





Schematics, Standards, Design Considerations & More

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Industrial control panels consist of power circuits or control circuits (or both) which provide signals that direct the performance of machinery or equipment. Industrial control panels don't include the main power, nor do they include the controlled equipment; rather, the panel is mounted on a back panel (or subpanel) or in an enclosure, depending on the application. Industrial control panel design begins with weighing design requirements and specifications and preparing schematics, but the design process can be quite complex in order to ensure that all applicable regulatory standards and safety requirements are met.



We've created this guide to provide an overview of the key design considerations applicable to industrial control panel design, including schematics, relevant regulatory standards, and design considerations relating to every facet of effective control panel design for industrial equipment and machinery.

Industrial Control Panel Design – Schematics

Control panel design for industrial equipment and machinery is an important undertaking, resulting in an interface designed to control a machine or process. It's not a simple matter of selecting an appropriate enclosure and a back panel that houses the electrical hardware. So, the proper hardware must be mounted on a back panel and properly wired and integrated into the machine – any improper configuration can result in malfunctioning machinery, but it's also likely to pose an unnecessary risk to operators.

The process should always begin with an evaluation of the specifications, requirements, and regulatory standards. After these considerations are evaluated, drawings are created to outline the specific configuration of wiring, circuits, controls,

and every other aspect of the final control panel. Good design addresses both the electrical and physical requirements. These drawings should include:

- Functional diagram
- I/O (Input/Output) diagram
- Power distribution
- Control cabinet and back panel layouts
- Bill of materials

Because there are so many elements in a proper schematic, a table of contents is also recommended. The schematic is the foundation for the subsequent development of an industrial control panel.

Regulatory Standards Related to Industrial Control Panel Design

Despite many Code cycles, many industrial control panels are still not compliant with the regulatory standards which are accepted industry-wide. Compliance, however, is critical for ensuring minimal safety risks associated with installing and operating industrial equipment and machinery.

Below is an overview of the most prominent regulations applicable to the design, manufacture, and installation of industrial control panels. Like all regulatory standards, industrial control panel standards are subject to change over time, and in fact, one of the most relevant standards, UL 508, has recently been phased out and replaced by an updated, harmonized international standard. Because of the changing nature of regulatory standards, it's important to stay up-to-date on current requirements.

NEC

The **National Electrical Code** (NEC), or NFPA 70, is a widely-accepted standard for the safe installation of electrical equipment and wiring. The NEC is adopted by state or by

region to standardize the enforcement of safe electrical practices. Article 409 covers industrial control panels and applies to panels intended for general use at 600 volts or less, in ordinary locations. Industrial Control Panel Design Regulatory Standards

Article 409 specifies that industrial control panels must be evaluated and marked for their **Short Circuit Current Rating** (SCCR), which is established by evaluating each feeder individually as well as all branch circuits. The smallest kA value is used as the kA value for the panel as a whole. The kA value must be greater than the kA value of the incoming source in order for the panel to be installed.



NFPA 79

NFPA (National Fire Protection Association) 79 is a **section of the NEC** that pertains to wiring standards for industrial machinery. The scope of this standard encompasses electrical and electronic elements of all machinery that operates at or below 600V, including injection molding machines, assembly machinery, machine tools, and material handling machinery, among others, as well as inspection and testing machinery. NFPA 79 provides safeguards for industrial machinery aimed at protecting operators, equipment, facilities, and work-in-progress from fire and electrical hazards.

Portions of NFPA 79 relate to control circuits and control functions, operator interface and control devices, location, mounting, and enclosures for control equipment, and other topics relevant to the design of industrial control panels.

UL 508 and UL 60947-4-1

UL 508 was one of the most important standards to recognize for many years, but this standard has recently been phased out and has been replaced by **UL 60947-4-1**.

- Before January 26, 2012, listed control panels were evaluated to standard UL 60947-4. If a customer specifically requested that a panel be evaluated to UL-508, this was permissible.
- From January 26, 2012 through January 26, 2017, new industrial control panels were evaluated to UL 60947-4. However, evaluating revisions to existing control panels to UL-508 was permissible if requested.
- After January 27, 2017, all listed industrial control panels are required to meet UL 60947-4-1 specifications.

The transition is meant to harmonize the standards from UL and other entities including the Canadian Standards Association (CSA) and the International Electrotechnical Commission (IEC) in Europe. It's worth noting that UL 508 and UL 60947-4-1 are largely the same in a technical sense but do incorporate important



national differences in order to harmonize and create an international standard. The primary impacts of the transition relate to how products are tested and qualified to a standard due to differences in voltages used around the world. Industrial voltages in the United States are 480 V at 60Hz, while industrial voltages in Europe are 400 V at 50Hz. The new UL 60947-4 standard "applies to the types of equipment listed in 1.1.1 and 1.1.2 whose main contacts are intended to be connected to circuits the rated voltage of which does not exceed 1 000 V a.c. or 1 500 V d.c."

A variety of other standards are applicable to certain types of industrial control panels, shown in the table below:

STANDARD	COVERS
UL 218: Standard for Fire Pump Controllers	Fire pump controllers
UL 1203: Standard for Explosion-Proof and	Equipment intended for use in hazardous
Dust-Ignition-Proof Electrical Equipment for	locations
Use in Hazardous (Classified) Locations	
UL 698A: Standard for Industrial Control	Industrial control panels with intrinsic safety
Panels Relating to Hazardous (Classified)	barriers intended for connection to circuits in
Locations	hazardous locations
UL 845: Standard for Motor Control Centers	Motor control centers
UL 864: Standard for Control Units and	Electrical control unit assemblies or equipment
Accessories for Fire Alarm Systems	containing electrical control units for fire-
	protective signaling systems
UL 891: Standard for Switchboards	Freestanding assemblies of circuit breakers and
	related applications
UL 924: Standard for Emergency Lighting and	Any equipment necessary for supplying
Power Equipment	automatic illumination and/or power to critical
	areas and/or equipment essential for the safety
	of human life
UL 1563: Standard for Electric Spas, Equipment	Control equipment for swimming pools and spas
Assemblies, and Associated Equipment	
UL 1640: Standard for Portable Power-	Portable control panels for specific applications
Distribution Equipment	
UL 1741: Standard for Inverters, Converters,	Equipment for controlling fuel cells, photovoltaic
Controllers and Interconnection System	systems, or utility interactive systems
Equipment for Use With Distributed Energy	
Resources	
UL 1773: Standard for Termination Boxes	Enclosures or pedestals that contain terminals
	for connecting power circuit conductors
UL 2017: Standard for General-Purpose	Covers control panels that contain emergency
Signaling Devices and Systems	alarm equipment, as well as the actual alarm
	equipment

UL 2075: Standard for Gas and Vapor Detectors and Sensors	Equipment for gas or vapor detection
UL 60950-1: Standard for Information Technology Equipment – Safety – Part 1: General Requirements	Covers control panels with predominantly communication equipment
UL 294: Standard for Access Control System Units	Control equipment for use in physical access control systems
UL 1037: Standard for Antitheft Alarms and Devices	Control equipment intended for theft deterrent or warning purposes
UL 916: Standard for Energy Management Equipment	Equipment for energizing or de-energizing electrical loads to achieve the desired use of electrical power

Other bodies have issued applicable standards as well, such as IEC 60204-1, which relates to the safety of machinery and electrical equipment of machines. Given the many standards applicable to specific types of industrial control panels and those intended for use in specific applications, it's imperative to identify the appropriate standards at the beginning of the design process.

Design Considerations for Industrial Control Panels

A variety of design considerations must be weighed throughout the design process in order to design a control panel that meets functional requirements, application specifications, and regulatory standards. The following design decisions represent the primary design considerations in developing an industrial control panel, although additional considerations specific to individual applications may apply.

Enclosures and Space Requirements

The intended environment largely dictates the appropriate type of enclosure for an industrial control panel. You'll need enough space to install and wire components, and it's also wise to plan for several receptacles to reduce the need for extension cords when it's necessary to power test equipment or appliances.



Placement is another consideration related to enclosures. Depending on where the panel will be located, you may need to account for swing requirements of cabinet doors (if a cabinet enclosure is being used). If a control panel will be located in an area with a high ambient temperature, a ventilation fan or air conditioning may be required to keep the control panel within an ideal operating temperature range. If

temperature control applies, it's necessary to allow for easy access to air intakes and exhaust vents (which makes it easier to access and replace filters). Both NEC required clearance around power wiring and UL required clearance around heat producing devices must be considered to allow adequate room for ventilation.

Space considerations are paramount, as one of the **most common NEC violations** involves control panels that are too small or too confined to allow for the proper space for wiring and wire bending. It's also wise to consider space requirements not only for the current configuration but possible future needs, as restricted space is a common challenge for retrofits.

Wire Sizing and Component Types

When it comes to **wire sizing** and selecting the appropriate component types, there are two important rules of thumb:

- Wires should be sized based on load current. In turn, circuit protection should be based on wire size. Selecting the appropriate wire size is essential for ensuring that the circuit is capable of delivering the required load current, while selecting the best circuit protection reduces the risk of fire by preventing wires from overheating.
- Component types should be selected based on functional requirements. Selecting components of the right size is critical, as well, as voltage and load current

requirements can mandate minimum size requirements. Components must be capable of handling the **voltage** and load current requirements reliably – but they also must function as required.

UL standards outline specific requirements for wiring, such as wiring materials, labeling for conductors, sizing for power circuit conductors, and wire sizing.

Control Components and Circuits

What type of controls are appropriate for the application? There are a variety of options from relays to timers to terminal blocks. Opt for the simplest control components possible.

Control circuits provide logic for the operation of power circuit components. These circuits are typically lower-voltage for safety, and components such as control power transformers (CPTs) and power supplies are utilized to convert the power circuit voltage to the control circuit voltage.

Supply Conductors

Supply conductors should allow for the highest possible load that may occur. This is typically calculated by determining the sum of all connected motors and apparatus (keeping in mind duty cycles and which motors and apparatus will operate simultaneously), and adding this sum to the full load current for all resistive loads plus 125% of the full load current of the highest rated motor.

Handling Overcurrent Protection

You'll also need to consider overcurrent protection in the design phase. There are two options: overcurrent protection can be placed ahead of the panel or incorporating a single, primary protective device in the panel itself. Depending on the application, it may not be desirable to integrate the protective device in the panel to minimize the need to open an enclosure.

Operator Devices

Operator devices include components such as push buttons, indicator lights, digital panel meters, levers, and the like, but these devices can also be more complex, touch-screen displays. Such HMIs (human-machine interfaces) allow for more complex functionality, but also require computing components and software development, which can add to the cost.



When it comes to controls, the old K.I.S.S. principle (Keep It Simple, Stupid) applies. Simpler is always better, but simpler may not always be possible. You should, however, opt for the simplest operator devices appropriate for the functional requirements to support ease of use.

All industrial control panels should include an **emergency stop** (which differs from a **cycle stop**), typically a self-latching control in a mushroom or palm type. Emergency stops, or E-stops, are also required by **OSHA** (Occupational Safety and Health Administration), and they cannot be buttons on an HMI; they must be a push-button design which is hard-wired into the safety circuit. Additionally, any start buttons or switches should be located directly above or to the immediate left of the associated stop button.

Labeling

It's imperative to properly label all wires, terminals, and other components in an industrial control panel. It's a time-saving strategy that also reduces the likelihood of errors in testing, routine maintenance, and repairs. Labels should be durable enough to withstand the conditions of the target environment to avoid fading and damage that renders them unreadable.



Front Panels and Faceplates

Front panels and faceplates may seem like an afterthought, but these elements are equally as important to the overall operation of machinery as the interior functional components. Front panels should be durable enough to withstand extreme temperatures, weather conditions, cleaning products, and chemicals to protect the underlying components.

Front panels and faceplates may include metal or plastic substrates, depending on the application specifications, and can be mounted with studs, adhesives, or fasteners. Digital or screen-printed graphics provide visual guidance for operators and incorporate labeling of operator devices to ensure usability. Therefore, face plates must have the durability necessary to remain readable for the life of the asset.

There are many, many individual components and elements that go into an industrial control panel. This guide is meant to provide an overview of the primary design considerations. Given the depth and complexity of control panel design, as well as the application specifications and regulatory considerations, partnering with an expert experienced in designing and developing industrial control panels is a time-saving and cost-effective option for manufacturers.



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