Recommendations for Control System Installations

This document is intended as a general guide to successful design and installation of electrical control systems. These ideas are intended to provide a ‘best practices’ approach to designing and installing electrical control components for industrial equipment. These concepts are not absolute or comprehensive rules as the infinite variations of machine design means some will be more applicable to your system design than others. They also do not guarantee you won’t have some type of noise issues, but following the basic guidelines shown here and in the individual installation guides of the equipment being used will help avoid major issues or design changes down the road. These suggestions do not remove your responsibility from understanding all local codes and applicable safety standards for your area and/or machine type. We do not try to cover those specifics in this article.

Should Do (recommended in all installations)

1) Motor power cable design should include a good braided shield (at least 85% coverage) enclosing the motor power leads and this shield should be bonded to the drive/amplifier as appropriate.
   a) This is the best way to manage the PWM switching noise that today’s drive systems will generate. The energy will radiate from the motor power leads and eventually find a way back to their source, which is the drive device itself. The braided shield provides a low impedance return path back to the source. Without this return path, the energy will couple to other paths and can then create undesired effects, such as false I/O transitions, faults, communication issues, etc.
   b) Ideally, the braided shield should also be bonded well to the motor case. The windings of the motor are really just extensions of the motor power leads which means they will also radiate this PWM switching noise and this energy will couple to the motor case. Providing that low impedance return path is important.
      i) The ground wire included in the motor power cable is not adequate for a noise return path. It is included solely for safety concerns to prevent the motor case from floating to dangerous voltage levels. It does not provide enough surface area (for RF noise, surface area is key for the return path) and thus it presents higher impedance than desired.
   c) At longer cable lengths (Parker uses 50 foot length as a rule of thumb), even the braided shield presents enough impedance that some of the energy may couple to other paths anyway. Additional measures may be required to manage these cases if problems are experienced, though in most cases following the other recommended practices will be adequate for a robust system.
   d) Any feedback cables (primarily in servo systems) should also be shielded with the shield properly terminated.

2) The earth grounding scheme should employ a ‘star’ configuration, with a primary earth reference that all devices are bonded to.
   a) Daisy-chaining of earth ground connections is not recommended as the longer the chain the more impedance in the earth ground path.
   b) Keep grounding connections as short as possible to reduce the impedance.
      i) Be sure to remove any paint on the back panel behind the drives and other devices to ensure maximum surface area for the earth bonds. DC continuity does not guarantee adequate bonding. Relying solely on the mounting screws to bond the device to the panel is generally not adequate.
   c) Bus bars and braided strapping are the best but large gauge stranded wire is also commonly used. (for RF noise, surface area is key for the return path) If stranded wire is used, keep the lengths as short as possible.
   d) If there are remote sections of the machine (which often require extended length motor cables over 50 feet in length), they may require local earth ground points rather than running an earth connection wire/strap long lengths to get back to the primary enclosure.
e) Low voltage ground references (DC common, Ref, Signal Ground, Gnd, etc.) are not earth ground and generally should not be tied directly to earth ground. There will be places in the system where this is done, such as in the DC power supplies, servo drives, etc. Avoid the temptation to tie them together in your system wiring unless a vendor specifically advises you to in their installation guides. Earth ground will usually be identified by the appropriate symbol or noted as a ‘shield’ connection.

f) Know where the earth ground reference is coming from and how good it actually is. Relying solely on the AC earth ground reference of your power grid may not be enough, especially if there isn’t a good earth reference in the plant overall (as in some older factories). A local earth ground at the machine may be required.

3) Plan a good cable routing scheme for your system, keeping noisy cables routed away from low power cables.
   a) As much as possible, route noise carrying cables (such as motor power leads) separately from low power control cables (such as I/O, communications, DC bus wires, etc.).
   b) One good concept is to have the noise generating devices (PWM amplifiers, etc.) located together in one section with the motor cables routed out one side of the enclosure, with any other control level cables routed out a different location, at least separated by 6-8” of space.
   c) Inevitably, system requirements will force cables to come in proximity to each other. Routing things so that the power cables cross the control cables at 90 degree angles prevents the energy from coupling between them.

4) Signal wires should also be shielded and differential when possible, especially those that will be run in close proximity to motor power cables or other noise radiating cables/devices. These shields should also be tied to an appropriate earth ground (shield) connection point.
   a) These can include digital and analog I/O lines, communication cables, and feedback cables.
   b) Use differential signals when possible versus single ended signals, as differential signals are more robust against electrical noise.
   c) For differential signals, always use twisted pair cabling. Without a twisted pair cable, the effectiveness of the differential scheme is greatly reduced.

5) All inductive devices being controlled by DC voltages should have fly-back diodes installed as close as possible to the coil terminals themselves.
   a) Inductive devices generate a significant amount of electrical energy when they are turned off (voltage is removed from the coil) due to the nature of an inductor. When the voltage is removed from the coil, the magnetic field collapses and the energy stored there needs somewhere to go. This energy is another form of electrical noise that needs to be suppressed. There is enough energy in these events to cause intermittent noise problems and to even damage circuits.
   b) One thing that differentiates inductive noise from PWM noise is that it is more sporadic, depending on how often the particular inductive device is turned off while the PWM noise will be present at some specific frequency whenever the drive is enabled. It can make chasing inductive noise problems even harder ‘after the fact’ as the symptoms may be even more intermittent.
   c) The fly-back diode is simple a basic diode installed across the terminals of the coil. The diode provides a localized return path for the noise energy to dissipate in the coil and diode rather than being transmitted back up the lines to the control circuit, the DC power supply, or coupling to other signal lines running in parallel with the cables connected to the coil.
   d) Examples of inductive devices are ice cube relays (coil based instead of solid state), solenoids, solenoid controlled valves, and motor contactors. Many of these devices will have fly-back diode options you can order as part of the device to save you having to select and install one later on.
Good to Do (best practices to follow)

1) Use separate DC power supplies (typically 24V) for control power (such as control power supplies for many drive designs), I/O requirements, and inductive devices (such as relay coils, solenoids, etc.).
   a) Sharing a DC power supply provides a handy path for electrical noise to propagate through a system.
   b) Twisting the DC bus wires together tightly can also help if noise levels are low enough. This allows the + side and the return side to both bounce with the noise and still provide the required DC voltage level to the devices using it.

2) Install AC Line Filters in the system.
   a) This is often a requirement for regulatory compliance, such as UL or CE. Refer to the specific installation guides for the devices being installed to see what they recommend.
   b) One approach is to install large filters on the main AC power coming to the control enclosure. This helps isolate that machine from other systems in the factory. However, any devices on the ‘inside’ of the mains filters will still be sharing those power lines and may provide noise paths internal to the enclosure.
   c) Another approach is to install the mains filters on the noise generating devices themselves, such as the servo amplifiers. Sharing a single mains filter for all these devices is ok as long as it is sized appropriately. This provides isolation for the noisy devices from other devices also using the AC power, such as the DC power supplies, HMIs, PLCs, etc.

May Need to Do (special techniques that may help)

1) Install a motor choke (sometimes called a motor output filter) at the motor output of the drive(s).
   a) These devices are essentially large inductors placed in-line with the motor output phases. They have multiple benefits, a primary one being reduced PWM switching noise radiating down the motor cable and the motor case. These should be installed right at the drive’s output or as close as is feasible.
      i) Longer cable lengths (especially in cases where the motor cabling may be over 50’) and systems with sensitive sensors or analog devices being used are prime candidates that will benefit from using a motor choke.
   b) Motor chokes cannot be shared between drives while a mains filter can be.

2) Install ferrite devices on signal level cables.
   a) Ferrite devices are just magnetic cores built in a way that allows it to be installed externally around a cable’s circumference. The ferrite core helps attenuate the unwanted signals (aka – the electrical noise) and suppress any noise radiated by the signals themselves.

3) Install an opto-isolation barrier for the I/O being used.
   a) This scheme is not generally required if the other suggestions are employed correctly, but in some cases may provide additional robustness.

4) Install an isolation transformer for the system’s main power input.
   a) Isolation transformers may be required or useful for other reasons in a system, but they also provide additional isolation for the AC power side of the system.
   b) Ensure an adequate earth ground is still maintained if using an isolation transformer.