminated at separate locations on an electric motor drive.](image-url)
The harmful effects of EMI from control wiring can be minimized by the following procedure:

- Control and power wiring should be separated as much as possible inside an electric motor drive enclosure. If control and power wiring must cross, they should cross at a 90° angle.
- Control wiring should not be installed in the same conduit as power wiring. Control wiring should be installed in a separate metal conduit.
- Install each category of control wiring in its own metal conduit.
- DC analog signals and serial communication signals should run in twisted shielded pair cable.

**Grounding.** Proper grounding is required for the safe and reliable operation of electric motor drives, motors, and related equipment. Grounding requirements can be divided into equipment grounding and signal wire grounding.

*Equipment grounding* is an equal potential between all metal components of an installation and a low-impedance path for fault currents to operate overcurrent protective devices (OCPDs). Equipment grounding also aids in containing EMI. All equipment grounds should be brought back to a single point at the electric motor drive. The connections should be tight and mechanically sound to guarantee a good electrical connection. When making a grounding connection to the interior of a metal enclosure, scrape away any protective coating to ensure bare metal-to-metal contact. See Figure 9-14.

Control wires carry analog signals and serial communication signals using twisted shielded pair cable. A shield is constructed of metal foil or mesh and a bare wire wrapped around the twisted conductors. The bare wire is also referred to as the drain wire. The shield/drain wire and the twisting of the conductors provide enhanced noise protection. The shield/drain wire is only grounded at the electric motor drive end. A shield/drain wire that is grounded at both ends introduces EMI into the signal circuit because of the difference of potential between the two points of grounding.

**ELECTRIC MOTOR DRIVE AND MOTOR CIRCUIT GROUNDING**

![Diagram of Electric Motor Drive and Motor Circuit Grounding](image)

*Figure 9-14.* Equipment grounds for line and load conductors are terminated at the electric motor drive.
Inductive Loads. Inductive loads such as solenoids or the coils of relays and contactors are a source of EMI. When inductive loads are de-energized, a large counter electromotive force (CEMF) is generated. CEMF is a voltage spike created by the inductive loads when de-energized that can cause electric motor drive faults. Coils in the same enclosure as an electric motor drive or coils controlled by relay contacts of a drive need to suppress voltage spikes.

Devices are installed across the coils to dissipate the CEMF and suppress EMI. Resistor-capacitor networks (RC snubber networks) or MOVs are connected across the AC coils. Diodes are connected across DC coils to suppress EMI. The diodes are connected in reverse bias across the DC coils in the same way fly-back diodes are used with transistors. See Figure 9-15.

Other EMI/RFI Reducing Devices. Other devices and techniques are used for reducing EMI/RFI. An output reactor or an output choke may be used to reduce interference with sensitive equipment. An RFI filter installed at the input of an electric motor drive reduces RFI interference. Lowering the PWM frequency also reduces EMI. See Figure 9-16.

WIRING
The National Electrical Code (NEC®) must be followed when connecting an electric motor drive. The wiring process of an electric motor drive is divided into NEC® and manufacturer requirements.

NEC® and Electric Motor Drives
The NEC® refers to drives as adjustable speed drive systems or conversion equipment. NEC® Article 430, Motors, Motor Circuits and Controllers, is the principal code source for drives. Part X of Article 430, Adjustable-Speed Drive Systems, contains specific requirements for the installation of electric motor drives. Other sections of Article 430 apply as well, as an electric motor drive is a controller that powers a motor. Other portions of the NEC®, even when not specifically named, also apply to drives. See Figure 8-17.
Manufacturer Instructions. NEC® Section 110.3(B) states, “Listed or labeled equipment shall be installed and used in accordance with any instructions included in the listing or labeling.” NEC® Section 110.3(B) makes the instructions of the manufacturer the primary reference for installation. Manufacturer instructions provide information on wire size, recommended mounting location, and the size and type of overcurrent devices. Electric motor drives may use fuses or circuit breakers as circuit overcurrent protection. Electric motor drive manufacturers specify the type of overcurrent protection to be used with particular drives.
ELECTRIC MOTOR DRIVE SYSTEMS – NEC® REFERENCES

Figure 9-17. NEC® Article 430 contains several parts that apply to electric motor drives.

**Wire Size.** In the event the instructions do not specify wire size, NEC® Section 430.122(A) states, “Circuit conductors supplying power conversion equipment included as part of an adjustable-speed drive system shall have an ampacity not less than 125% of the rated input to the power conversion unit.” The wire size can be calculated using the electric motor drive (power conversion equipment) nameplate current and NEC® Table 310.16.

**Disconnects.** A disconnect is a device that isolates an electric motor drive and/or motor from the voltage source to allow safe access for maintenance or repair. NEC® Article 430 Part IX contains general requirements for disconnects. Article 430 Part X contains specific requirements for the disconnect located in the incoming line to the electric motor drive. NEC® Section 430.128 states “The disconnecting means shall be permitted to be in the incoming line to the conversion equipment...
and shall have a rating of not less than 115 percent of the rated input current of the conversion unit.” Circuit breakers and motor-circuit switches rated in horsepower are devices used as disconnecting means. A circuit breaker or fused motor-rated disconnect can serve as both a disconnecting means and overcurrent device. A motor-circuit switch is commonly referred to as a motor-rated disconnect.

NEC® Article 430 Part IX has specific rules regarding disconnects for various applications. One of the more commonly applied sections, NEC® 430.102(B) exception, allows a controller disconnect that is capable of being locked open to also serve as the motor disconnecting means. Articles and exceptions in the NEC® may be superseded by other building codes such as a mechanical code requiring a disconnect be located at all HVAC equipment.

**Overload Protection.** In a majority of electric motor drive applications, the drive provides overload protection for the motor. See Figure 9-18. NEC® Section 430.124(A) states, “Where the power conversion equipment is marked to indicate that overload protection is included, additional overload protection shall not be required.” In order for the electric motor drive to provide overload protection, the nameplate information of the motor must be programmed into the drive. The electric motor drive control board provides the overload protection based on the information entered.

If an electric motor drive is not approved for use as an overload, or if multiple motors are fed from the drive, an external overload relay(s) must be provided. See Figure 9-19. NEC® Article 430 contains information on selecting and sizing overcurrent devices and overload protection. The normally closed contacts of the overload relays are connected in series and terminate at the control terminal strip of the electric motor drive. An overload in any motor opens the circuit and causes the electric motor drive to stop outputting voltage to the motors.

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**Figure 9-18.** Motor nameplate information is entered into an electric motor drive and the information is processed by the CPU to calculate overload protection levels.
OVERLOAD PROTECTION PROVIDED BY OVERLOAD RELAY

**SINGLE MOTOR PROTECTION**

CONTACT OPENS ON THERMAL OVERLOAD SIGNALING ELECTRIC MOTOR DRIVE TO SHUT DOWN MOTOR

NORMALLY CLOSED OVERLOAD RELAY CONTACT

FUSES PROVIDE OVERCURRENT PROTECTION FOR EACH MOTOR

**MULTIPLE MOTOR PROTECTION**

CONTACT OPENS ON THERMAL OVERLOAD SIGNALING ELECTRIC MOTOR DRIVE TO SHUT DOWN MOTOR

NORMALLY CLOSED OVERLOAD RELAY CONTACT

Figure 9-19. External fuses and overload relays may be required along with the electric motor drive in certain applications.
Clearances. NEC® Article 110 Part II lists requirements for dedicated working space and dedicated electrical space. The working space requirements are intended to protect the technician who must adjust or service the equipment by providing minimum working spaces, and include illumination requirements. The equipment space requirements are intended to protect the electrical equipment by limiting nonelectrical piping systems above electrical equipment. Electric motor drive installations must comply with NEC® Article 110 Part II requirements. See Figure 9-20.

Grounding. Proper grounding of an electric motor drive provides equal potential between all metal surfaces, a low-impedance path to activate overcurrent devices, and EMI reduction. NEC® Article 100 defines an equipment grounding conductor as “The conductor used to connect the non-current-carrying metal parts of equipment, raceways, and other enclosures to the system grounded conductor, the grounding electrode conductor, or both, at the service equipment or at the source of a separately derived system.” The NEC® permits certain metal raceways to be used as equipment grounding conductors. For added safety and enhanced EMI reduction, electric motor drive manufacturers require an equipment grounding conductor in addition to the metal raceway containing the power and control conductors of the drive. Grounding requirements and the sizing of equipment grounding conductors are covered in NEC® Article 250.

Power Wiring

Power wiring for an electric motor drive consists of the conductors supplying power to the drive (line conductors) and the conductors supplying power to the motor (load conductors). A variety of wiring methods are available, depending upon installation considerations. The load conductors may power a single motor or multiple motors. Certain applications use a line bypass contactor to provide standard 60 Hz power to the motor in the event the electric motor drive fails.

NEC® EQUIPMENT SPACE REQUIREMENTS

Figure 9-20. The NEC® requires a dedicated working space and a dedicated electrical space for indoor installations of electrical equipment.
Power Terminal Strip. The power terminal strip and the control wiring terminal strip are separated from one another to reduce EMI. The line conductors and load conductors are terminated at the power terminal strips. Many electric motor drives have a location on the power terminal strip to connect an auxiliary braking unit directly to the DC bus. The North American designations for conductors are L1, L2, and L3 for line; and T1, T2, T3 for load. The European designations for conductors are R, S, and T for line; and U, V, W for load. Care must be taken to ensure the line conductors are connected at the line terminals, and the load conductors are connected at the load terminals. The DC bus connection is designated by DC+, DC−. Some drive manufacturers denote the DC bus with B+ and B−. This is done to indicate the location where a dynamic braking resistor can be installed. The ground terminal is designated by potential earth (PE), or the ground symbol (). See Figure 9-21.
The type of terminal strip required varies depending on the horsepower rating of the electric motor drive. Small electric motor drives have screws with pressure plates. Large electric motor drives have threaded studs or busbars with nuts and washers. Ring lugs are also used to terminate conductors onto threaded studs. Ring lugs are used instead of fork lugs because they do not fall off the threaded stud if the nut and washer become loose. Always use the lugs recommended by the electric motor drive manufacturer. The terminals need to be tightened for a secure electrical connection.

**TECH FACT**

Nonmetallic conduits and raceways must not be used for power wiring and control wiring when nonshielded cable (wiring) is used.

**Wiring Methods.** The NEC® permits conductors 1/0 AWG and larger to be paralleled. Conductors may be paralleled for ease of installation, or where wire-bending space for large conductors is limited. Where conductors are paralleled, conductors must be kept together in sets with T1(1), T2(1), T3(1) in one conduit, and T1(2), T2(2), T3(2) in another conduit. NEC® Section 310.4 contains the specific requirements for paralleling conductors.

Commonly used wiring conduit for power conductors include armored cable (Type AC), metal-clad cable (Type MC), rigid metal conduit, electrical metallic tubing (EMT), intermediate metal conduit (IMC), and shielded power cable. The specific location and application determines the wiring conduit to be used, such as in commercial HVAC installation, industrial installation, or an original equipment manufacturer (OEM) piece of machinery. See Figure 9-22. Plastic raceways are not recommended because plastic raceways do not provide shielding to limit EMI.

The final connection to the motor should be made with a short length of flexible conduit (6′ or less) and stranded wire. Either flexible metal conduit (flex) or liquidtight flexible metal conduit (Sealtite™) can be used. Each method allows the motor to be moved for minor adjustments and prevents vibration from the motor and driven load from damaging a solid raceway or solid conductor. See Figure 9-23.

**Single-Motor Installation.** The most common electric motor drive application involves a single motor powered by a drive. The overcurrent device that protects the electric motor drive also protects the load conductors and motor. The electric motor drive provides the overload protection to the motor if it is approved for this purpose. An electric motor drive controlling an HVAC fan motor is a common single-motor installation. See Figure 9-24.

**WARNING**

Always follow the instructions and recommendations of electric motor drive manufacturers and applicable federal, state, and local codes. Failure to do so can result in serious physical injury and/or equipment damage. Only qualified personnel are allowed to install, start up, and troubleshoot electric motor drives.
A wide variety of wiring methods are available for installing an electric motor drive and motor.
**FLEXIBLE MOTOR CONDUIT**

![Diagram of a flexible motor connection](Image)

**Figure 9-23.** A flexible connection to a motor allows motor adjustment and negates the effects of vibration from the motor or building.

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**ELECTRIC MOTOR DRIVE AND SINGLE-MOTOR SYSTEM INSTALLATION**

![Diagram of an electric motor drive system](Image)

**Figure 9-24.** A basic electric motor drive application involves a single motor powered by a drive.
**Multiple-Motor Installation.** A multiple-motor installation involves multiple motors being fed from a single electric motor drive. An electric motor drive controlling a conveyor with multiple motors that operate at the same speed is a common multiple-motor installation. Each motor has its own set of conductors. Supplemental overcurrent devices and overload protection must be installed, as the rating of the individual motors is less than the electric motor drive rating. A multiple-motor installation requires that all the motors have the same NEMA design letter. Open-loop or closed-loop vector drives cannot be fed from a single electric motor drive. See Figure 9-25. NEC® Article 430 contains information on sizing overcurrent devices and overload protection for multiple-motor installations.

**Bypass Contactor.** A bypass contactor is a contactor that allows line power to a motor that is normally controlled by an electric motor drive. A bypass contactor allows a critical load to operate during electric motor drive maintenance, or when a drive fails. An electric motor drive controlling an exhaust fan that removes fumes from a parking garage is a common application requiring a bypass contactor. Speed control is not possible when operating in bypass mode.

The bypass contactor works in conjunction with an input contactor, output contactor, overload relay, and other control components. See Figure 9-26. When in the electric motor drive mode, the bypass contactor is open, the input contactor and output contactor are closed, and the motor is powered by the drive. In the bypass mode, the bypass contactor is closed, the input and output contactors are open, and the motor is powered by the line voltage, not the electric motor drive.

The bypass contactor is mechanically interlocked to the output contactor and electrically interlocked to the input contactor. The interlocking ensures that both the output contactor and input contactor are de-energized (open) when the bypass contactor is closed. Isolating the electric motor drive prevents line power from reaching

![Figure 9-25. Multiple motors fed from a single electric motor drive require supplemental overcurrent and overload protection.](image-url)
the drive output. The overload relay is provided to protect the motor when the electric motor drive with its integral overload protection is bypassed. The controls to initiate the bypass function may be manual or automatic. Other bypass control systems are found in industry for specific applications.

The input contactor and output contactor do not control stopping and starting of an electric motor drive. The starting and stopping of an electric motor drive is controlled by inputs to the drive. The output contactor must be closed prior to starting an electric motor drive, and the drive must be OFF before opening the output contactor.

Figure 9-26. A bypass contactor provides line power to a motor if the electric motor drive fails.
Control Wiring

Control wiring consists of inputs and outputs connected to the electric motor drive, excluding the power wiring. The inputs and outputs are connected to the electric motor drive at the control terminal strips. The type of inputs and outputs determine the wiring method. Various wiring schemes are used, depending upon the specific application.

Control Terminal Strips. Digital inputs, analog inputs, digital outputs, and analog outputs are connected to the control terminal strips. The number and type of inputs and outputs varies with the complexity of the electric motor drive. The functionality of an input or output may be controlled by the programming parameters of an electric motor drive. The functionality of a relay output (digital output) may be programmed to indicate motor over-current, motor overload, or an electric motor drive fault.

Electric motor drive inputs control the starting, stopping, and speed of a motor. Digital inputs consist of control devices that provide an on/off signal such as a selector switch or pushbutton. Analog inputs consist of signals that vary over a range of values, such as a potentiometer with a 0 VDC–10 VDC signal. A combination of digital and analog inputs can control an electric motor drive by using a selector switch to start a motor and a 4 mA–20 mA signal to control the speed of the motor.

The outputs can control devices related to the electric motor drive or provide metering and annunciator functions. A digital output such as a relay can be used to start and stop an external electromechanical motor brake. An analog output can be used with an external meter that displays frequency or motor current. See Figure 9-27.

Wiring Methods. Digital inputs and outputs are connected to an electric motor drive with individual conductors. Analog inputs and outputs are connected to an electric motor drive with twisted shielded pair cables. See Figure 9-28. The following items must be considered when installing control wiring:

- Control wiring and power wiring should be installed in separate metal conduits.
- Wiring for digital signals, analog signals, and serial communication signals should be installed in separate metal conduits.
- Do not mix wiring for AC and DC control signals in the same conduit.
- Inside an electric motor drive enclosure, control and power wiring should be separated as much as possible. If control and power wiring must cross, they should cross at a 90° angle.
- Care must be taken when terminating the twisted shielded pair cables to ensure the shield is terminated only at the electric motor drive end, and the pairs should be twisted as close as possible to the terminals.

Figure 9-27. Programming the parameters of an electric motor drive allows the functions of the inputs and outputs to be modified.
Control Wiring Schemes. Wiring schemes involving digital inputs fall into two categories, 2-wire control and 3-wire control. Two-wire control is the simplest. Two-wire control consists of two wires to an electric motor drive from a single digital input such as a selector switch. Opening and closing the digital input stops and starts the electric motor drive operation. Three-wire control consists of three wires from two digital inputs. One of the inputs is a normally open start and the other is a normally closed stop. The scheme is similar to the 3-wire control used with magnetic motor starters. See Figure 9-29.

Wiring schemes involving analog signals fall into two categories, 2-wire control and 3-wire control. Certain analog signals only require a two-conductor twisted shielded pair cable with a 4 mA–20 mA or a 0 VDC–10 VDC signal. Other analog signals require a three-conductor twisted shielded pair cable as with a potentiometer.

Many electric motor drives have the capability to communicate with PLCs, other drives, building automation systems, HMIs, and PCs via serial communication. The serial communication may be RS-232 or RS-485. The serial communication may be integral to the electric motor drive or require an interface board. An electric motor drive is connected to other devices with twisted shielded pair cables. The advantages of serial communication include less wiring between control equipment, and the electric motor drive can be monitored and controlled from a central location.

**TECH FACT**

Electric motor drives on HVAC fans include a bypass contactor that is used to power the fan with utility power when drive failure occurs.
CONTROL WIRING SCHEMES

2-WIRE CONTROL

3-WIRE CONTROL

ANALOG CONTROL

SERIAL COMMUNICATION

Figure 9-29. Electric motor drive control wiring schemes include 2-wire control, 3-wire control, analog control, and serial communication.